# Are CAPTCHAs preventing robotic intrusion or accessibility for impaired users?

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***Abstract*—Is the World Wide Web for everyone? Long story short: no and unfortunately it is not only a matter of infrastructures, level of instruction or economic conditions. People affected by visual impairments have often difficulties in navigating web pages for a wide range of reasons. One of the biggest obstacles nowadays is the use of CAPTCHAs, powerful tools against bot attacks but also potential virtual barriers for the aforementioned category of users. In this paper we tested various categories of CAPTCHAs with people affected by visual impairment and not, to understand how discriminatory can be these cybersecurity measures.**

***Index Terms*—accessibility, CAPTCHA, visual impairment**

## I. Introduction

Web technology should be developed keeping in mind the widest range of users, regardless of their abilities or disabilities; even better they could also be used to improve inclusiveness of our society [1], [2], [3]. Unfortunately, this aspect is often overlooked and, in this work, we specifically focus on accessibility issues concerning one of the most popular web tools: *CAPTCHA, Completely Automated Public Turing Test to Tell Computers and Humans Apart*. Indeed, many web sites are developed with the intent to prevent robotic access to their services. The use of login and password does not provide an adequate level of protection, therefore many efforts have been spent to create a reliable Turing test. Researchers at Carnegie Mellon University have been the pioneers that introduced the CAPTCHA technology[1], which requires users to recognise distorted text inside a picture. The idea is to have a task that is simple for humans but not for computers/algorithms. Unfortunately, the task results simple only for humans *without* any kind of impairments, while being extremely difficult, when not impossible, for other categories of users. E.g., asking people with visual impairments or dyslexia to identify characters in a distorted graphic embodies a very tough challenge for these users.

During the years, the CAPTCHAs have evolved; yet, although they currently provide audio alternatives to images, they still pose a strong barrier to impaired people. E.g., it is not possible to ask people with hearing impairments or with an auditory processing disorder to transcribe the content of an audio CAPTCHA.

Moreover, CAPTCHAs often use the English language, thus excluding the non-English speaking web users in the world.

In this paper, we present an overview of CAPTCHA's current technologies and data collected during an experiment involving both regular users and visually impaired ones navigating the web with the aid of a screen reader. We asked participants to answer to a questionnaire organized in ten pages, each of which contained a CAPTCHA. Different types of CAPTCHA have been used and we collected data about users' answers, mouse's movements and interactions, as well as data about the success or failure of the CAPTCHAs. Results showed that CAPTCHAs, instead of just discriminating between humans and computers, often discriminate between regular users and visually impaired ones with the latter left unable to access web contents and services.

The paper is organized as follows: Sections II and III overview the current state of CAPTCHA technologies and the related works. In Section IV we describe the questionnaire proposed to users with and without visual impairment. Analysis of the collected data is presented in Section V. Finally, conclusions are drawn in Section VI.

## II. CAPTCHA

Many different solutions have been proposed in the recent years as CAPTCHAs [4]. The first proposed CAPTCHAs were based on the identification of static images. At the beginning, they required to recognize text or numbers in a distorted image; later, they required to recognize a particular shape inside a picture. As anticipated, distorted text can prevent robot intrusions but it also embodies a very challenging or even impossible task for users with visual impairments or affected by cognitive and learning disabilities.

Many CAPTCHAs provide an audio alternative to distorted text, but this is not a valid solution. To avoid automatic recognition by robots, web developers have to introduce a certain level of noise in the acoustic CAPTCHA. If the surrounding environment is acoustically quiet and the user possesses good audio speakers, earphones or headphones, he/she can solve the required task. On the contrary, if the environment is noisy or the audio speakers are not good, the task can become quite difficult, or even impossible, to solve.

[1]http://www.captcha.net/

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In general, audio CAPTCHAs are known to impose a cognitive overload to all human users in comparison to the cognitive load necessary to understand normal human speech [5]. Moreover, audio CAPTCHAs often use the English language, thus challenging even more non-English speakers.

Another type of CAPTCHA uses simple mathematical or work puzzle, spatial tasks or logic test. These tasks raise the bar for robots, but they represent barriers to access for people with language, learning or cognitive disabilities.

More sophisticated CAPTCHAs collect biometric information, but they cannot be used when it is necessary to preserve the user's anonymity.

Honeypots are forms created to attract robots and not humans. They usually contain labels that precisely tell the user to check or to leave blank an input. These labels are understood by humans and not by robots.

Google reCAPTCHA v2 uses a checkbox with the label *"I'm not a robot"* . Actually, it is not a simple checkbox, but it collects a lot of data about user, e.g., mouse movements and clicks, keyboard navigation, language of the browser, cookies saved during the last 6 months, touches (for touch devices), installed plugins, etc. This information is then used to distinguish between humans and robots. Unfortunately, people with disabilities expose different navigation habits compared to other users, e. g., blind people prefer keyboard navigation to the use of mouse, and the same holds for other collected data, e. g. plugin. Moreover, these CAPTCHAs always fail when the anonymous navigation is employed. This study intends to investigate whether this difference in behavior models also implies different percentage of success/failure with CAPTCHA. In case of failure, users are presented with traditional inaccessible CAPTCHAs, which are barriers for impaired users.

Invisible reCAPTCHA v2 badge does not require the user to click on a checkbox, but it is invoked via a Javascript API or clicking on a submit button. Google doesn't provide detailed information about how it works, simply stating that the system uses a combination of machine learning and advanced risk analysis that adapts to new and emerging threats. Even in this case, in case of failure, the user is prompted with a challenge that can be accessible or not according to the choice of the content provider.

Google reCAPTCHA v3 invisible was released in late 2018. It is a non interactive Turing test which collects data about users without displaying any checkbox and returns a score indicating high confidence that the user is human, or a high confidence that the user is a robot. Unfortunately, it does not provide a fallback mechanism in case of failure.

## III. Related Works

Given its wide use, CAPTCHA now embodies a crucial component, and a main issue, when considering the usability of websites by visually impaired people. Indeed, CAPTCHA versions implemented by major players as Microsoft and Yahoo have been defeated with a success rate higher than 60% [6] and the success rate of audio CAPTCHA has been reported to be below 50% [7]. It is hence clear that current CAPTCHAs can be a significant access barrier for people with disabilities while not even fully succeeding in blocking non human agents [8]. Due to their importance, the scientific community has focused its attention on CAPTCHAs and accessibility [9], [10]. For instance, accessibility issues related to screen readers have been discussed in [11], where the authors consider blind people as active users in terms of developing and employing browsing strategies to overcome accessibility issues. Furthermore, in [12] the authors report the outcome of an interview with a blind person focusing on the issues he directly experienced while browsing the web through a screen reader.

Considering a period of 14 years, the authors of [13] demonstrated that websites' improvements in accessibility are mainly due to the advent and use of new and more intrinsically accessible technology rather than to an actual effort by websites creators into this direction. As a result, Web accessibility is still a main issue and even top-traffic and government websites suffer from multiple violations of accessibility rules [13], [14], [15].

A screening application able of computing accessibility-related metrics was presented and discussed in [16]. This tool is specifically intended for enabling public institutions to face and (hopefully) solve accessibility issues; yet, it can provide metrics and a synthesis of time evolution of web sites to any web site manager. Instead, in [17] the authors propose a tool to monitor Web accessibility from a geo-political point of view, by referring resources to the institutions which are in charge of them and to the locations they are addressed to.

Focusing on web browsing and navigation, it has been demonstrated that blind users heavily depend on scanning navigation rather than logical navigation [18]. The authors of the paper considered both an automatic analysis method for web page usability and a fine-grain analysis of user's behaviors, coming to the conclusion that simple structures should be preferred.

Similar, in [19] Carvalho *et al.* investigate the navigation of four websites performed through mobile devices. Their usability test included six blind users and four mainstream users and reported 514 problems and/or violations, 409 experienced by blind users and 105 by regular-vision users. More in detail, main issues involved the lack of navigational aids, unclear interaction and absence of text alternative for images.

To this aim, [20] proposed an interaction model specifically designed for blind users in order to measure their experience in terms of accessibility of a website and time required to execute a task. The model is intended to represent an approach for the aforementioned accessibility issues regarding web navigation and can be used to support the best choice among possible alternative layouts; unfortunately, no model verification has been performed yet.

Even if the World Wide Web Consortium (W3C) has defined the Web Content Accessibility Guidelines (WCAG) [21], there is still a lot to do in this direction. For instance, an empirical study involving 32 blind users showed that many problems faced by these users cannot be captured by the WCAG [22]. During the test, the users had to navigate 16 websites and, as a result, 1383 accessibility issues were reported and only 50.4% of them are covered by the WCAG 2.0. Therefore, not only very few developers know and implement the WCAG but, making this even worse, the WCAG are inadequate to fully guarantee accessibility. The paper suggests to move from a problem-based approach towards a design principle approach.

Finally, Dattolo and Luccio [23] studied the problem of accessibility for people with Autism Spectrum Disorder (ASD). Indeed, even if it is well known that computer technology can support the lives of people affected by ASD, only few websites result as accessible for them. To this aim, the authors propose ASD-specific guidelines for the design/development of websites and mobile applications.

## IV. The survey

In the following section we will discuss the main characteristics of the survey administered to the users that agreed to take part in our research project. We will present the structure of the survey, describe how we managed the user tracking applied in order to detect the CAPTCHA failures and survey abandonment and finally we explain what tools have been used to prepare it.

### A. Main structure

The survey is based on a classic structure but with some modifications: the first pages contain general questions to define the demography of our group of respondents, then we proceed with more specific questions regarding their computer skills, the software and tools that they use for Internet browsing and their general experience on the web.

The demographic section also includes a specific question in which the users are asked to indicate their degree of visual impairment. The available options go from ”total blindness” to ”no visual impairments”. This division allows for better filtering of the obtained data.

The questions are grouped in 10 pages and each of them presents a specific CAPTCHA which has to be solved by the user in order to proceed to the next page. The CAPTCHAs used in the survey are visual CAPTCHAs with audio alternatives, Google reCAPTCHA v2 with checkbox (i. e., *“I'm not a robot”* described in Section II), Google reCAPTCHA v2 invisible and Google reCAPTCHA v3 invisible. Table I presents in details the complete structure of the survey.

The system keeps track both of the number of successes and failures. Furthermore, we also investigated participants' perception of the CAPTCHAs that they have just faced. We asked them to estimate their level of difficulty and intrusiveness during a standard web navigation. Having completed the survey, the participants also had the possibility to leave their comments and suggestions.

### B. User tracking

The system automatically collects various information about the users' navigation during the compilation of the survey.

| Page | N° of questions | Type of questions | Type of CAPTCHAs |
|---|---|---|---|
| 1 | 3 | Single choice | Classic visual CAPTCHA with audio alternative |
| 2 | 1 | 5-point Likert scale | Google reCAPTCHA v3 Invisible |
| 3 | 3 | Single choice | Classic visual CAPTCHA with audio alternative |
| 4 | 2 | 5-point Likert scale | Google Invisible reCAPTCHA v2 badge |
| 5 | 4 | 5-point Likert scale, Checkbox | Google reCAPTCHA v2 Checkbox |
| 6 | 4 | 5-point Likert scale, Checkbox | Google reCAPTCHA v3 Invisible |
| 7 | 2 | 5-point Likert scale | Google reCAPTCHA v2 Checkbox |
| 8 | 2 | 5-point Likert scale | Google Invisible reCAPTCHA v2 badge |
| 9 | 2 | 5-point Likert scale | Google reCAPTCHA v3 Invisible |
| 10 | 4 | Yes/No, Open answer, 5-point Likert scale | Google reCAPTCHA v3 Invisible |

TABLE I: Survey structure in details

We anonymously tracked the activity of the respondents from the first page of the survey to the last one with the aim of understanding their behavior during the resolution of the CAPTCHAs. Not only we collected participants' direct answers to the questions, but we also recorded the number of failed attempts to pass the tests and investigated if they decided to continue or to abandon the survey. Since we did not want to force the users to withdraw from the study as a response to a CAPTCHA they were not able to overcome, we decided to allow the users to proceed to the next page after having failed three times in the attempts to resolve a CAPTCHA.

### C. Technical realization

The survey was implemented as a web site which uses the last versions of web technologies (i.e., HTML5 and CSS3) and a minimal layout style to avoid accessibility problems. The whole site was tested with TotalValidator[2]. The web pages contain links to help navigation with screen readers, like *“Go to content”* or *“skip menu”*, and each input is associated to a correct label.

The web site was tested by a completely blind user to be sure that the only difficulties encountered by the participants during the survey were the CAPTCHAs and not due to any accessibility issue.

We use javascript to collect timestamp of the first and the last interaction with each page, mouse motions, keys pressed on keyboard and time spent over each item of the page. Data are saved in JSON objects and stored in a MySQL database.

reCAPTCHAs have been implemented by Google, while traditional CAPTCHAs have been implemented with an external script[3].

[2]https://www.totalvalidator.com/
[3]downloaded by https://www.phpcaptcha.org

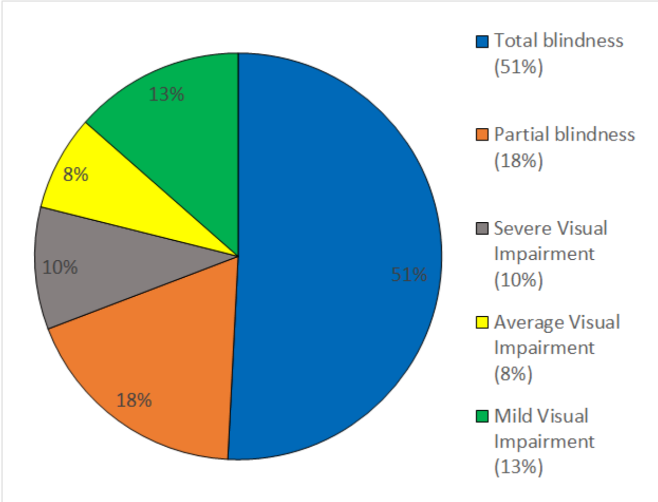


Fig. 1: Percentage of users for each category of disability

| | | Visually Impaired | Non Visually Impaired |
|---|---|---|---|
| **Age** | under 26 | 15.25% | 35.26% |
| | 26 to 45 | 31.64% | 50.00% |
| | 46 to 60 | 31.64% | 8.95% |
| | over 60 | 21.47% | 5.79% |
| **Sex** | Male | 64.57% | 31.05% |
| | Female | 35.43% | 68.95% |
| **Level of instruction** | Middle school | 9.09% | 2.63% |
| | High school | 43.18% | 43.16% |
| | Degree | 40.34% | 49.47% |
| | Other | 7.39% | 4.74% |
| **Computer Skills** | Excellent | 25.68% | 38.41% |
| | Good | 44.59% | 52.44% |
| | Sufficient | 20.27% | 9.15% |
| | Mediocre | 6.76% | 0.00% |
| | Poor | 2.70% | 0.00% |

TABLE II: Demographic data of the participants

## V. Data analysis

In the following section we will discuss the results obtained from the administered survey. We will also present the demographic data of the participants that, for practical reasons, have been divided into two groups - users with or without visual impairment.

### A. Demography

The dissemination of the survey brought us a considerable amount of respondents, 352, that have been divided into two main groups on the base of their degree of disability. The first group counts 177 participants and includes users with total or partial blindness and with severe, average or mild visual impairment. As depicted in Figure 1, 69% of the respondents are affected by total or partial blindness, while only 13% of the participants are affected by a mild visual impairment. The users' distribution perfectly suits our research goals - CAPTCHAs testing. Instead, the second group is composed of 175 participants and includes users with other visual impairments, such as, presbyopia and astigmatism (that can be easily corrected to a normal vision with the use of glasses) or with no visual impairment at all.

As depicted in Table II, the first group is characterized by a more balanced age distribution while respondents in the second group concentrate mainly in the first two age ranges (under 26 and from 26 to 45). Despite the differences in the age distribution, both groups of respondents present a similar level of instruction and they mostly evaluate their computer skills as excellent, good or at least sufficient.

### B. Users' Failures

The first parameter that we studied is the number of users' failures in solving a CAPTCHA. As described in Section IV, each page of the survey presents a specific CAPTCHA to get through in order to have access to the next page. The CAPTCHAs are either visible or invisible to the user, according to the chosen technology (see Table I) and after three failed attempts the user is automatically moved to the next page.

Figure 2 presents the performance of visually impaired respondents. Although most users succeed at the first attempt (more than 50%), we can note that there is a relevant number of users that fails at least once. As expected, the classic CAPTCHAs located in pages 1 and 3 are difficult to be solved by visually impaired users, as they require specific environmental conditions or earphones in order to properly listen to the audio file containing the solution.

Another category of CAPTCHA that caused problems is Google reCAPTCHA v2 that uses a checkbox. The hypothesis is that the recognition algorithm wrongly classifies visually impaired users as robots, due to their different patterns of navigation usually based on keyboard movements while other users use the mouse to tick a checkbox.

Google reCAPTCHA v2 invisible (page 4 and 8) seems to perform well, leading only to a very few failures, while the newest Google reCAPTCHA v3 invisible presents a strange pattern of behavior. In its first occurrence on page 2, the CAPTCHA demonstrates discrete capabilities of classification as much as on page 9; page 6 instead presents the highest number of failures in the whole survey (around 40%). A plausible explanation can depend on the number and type of questions: page 6 has four questions, three with a radial button selection and one with a checkbox, while pages 2 and 9 have respectively one and two questions with radial button selection. Therefore the classification algorithm on page 6 has to deal with more data and it wrongly classifies the users as robots since their behaviour patterns are different.

The number of failures increases again on page 10, that has 3 questions with radial button selection and one with a text field, evidencing a sort of a pattern. Again, the more the recognition algorithm of Google reCAPTCHA v3 analyzes the visually impaired users' behavior, the more it causes failures in the classification. The same pattern that is not detected among the users without visual impairments who present, instead, a lower average failure rate (see Figure 3).

We evidence here that Google reCAPTCHA v3 really dis-

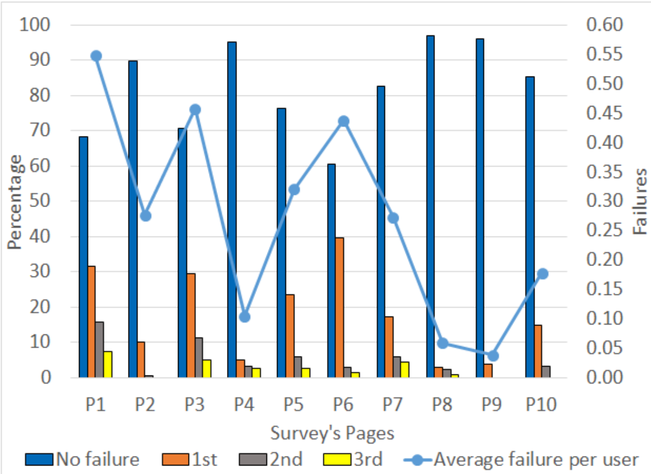


Fig. 2: Failures per page of the visually impaired users

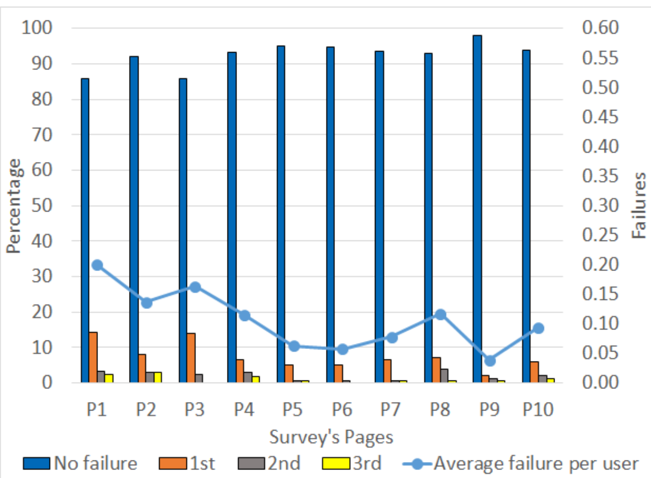


Fig. 3: Failures per page of the non visually impaired users

criminate visually impaired users because, as already discussed in Section II, it does not provide an alternative to the analysis of the classification algorithm. Therefore it creates a barrier that cannot be passed by this kind of users.

### C. Drop out frequency

Through the survey we also collected information about the number of users who abandoned the task and in which part of the survey they decided to stop. The number of drop outs of visually impaired users was relatively high in the first part of the survey (18.64% of the respondents) while decreased in the second part (8.46% of the respondents). In long and difficult tasks, like the ones presented, it is quite common that the abandonment rate increases with the approaching end of the survey due to tiredness of the users caused by answering the questions. However, in our case, the trend is almost opposite (as depicted in Figure 4) and it can be understood, according to the comments that we received from the users, as an indicator of the importance of the topic of this study for visually impaired users. Moreover, the number of drop outs decreases

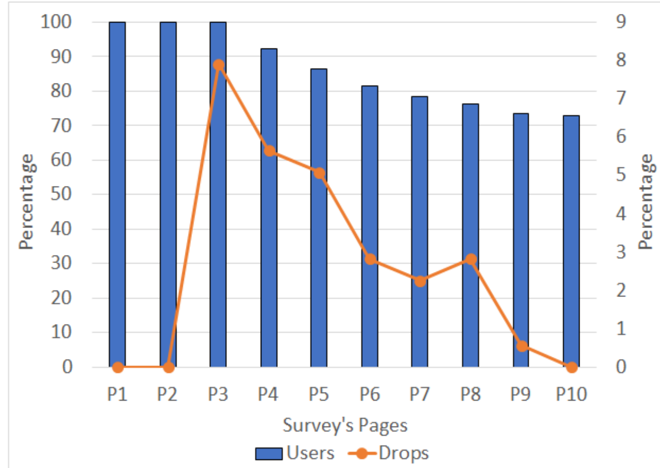


Fig. 4: Number of visually impaired participants for each page and the number of drop outs

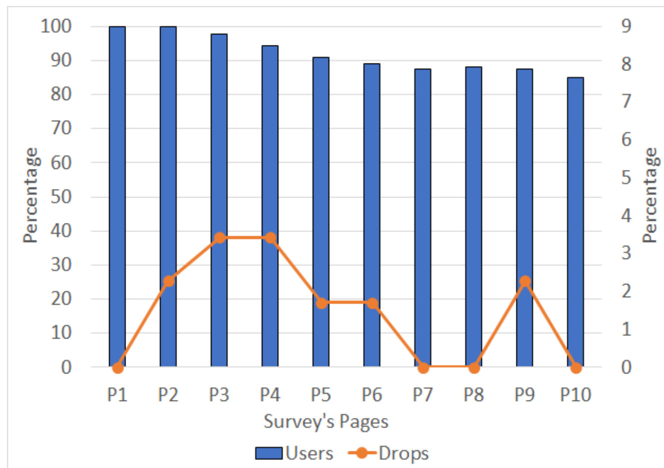


Fig. 5: Number of non visually impaired participants for each page and the number of drop outs

despite the fact that the users continue to encounter difficulties in passing the CAPTCHA tests.

The abandonment rate for respondents without visual impairment is almost half the number of the other group of users (14.86% against the 27.1% of the respective respondents). This is another measure of how much CAPTCHAs are barrier for visually impaired users. In Figure 5 we can also observe that the trend is generally decreasing as for the visually impaired respondents. It is worth to mention that the lower amount of drop outs is probably due also to the minor level of difficulty perceived by users without visual impairment when challenging the CAPTCHA tests (see Figure 6).

## VI. Conclusions

In this paper we have presented data collected with a questionnaire proposed to users with or without visual impairment. In each page of the survey, the participants must solve a

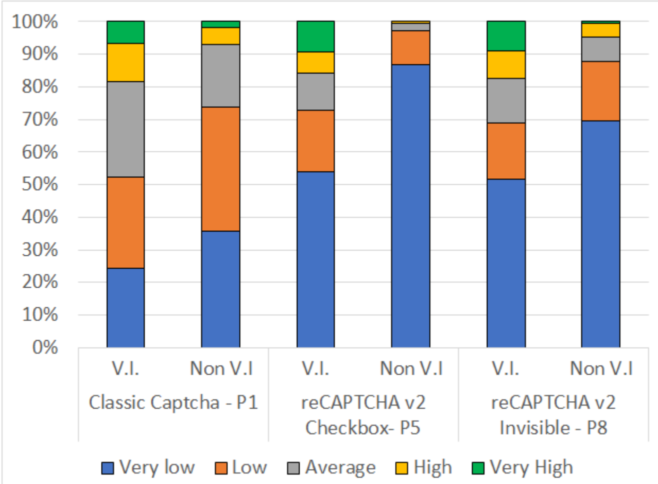


Fig. 6: Level of difficulty that the two group of users, visual impaired (V.I.) and non visual impaired (Non V.I.), encountered in passing some of the CAPTCHA tests

CAPTCHA to move to the next page and we collected the number of failures and successes.

The obtained analysis reveal a bad news: CAPTCHA seems to be more good in discriminating between able or disable people instead that from human beings and robots. Infact, previous works have shown that CAPTCHAs, as security solution, are becoming really ineffective since they can be largely cracked using both simple and complex algorithms.

Although we understand the good reasons of service providers, the actual state of technology of CAPTCHAs does not give a usable solution to the problem. So, if the question is keeping out robots (maybe) or allowing users with visual impairments to enjoy a service, maybe the answer should be the second one. As an example, the developers of the BBC web site[4] decided to not use CAPTCHAs in their web site to avoid compromising their reputation among users with visual impairment.

But the very bad news is that technology does not seem to go in the right direction since our analysis showed that Google reCAPTCHA v3 is even worse than its antecedent v2.

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