

A study on Accessibility of Google ReCAPTCHA Systems

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Web sites and social media should be developed keeping in mind the widest range of users, regardless of their abilities or disabilities. Instead they often use CAPTCHAs to prevent robotic access to data even if they base their tests on the use of sight, since the ability to see an image or a text and recognize or understand its content is a way to make out a human being from a bot. This study shows that Google reCAPTCHA v2 discriminates against users with visual impairments, while reCAPTCHA v3 doesn't and, for this reason, it is the best available solution nowadays from an accessibility point of view.

CCS Concepts: • **Human-centered computing** → **Empirical studies in accessibility**; **Accessibility systems and tools**; Accessibility technologies.

Additional Key Words and Phrases: web, captcha, accessibility, wcag

ACM Reference Format:

Ombretta Gaggi. 2022. A study on Accessibility of Google ReCAPTCHA Systems. In *Open Challenges in Online Social Networks (OASIS'22)*, June 28, 2022, Barcelona, Spain. ACM, New York, NY, USA, 11 pages. <https://doi.org/10.1145/3524010.3539498>

1 INTRODUCTION

CAPTCHAs, *Completely Automated Public Turing-test-to-tell Computers and Humans Apart*, are tests developed with the intent to prevent robotic access to web sites, social media and services for thwarting spam and automated extraction of data. They have always been a problem from the point of view of accessibility [9], because they often base their tests on the use of the sight, since the ability to see an image or a text and recognize or understand its content is a way to make out a human being from a bot. But visually impaired users are unable to see, nevertheless they are human beings.

Web sites and social media 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 [4], [15], [20]. Improving web and social media accessibility, in fact, allows to create a more inclusive society where all users can access the same information and use the same services: consider that digital services are often more useful for people with disability, e. g., visually impaired people cannot drive, or people in wheelchair cannot walk. Therefore, a solution to block malicious bots, but at the same time to prevent access to people with disabilities, is unfair and should be avoided or, at least, should rise important ethical issues. Instead, CAPTCHAs are still widespread.

Unfortunately, this aspect was overlooked for many years and only recently, following the enhancement of new regulations and the increase in security attacks, computer scientists have begun to study the problem and demonstrated the unreliability of many CAPTCHA systems.

Numerous CAPTCHA systems have been proposed: the first system, proposed by Researchers at Carnegie Mellon University¹ (see Figure 1), was based on the identification of static images, asking users to recognize text or numbers in a distorted image. Afterwards, CAPTCHA systems began to ask users to recognize a particular shape or object inside a

¹<http://www.captcha.net/>

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Manuscript submitted to ACM

picture to pass the test as depicted in Figure 2. 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.



Fig. 1. Example of a “hard” GIMPY image produced by CAPTCHA by the Carnegie-Mellon University.

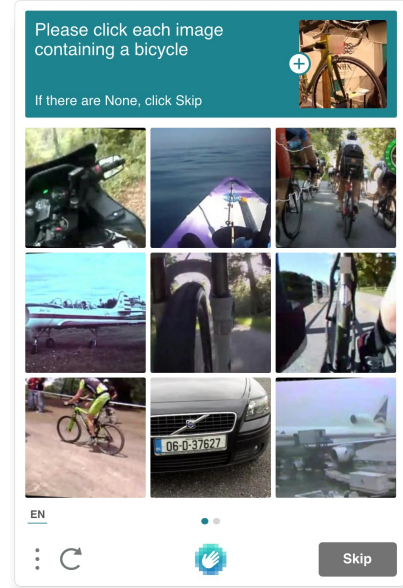


Fig. 2. A challenge asking to recognize a particular object inside some images.

During the years, the CAPTCHAs have evolved; yet, although they currently provide audio alternatives to images (see Figure 3), 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, because it corresponds to a task they are intrinsically least likely to accomplish.



Fig. 3. Google reCAPTCHA with audio alternative.

Moreover, to avoid automatic recognition by robots, web developers introduce a certain level of noise in the acoustic CAPTCHAs. 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 enough, the task can become quite difficult, or even impossible, to solve.

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 [23]. 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.

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 (see Figure 4). These labels are understood by humans and not by robots.



Fig. 4. Google reCAPTCHA v2 “I’m not a robot”.

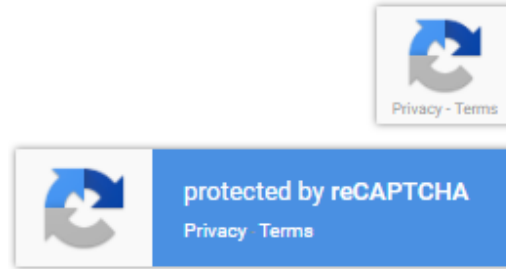


Fig. 5. Google Invisible reCAPTCHA v2 badge and v3.

A new generation of CAPTCHAs, developed in the last years, studies behavior of users and the traffic they generate to determine if it is produced by a person or not, without requiring any challenge. Google reCAPTCHA v2 uses a checkbox with the label “*I’m not a robot*” as depicted in Figure 4. 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. In case of failure, users are presented with traditional inaccessible CAPTCHAs, which are barriers for impaired users.

Invisible reCAPTCHA v2 badge, depicted in Figure 5, 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, but simply a badge. It returns a score indicating a 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.

In [1], the authors submit a survey to users, with and without disabilities. The survey contains different types of CAPTCHAs with the intent to test the percentage of success/failure by different categories of users. The results obtained highlighted a discrimination of users with visual disabilities.

In this paper, we have studied the current state of the art, in particular, we collected new data through a new questionnaire to check if the last implementation of Google reCAPTCHA still discriminate people with disabilities,

in particular we focused on people with visual impairment. The data collected showed how the new reCAPTCHA v3 security system is the best solution from the point of view of web accessibility for all categories of users, while reCAPTCHA 2 still classifies a set of users with visual impairment as bot.

The paper is organized as follows: Sections 2 overviews the related works and in Section 3 we describe the questionnaire proposed to users with and without visual impairment. Analysis of the collected data is presented in Section 4. Finally, conclusions are drawn in Section 5.

2 RELATED WORKS

CAPTCHAs are one of the biggest barriers for accessibility of web sites and media by visually impaired people and, unfortunately, they often represent a barrier only for unpaired users while they do not prevent bots, their actual target, from accessing services and data [29]: in fact, Yan and El Ahmad [27] had shown that CAPTCHAs, implemented by major players as Microsoft and Yahoo, have been defeated with a success rate higher than 60% and the success rate of audio CAPTCHAs has been reported to be below 50% [11]. Wang et al [25] demonstrated that Google reCAPTCHA v2's image challenges can be reliably solved by a computer using deep learning model with a success rate of 68% and with Google's Cloud Vision API with a success rate of 73%. 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 [1, 21].

Other papers investigate the weaknesses and vulnerabilities of CAPTCHA generator systems: in [17] the authors present a customised deep neural network model with a cracking accuracy of 98.94% for numerical test datasets and 98.31% for the alpha-numerical test datasets. Zhang et al [29] discussed the difference between three types of schemes and attack methods for text-based CAPTCHAs. Sivakorn et al [22] conducted a comprehensive study of reCAPTCHAs, identifying flaws that allow adversaries to effortlessly influence the risk analysis, bypass restrictions, and deploy large-scale attacks. Their system is able to automatically solve 70.78% of the image reCAPTCHA challenges, requiring only 19 seconds per challenge. In the same manner they solved Facebook image CAPTCHA with an accuracy of 83.5%.

A framework for automated breaking of dark web CAPTCHAs to facilitate dark web data collection is proposed in [28]. It eliminates the need for human involvement using Generative Adversarial Network (GAN) to counteract dark web background noise and leverages an enhanced character segmentation algorithm to handle CAPTCHA images with variable character length. The framework significantly outperformed the state-of-the-art benchmark methods on all datasets, achieving over 94.4% success rate on a carefully collected real-world dark web dataset.

Due to its importance, the scientific community has focused its attention on accessibility [8], [10]. For instance, accessibility issues related to screen readers have been discussed in [2], where the authors considered blind people as active users in terms of developing and employing browsing strategies to overcome accessibility issues. Furthermore, in [6] the authors reported the outcome of an interview with a blind person focusing on the issues he directly experienced while browsing the web through a screen reader.

Even if the World Wide Web Consortium (W3C) has defined the Web Content Accessibility Guidelines (WCAG) [26], 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 [18]. 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.

The authors of [7] analysed websites during a period of 14 years. They showed that 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 the authors of the websites. As a result, Web accessibility is still a main issue and even top-traffic and government websites suffer from multiple violations of accessibility rules [5],[16], [19].

Lengua et al [12] reported that accessibility guidelines are often perceived as hard to understand, not suitable for practical problem solving, and proposed the Sighted Architects Helper for Aria Notation (Saharian), a browser extension available for Google Chrome to increase integration between development tools and accessibility testing tools in usual web development workflows. In particular this extension helps not impaired authors to simulate web browser of people with visual impairment.

A screening application able to compute accessibility-related metrics was presented and discussed in [14]. 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 [13] the authors proposed 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.

Similarly, in [3] Carvalho et al investigated 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 users without visual impairment. More in detail, main issues involved the lack of navigational aids, unclear interaction and absence of text alternative for images.

To this aim, [24] 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.

3 THE SURVEY

The goal of the survey was to understand if the new implementation of Google reCAPTCHA v3 really discriminates visually impaired users. Moreover, we also wanted to evaluate how reCAPTCHA v2 “Checkbox” has changed in the classification of users. Specifically, we wanted to determine if, interacting with a site that implements reCAPTCHA v2, the use of Google services, e. g., Gmail, affects the outcome of the reCAPTCHA verification.

The survey was composed of 5 pages, with a variable number (from 2 to 4) of questions of different types:

- single answer questions,
- multiple answers questions,
- Likert scale questions and
- open questions.

Each page contained a CAPTCHA to solve in order to step to the next page. After three failures, the user could step to the next page even without passing the test. The user could never go back to previous page. The used CAPTCHAs were reCAPTCHA v3 and reCAPTCHA “I’m not a robot” as shown in Table 1.

Data are collected anonymously but we asked users the level of education, interval of age, if they have an impairment and of which type. The second section of the survey collected information about users’ frequency of use of computers and if they are familiar with web browsing and Google services like Gmail and reCAPTCHA. Moreover, the survey collected data about which assistant technology is preferred by the user and if he/she had already found any CAPTCHA

during web browsing. Each page contained a question on the level of difficulty encountered in solving the CAPTCHA in the previous page.

Page	Number of Questions	Type of Question	reCAPTCHA Type
1	4	Single answer questions	reCAPTCHA v3
2	3	Single answer questions, Likert scale questions	reCAPTCHA v2 "I am not a robot"
3	3	Likert scale questions	reCAPTCHA v3
4	3	Single answer questions, Likert scale questions, open questions	reCAPTCHA v3
5	2	Single answer questions, multiple answers questions	reCAPTCHA v2 "I am not a robot"

Table 1. Structure of the survey.

All the interactions were saved in a database, any click by the user or mouse movement was stored together with the position of the click, or movement, and timestamps. Interactions through the keyboard were also captured as well as successes or failures in solving the CAPTCHAs. Moreover, the survey also checks if the user is logged on any Google service and saved this information (but not the users' login). Collected data were stored in a MongoDB, a no sql database which stores information as JSON objects.

The survey was implemented using web technologies, in particular HTML5, CSS and Javascript. We paid particular attention to the accessibility to be sure that the only barriers in the survey are the CAPTCHAs. In particular, the web pages used colors with high contrast, all the images had an alternative text description and navigation with the keyboard was correctly supported. A responsive layout allowed the user to answer the survey from any device².

4 ANALYSIS OF THE DATA

The survey was sent to a large number of associations for people with visual impairment. Moreover it was advertised through social media. 479 participants answered to the questionnaire: 285 (59%) did not declare to have a disability, while the remaining 194 (41%) were affected by visual impairments. Figure 6 shows the distribution of the participants with visual impairments: 78% of users are affected by blindness (28% were able to see the light, 16% were affected by partial blindness, the remaining 34% were unable to see the light), while 21% were users with low vision. Users who declared to be short-sighted, whose sight can be corrected with the use of glasses, or who are unable to see colors, were considered users without visual impairment.

As already said, we collected information about gender, age, level of education, ability to use the PCs and use of Google services. 67% of the participants were males, 32% females, while 7 users did not declare their gender.

The distribution of the age of the users is described in Table 2. Probably due to the use of social media for dissemination, most of the users were less than 26 years old (282, 59%), 85 participants (18%) were aged between 26 and 45 years old and 23% were more than 45 years old.

The age of the participants had an influence even on the device used to answer to the questionnaire: 53% of participants used a smartphone to fill the survey, 46% a desktop computer and only 4% used a tablet.

Participants had a good level of education: 21% got a bachelor or a master degree and 60% had an high school diploma. The majority of the participants has a Google account (89%) and uses Gmail (32% very often, 23% often and only 9% randomly). Moreover, 33% of the participants declared to have excellent computer skills and 42% to have good skills.

²We must note here that the previous study [1] did not consider the smartphones.

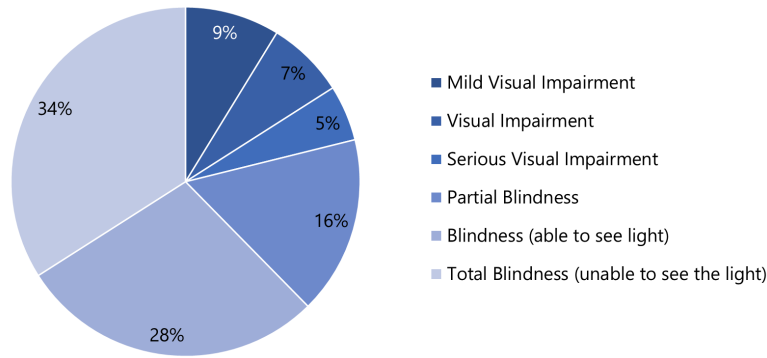


Fig. 6. Distribution of users with visual impairment.

Age	# of Participants	Percentage (%)
< 26 years old	282	59
26 – 45 years old	85	18
46 – 60 years old	79	16
> 60 years old	33	7

Table 2. Age distribution of the Participants.

This information is important for our study because let us assume that if they found some difficulties in filling the survey, these were due to inaccessibility barriers and not to the absence of skills. In fact, in most cases, participants also declared excellent or good skills in web browsing as depicted in Figure 7.

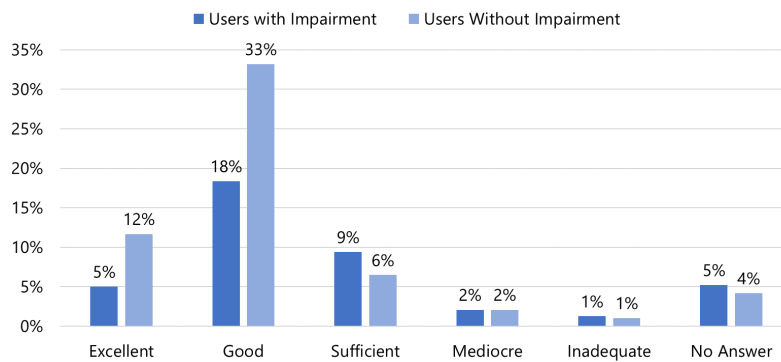


Fig. 7. Web browsing skills declared by the participants to the survey.

We also asked to participants which assistive technology they usually use. The answers showed that the screen reader is the preferred solution by users with visual impairment (43%), even because NVDA is free ³. Braille keyboards seem to have a lower diffusion (12%), maybe because they are very expensive.

³We must note here that this question belong to the last page, therefore we have a lower number of valid answers because of the abandons due to failure in the CAPTCHA solution (7% of no answer).

4.1 Success and failure rate in the solution of the CAPTCHA systems

The survey collected the number of successes and failures for each page, thus allowing a comparison between the two different CAPTCHA systems: reCAPTCHA v3 and reCAPTCHA v2 “I am not a robot”.

The first system was used on pages 1, 3 and 4 reporting excellent results since 99.42% of the participants was able to pass the test as depicted in Figures 8 and 9. Moreover, what is more important, there was no a clear distinction between users with or without disability that seems to did not have an influence on passing or not the test. Additionally, the system never imposed a challenge to users. In fact, we use a threshold equal to 0.5, as recommended by Google, but all users who passed the reCAPTCHA received a rating of 0.9.

This result completely changes the situation presented in [1], so we can declare that reCAPTCHA v3 is now accessible. For this reason, this solution is the best available nowadays (from an accessibility point of view).

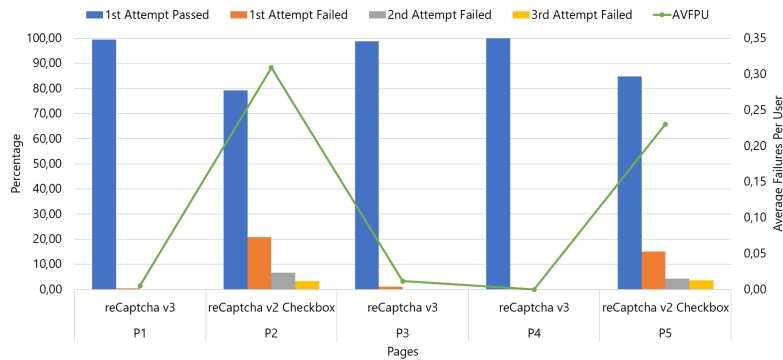


Fig. 8. Participants with visual impairment.

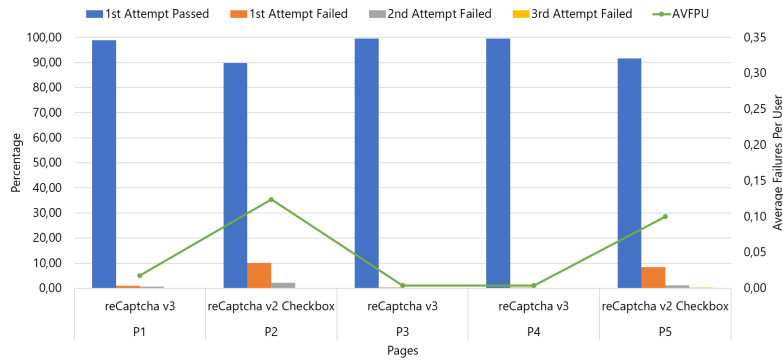


Fig. 9. Participants without visual impairment.

Another good result is that the reCAPTCHA v3 badge, placed at the bottom right corner of the page, was not intrusive at all as reported in Figure 10 by the answers of the users to the question: “On the previous page (page 3 of the survey) there was an invisible CAPTCHA, have you find some difficulties in passing from the previous page to the next one?” that showed that 77% of participants did not notice the CAPTCHA and 21% did not experience any difficulty. Moreover,

when we asked participants to report the difficulties in passing the test, results showed that many of them did not understand the question and went off topic, reporting accessibility barriers in other web sites.

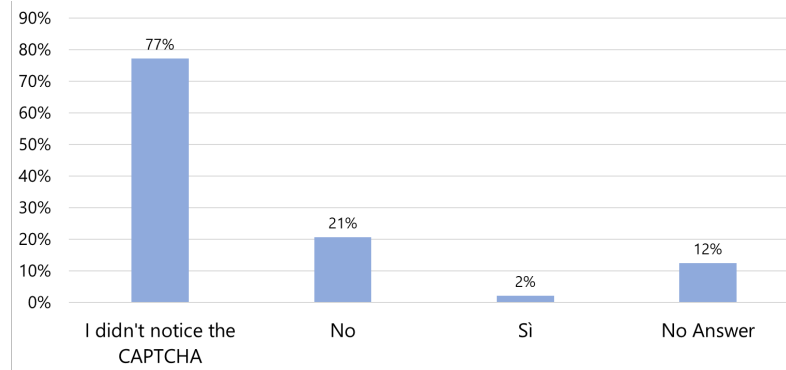


Fig. 10. Answers to the question: "On the previous page (page 3 of the survey) there was an invisible CAPTCHA, have you find some difficulties in passing from the previous page to the next one?".

Overall, we can say that participants, including those with visual impairments, considered reCAPTCHA v3 unobtrusive, or even did not notice it at all.

The situation is not the same for reCAPTCHA v2 "I am not a robot" that was on pages 2 and 5. Figure 8 shows an average number of failures per user (AVFPU) with visual impairment equal to 0.31 on page 2. Although this value is relatively low, compared with valued of v3 which has an AVFPU always below 0,02, it is significantly higher. Moreover, on the same page, the AVFPU for users without visual impairment is 0,12, significantly lower than the same value for people with disability.

Although 77% of participants did not face any challenge, only 27% of them have a visual impairment. For all these reasons, this CAPTCHA system discriminates between users with or without disability and therefore its use must be discarded. In fact, further analyses had shown that reCAPTCHA v2 favored users who used the mouse, as already discussed in [1], thus presenting more often challenges to visually impaired users who use more the keyboard.

A factor that seems to have an influence on passing the CAPTCHA v2 was if the user is logged in with a Google account. As depicted in Figure 11, analysing the correlation between the success on passing the test on the second page of the survey and the use of a Google account, we found that only 7% of participants that experienced a failure was logged in with a Google account, while the percentage of users without an account that failed the test was 10%. In the same way, 47% of user that passed the test was logged in, while 36% of them was not logged.

Another factor that influenced the success or failure in passing the test, and even the request to pass a challenge, was the frequent use of the Gmail service. Indeed, the results reported that:

- 60% of participants, that have not been challenged, used Gmail with high or very high frequency and
- 48% of the participants have been challenged, even if they use Gmail with high or very high frequency.

In conclusion, reCAPTCHA v3 service has improved, being nowadays an accessible solution to tell computer from human apart. On the contrary, reCAPTCHA v2 continues to be a barrier for users with visual impairment.

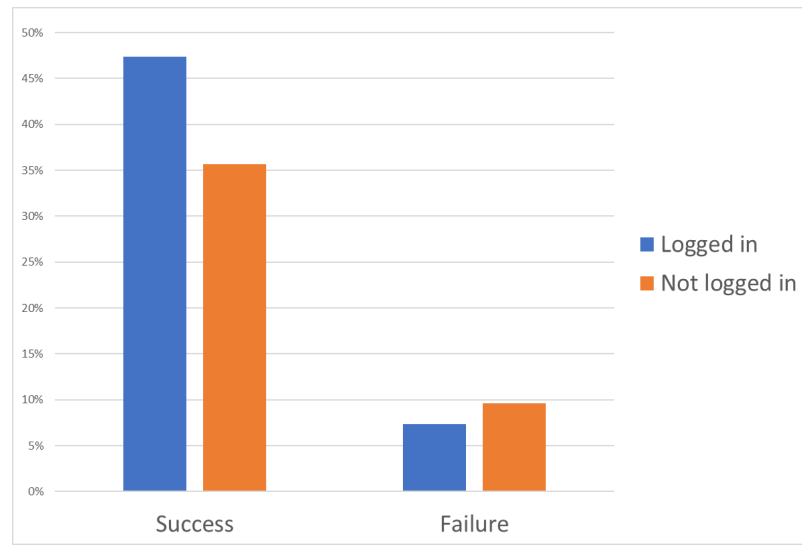


Fig. 11. Participants without visual impairment.

5 CONCLUSION

This study showed that Google reCAPTCHA v3 does not discriminate against users with visual impairments, obtaining excellent results in term of accessibility. Nevertheless, it must be noted that it is more difficult for developers to add it to a web page with respect to the previous versions. Moreover, it requires periodic evaluation of the assigned scores and security level to avoid bots intrusion.

reCAPTCHA v2 instead is a barrier for users with visual impairment, since it favours users that interact with web sites or social media using the mouse. But the analysis also showed that user authentication on Google services and the frequent use of Gmail, which generates numerous cookies, are two factors that can help users to be recognized as human being and passing the CAPTCHA test.

For these reasons, reCAPTCHA v3 is, at the time of writing, the best solution for including people with disability. The next question to answer in the future works will be if it is also the best solution in term of security, i. e, if it is able to prevent bots from accessing data contained in web sites or social media.

ACKNOWLEDGMENTS

I would like to thank Francesco Magarotto for the implementation of the survey. I'm very grateful to the participants of the survey. Moreover, we would like to thank the associations of people with visual impairment for helping us to spread the survey.

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