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The Usability of Mobile Devices for Individuals with Vision Impairments and Color Blindness, as well as Image Correctness

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Abstract: About 0.5% of women and 8% of men suffer from color blindness, also known as Color blindness and Color vision deficiency (CVD), which affects the ability to distinguish between specific colors, such as red and green or blue and yellow. The purpose of this project is to investigate the efficiency, effectiveness, satisfaction and design of an adaptive mobile interface that enhances usability for people with Color Vision Deficiency disease. The developed program detects the user's color vision impairment using the Ishihara test and automatically modifies the interface to an appropriate color mode. 76 color-blind and an equal number of color-deficient users completed three different tasks in both adaptive and non-adaptive environments as part of a usability test. According to the findings, the adaptive interface considerably raised productivity by up to 20% and improved work effectiveness by up to 85%. Furthermore, there was a significant improvement in user happiness in the adaptive environment; Protanopia users reported a substantial 40.54% increase in satisfaction. This study shows that adaptive interfaces can significantly improve task performance and overall happiness for those with color vision deficits, underscoring their potential to improve the user experience.

Keywords: Color Blindness, Human Computer Interaction, Color Vision Deficiency, User Efficiency, User Experience Improvement.

1. Introduction

It is well recognized that color blindness, often known as color vision deficit, poses a serious obstacle to efficient computer use. A recent UK Disability Rights Commission usability study [1]. As a result, it is necessary to model, simulate, and account for the effects of CVD. The fact that it is challenging to satisfy this need since there are various types of CVD and variations in each person's level of CVD. Table 1, which was adapted from, lists the common types of CVD along with the prevalence rates in Western Europe and North America as well as the technical nomenclature for the many types of defective color vision systems [2] .A person with color blindness lacks the ability to distinguish between colors such as red, green, and blue. The retina of the human eye contains photoreceptors that allow the brain to receive light information in order to view objects [3-4].

Photoreceptors come in two varieties: rods and cones. Rods are not color sensitive, but cones are in charge of color vision. Three different kinds of cones exist: (i) S cones: Blue color and short wavelengths are sensitive to them. (ii) M cones: Green in color, sensitive to medium wavelengths. (iii) L cones: Red color; sensitive to long wavelengths [3]. Anomalies related to anomalous trichromatism, dichromatism, and monochromatism are the three primary categories of aberrant color vision systems.

Table 1. Categories of aberrant color vision systems

Kind of Cone	Cause	Frequency in Female	Frequency in Male
Monochromic	Missing all cones	0.00001%	0.00002%

Dichromacy	Missing	0.02%	1.0%
Protanopia	L cone	0.1%	1.1%
Deuteranopia	M Cone	Very rare	Very rare
Tritanopia	S cone		
Anomaous	Abnormal	0.02%	1.0%
Trichomacy	L cone	0.04%	4.9%
Protanomaly	M cone	Very rare	Very rare
Deuteranomaly	S cone		
Tritanomaly			

Deuteranopia is caused by an M cone defect and affects approximately 0.1% of the population, consisting of males and females. The patient has trouble telling the difference between red, blue, and green in some color spectrums. Tritanopia, the 3rd type of blindness is caused by an absence of S cone, which is significantly more common in the male population (0.0001%) than in the female population, where it is rare [6-9]. Popular mobile operating systems, such as IOS and Android, now include built-in support for Color Vision Deficiency to help those who are colorblind. Due to the restrictive modes, limited functionality alternatives, and complicated interfaces to access facilities to overcome Color Vision Deficiency, usability issues still exist for these people [10-11]. Golden shore Technologies Limited Liability Company (LLC) created the Color Find interface, which has a quit button and a single camera view. The output is a simple line that displays the color name in the center of the camera view. Different interfaces are available with varying features and functionalities to mitigate or overcome color shortage. Although these efforts have good functionality, they do not support applications from other parties [12].

This study suggests a novel approach that can remap colors to new ones that users with color blindness can sense more effectively by modeling the human vision system.

Creation of a Mobile Adaptive Interface: This study presents a novel mobile application that dynamically modifies its user interface according to the user's unique type of color blindness as determined by the results of an Ishihara test. This adaptive function offers a customized visual experience to improve usability for persons with various types of Color Vision Deficiency (CVD).

Usability Assessment: We worked with thirty color-blind and thirty color-deficient users to do a thorough usability assessment. The assessment examined how well users performed on various tasks in both adaptive and non-adaptive contexts, and it found that there were notable gains in task efficacy, efficiency, and user satisfaction in the adaptive environment.

Empirical Results: Adaptive interfaces have been shown to significantly improve user satisfaction and performance. More specifically, there was an impressive 85% increase in task efficacy and a 20% increase in production as a result of the adaptive environment. Protanopia customer's happiness increased by 40.54% under the adaptive mode, demonstrating the usefulness of the interface.

Recommendations for Upcoming Studies: The study underscores the importance of user-centered design in adaptive interfaces and suggests directions for future research, including the development of personalized interfaces based on user class ontologies and specific visual contexts.

2. Literature Review

A form of physical impairment known as colorblindness causes a person to be unable to distinguish between individual or complete colors. Trichromats, Individuals who can distinguish between a variety of color such as yellow, coral, orange, blue, and canary yellow, who possess normal color vision.You may use red-green dichromats to distinguish between any of these hues. Therefore, individuals are red-green dichromacy are not mildly color deficient rather; they, are considered colorblind [13]. Less than 1% of women and about 8% of males were born with incorrect perceptions of color [14].The cartographer should be in charge of supervising the color correction [15]. When the participants are completely colorblindess they can experience a decline in visual acuity. As a result, distinct issues may arise in bright surroundings .8% of males who identify as Caucasian are colorblind, according to [16].

Specifically, the red-blind Protanopia are just 1%, the green blind Deuteranopia are only 1.1%, the red-insensitive Dichromats are only 1% and green-insensitive Trichromats have the greatest percentage of 4.9. The authors said that only .002% males were found to be entirely blue-blind .003% of men to be completely color-blind. Additionally, it showed that just .4% of women had any kind of color vision issue, with the majority of forms being red or green. An additional intriguing examination was carried out in [17]. Created three computer tools to aid those who are color-blind. Specifically, three instruments were used to assess the degree of colorblindness in order to imitate red and green colorblindness and improving visual quality based through fuzzy logic adaptation.

All correction variables were analyzed using RGB histogram equalization. As a result, 46% of the evaluation's participants were determined to be better, and 14% to be the least tested. Additionally, histogram equalization was carried out for the L, M and S color models. According to the results 17% of participants performed better on the test, while only 7% performed worse. Finally, an analysis on images retrieval task based on color co-occurrence characteristics was conducted in [18]. Where three cases of colorblindness and two cases of normal vision were discussed.

12000 photos converted in three dichromatic, a simulation program, was used to find out the answers to 48,000 questions posed by people who are color-blind. The findings indicated that only 32% to 35% utilized the top 20 retrieved pictures used color attributes to compete with normal visibility [19].Developed a ICD-2 (International Color Vision Database) model,ssnew human color discrimination model, to get beyond Color Vision Deficiency's drawbacks. Compared to the RGB color space used by the previous specific models, new model's color space was more in line with how people perceive color. The old model was found to be 24 times slower than the new ICD-2 model through an empirical comparison of the two models. In [20], a novel wearable enhanced vision system based on augmented reality was unveiled with the goal of improving color vision in a color vision deficiency patient.

An experiment aimed at enhancing color vision in individuals affected by Color Vision Deficiency (CVD) was conducted. The study comprised 24 color vision deficiency subjects, having a mean age of 37.4 years and a gender distribution of 45 males and 25 women.The results obtained from the experiment showcased significant improvement in color perception as assessed by the Ishihara Vision Test. Specifically, the mean score increased from 5.8 without any correction to 14.8 with the aid of the proposed system. Additionally, a color compensation vision system tailored for CVD individuals was introduced in [21]. The method described in utilized a Gaussian Mixture Model (GMM) to represent the distribution of colors within images. This approach facilitated the rapid recoloring of images, with a size of 300×300 pixels, in under 4 seconds. Importantly, this method operated efficiently without imposing excessive computational strain, thus optimizing speed. Furthermore, the proposed technique prioritized the preservation of image information during recoloring, ensuring that the resulting images maintained a natural appearance. This approach was specifically tailored to meet the needs of individuals with Color Vision Deficiency (CVD) while also ensuring compatibility with the visual preferences of individuals with normal color perception [22].

Additionally, a novel algorithm was put forth to identify colors that the color vision deficiency individuals would not be able to perceive. The experiment's findings demonstrated that the suggested method could maintain pictures that would seem natural to the average observer. It was also able to provide visuals that were easier for persons with color vision deficiency to grasp. A situation-specific modeling idea was used to construct the recoloring tool Situation Specific Model (SSM Recolor) in [23]. This model indicates that the recoloring procedure was carried out. An investigation was conducted with the participation of numerous participants in a controlled research, both with and without congenital color vision deficiency. In various environmental circumstances, the color matching performance of SSM Recolor and the other two approaches was assessed. The outcomes demonstrated that the suggested Situation Specific Model (SSM) Recolor performed faster and with greater accuracy in color matching challenges.

It shown that color displays might be made more useful for a variety of subjects by employing a situation-specific technique for re-coloring. Furthermore, the work in [24]. Also, the work in to create a new video recoloring algorithm for individuals with dichromacy. The suggested method was tested on four videos from the Internet. To be more precise, 11 volunteers made up the experiment, one of whom had Protanopia and was initially shown the original movies. The test volunteers next evaluated the videos that had been recolored. The subject of Protanopia evaluated the four videos based on contrast, naturalness, and performance. The Ishihara color plate test computerized version has been assessed using adaptive into face-based algorithms. Additionally, a simulator for assessing assistive interfaces was suggested [25].

An investigation was carried out on 28 participants, selected based on the icon and caption for the candidate matching click. An Every subject looked through and pointed at a total of 72 activities. The results of the experiment showed a 0.7 correlation, an average relative error of 16% with a 54% standard deviation and a relative error within ±40% in 56% of the trials. With an average relative error of 6% and a standard deviation of 42%, the model yielded the intended outcomes in 90% of the trials. Color Bless and Pattern Bless, two of the most well-known color-blind techniques, were first shown in [26]. The visual information of those who are color blind was analyzed using a binocular luster with stereoscopic-3D in order to make them more useful and practical. The experiment involved contrasting these prototypes with other methods that are currently in use. Ten individuals with normal color vision and ten with color blindness, ranging in age from 21 to 30, participated in the study. Analysis of Variance (ANOVA) measurements were used to assess how the three dependent variables were impacted by colors and contrast polarity. The obtained results demonstrated that the luster effect's notice ability was influenced by the contrast polarity.

An additional effectiveness, efficiency, and satisfaction analysis was conducted for the purpose of evaluating the use of adaptive features. Specifically, kid mode, Light Emitting Diode (LED) notifications, voice controls, and screen rotation [27]. Children's tablets were thought of as iOS and Android platform adaptable characteristics. There were 150 participants in the experiment. The study that was given revealed some interesting usability trends, with voice commands and screen rotation showing particularly poor usability. In contrast, LED notifications seemed to be the most prominent feature, operating at over 95% efficacy in a non-adaptive setting. In the Republic of Rwanda, a second usability research was carried out utilizing an internet interface for semiliterate people.

3. Methodology

Numerous studies are conducted on real-time data sets to evaluate the usability elements of customized mobile interfaces for those with disabilities, including color blindness. A specially designed application with adaptive features was created for those who are color-blind. This application does some simple color-blind checks to ascertain the user's status before transitioning to the appropriate mode. The Ishihara test was developed to detect those who are colorblind and will rapidly transition to a new user interface. To ascertain effectiveness, efficiency, and satisfaction in both adaptive and non-adaptive environments, a usability assessment was conducted. Information regarding the uses of color blindness and color vision impairments in adaptive and non-adaptive settings was also disclosed by a comparison analysis.

3.1. Adaptive Environment for Color-Blind

Numerous studies are conducted on real-time data sets to evaluate the usability elements of customized mobile interfaces for those with disabilities, including color blindness. A specially designed application with adaptive features was created for those who are color-blind. This application does some simple color-blind checks to ascertain the user's status before transitioning to the appropriate mode.

The Ishihara test was developed to detect those who are colorblind and will rapidly transition to a new user interface. To ascertain effectiveness, efficiency, and satisfaction in both adaptive and non-adaptive environments, a usability assessment was conducted. Information regarding the uses of color blindness and color vision impairments in adaptive and non-adaptive settings was also disclosed by a comparison analysis. The adaptable system comes with many color schemes for its user interface. Specific forms of color blindness, such as Protanopia, Deuteranopia, Tritanopia, Protanomaly, Deuteranomaly and Tritanomaly, are all catered for in each style. To choose the proper color mode for the session, users first take the Ishihara test [29].

An example of a test used to identify the user's visual type is shown in Figure 1. It displays the test screen's visual observations for both users with normal vision and those who are colorblind. The application automatically transforms to a specific interface style based on the findings of the Ishihara test. Users of any form of colorblindness may utilize this program with ease thanks to its color scheme.

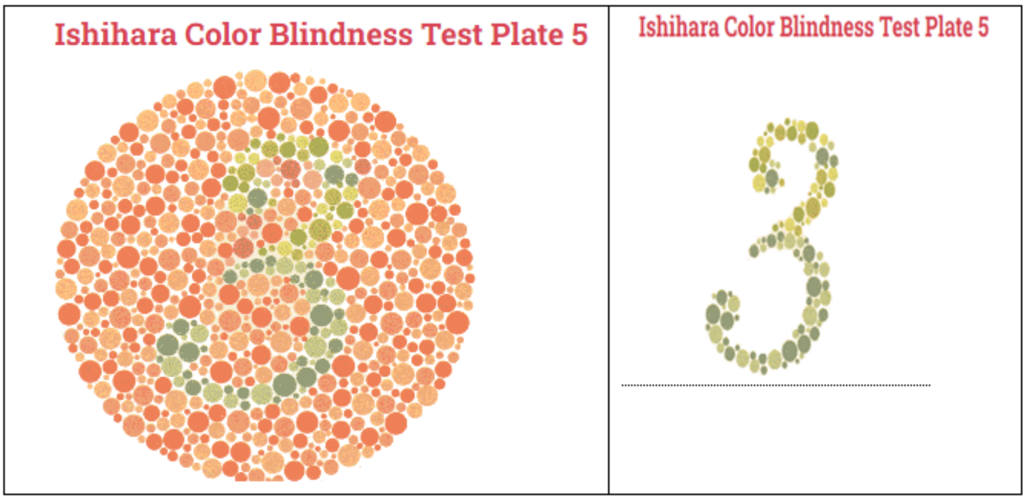

Figure 1. Ishihara test for users who are colorblind and normal.

3.2. Experimentation

3.2.1. Participants

A simple set of users from the desired domain is required for the sampling for a usability evaluation [28]. The population of people who are colorblind or have color vision impairments is the target domain for this user. 76 users were experimented with prior to the study. This is a sufficient sample size for users with particular visual impairments from a given geographic area. The sample Groups of people with color blindness and color vision deficiencies who have used smartphones and laptops for more than a year individuals [30], comprising 51 men and 25 women, were selected based on the worldwide ratio of men to women with color vision impairments. The experiment's participants ranged in age from 15 to 32.

Three different activities in both adaptive and non-adaptive contexts were given to the participants to complete. These tasks includes:

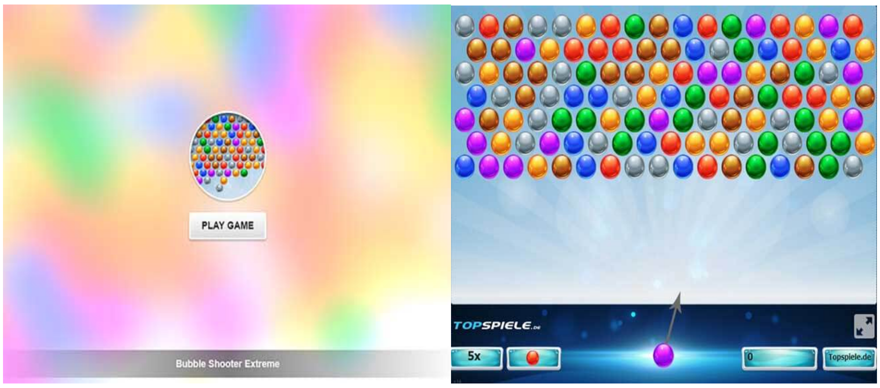

Figure 2. Bubble shooter game

Figure 3. Locate matching jewels in parallel rows

This is the most severe bubble shooter game currently available, with fast-paced action and additional colorful things like power ups and explosives. Mouse over the bubbles to shoot them. Bubbles Extreme is simple to play and enjoyable. You may kill time immediately by launching the game and beginning to pop those enormous bubbles. A bomb detonates, causing all linked bubbles to burst. You will eliminate all bubbles of that color if you strike the nuclear bubble. Certain bubbles have two colors; you can explode them by connecting the two colors. For bonus points, gather every pill.

Jewel Shuffle: Locate matching jewels in parallel rows. Realign a single jewel within one move with another jewel so that it lines up with two jewels in the same or different rows to create a line of three matching jewels. Align and remove jewels until the blue progress bar fills up completely. Swap the jewels to make combinations of 3 or more. Reach each levels target to advance.

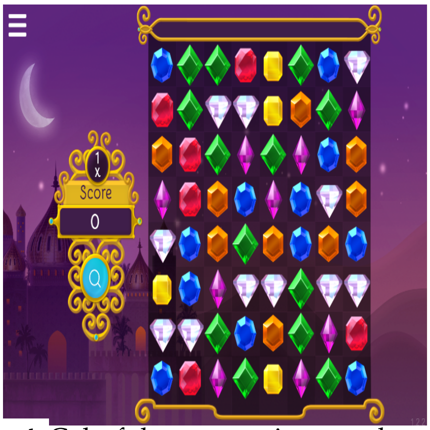

Figure 4. Colorful water sorting puzzle games

Color water filling: These colorful water sorting puzzle games provide a stimulating and enjoyable approach to increase your Color Vision Deficiency. Play water sort puzzle games and enjoy the mental challenge of sorting colored liquids into tubes. In this sort it water sorting game, test your skill at organizing the colored water into various tubes.

3.3. Evaluation of Usability

The ISO 9241-11 standard was followed in the usability evaluation, applying the criteria of effectiveness, efficiency, and satisfaction [31]. The calculations for these measurements are as follows:

Effectiveness: Measured by the completion rate of tasks.

Efficiency: Measured by the time taken to complete tasks [32].

Satisfaction: To measure participant satisfaction in this study, the After Scenario Questionnaire (ASQ) is used. The post-task usability evaluation method's brief questionnaire serves as the foundation for the ASQ. Assessing customer satisfaction using the ASQ is quick and easy to use. It consists of three questions: the first asks about the task's ease of completion, the second about the task's duration, and the third asks about your level of satisfaction with the supporting information that has been supplied. A seven-point Likert scale, with equal distances between points, is used to score each topic. The points range from strongly disagree (0) to strongly agree (6) [30] [33]. This study uses the After Scenario Questionnaire (ASQ) to measure participant satisfaction.

$$\text{Effectiveness} = \frac{\text{Total tasks completed}}{\text{Total tasks undertaken}}$$

$$\textit{Time based Efficiency} = \frac{\sum_{j=1}^{R}\sum_{i=1}^{N}\frac{n_{ij}}{t_{ij}}}{N \times R}$$

Let N= represents the total tasks and R= denotes the participants n_{ij} represents outcome of task i by participant j where n_{ij}=1 otherwisen_{ij}=0, t_{ij}=Time takens by user j to finished, the task I [34].

3.4. Contribution

In this study, we created an adapted mobile interface for users with color blindness and color vision defects (CVD) in this study with the goal of improving their comfort and usability.

The contribution consists of:

3.4.1. Creation of Adaptive and Non-Adaptive Interfaces

Developing an application that modifies its interface dynamically according to the user's visual skills as assessed by the Ishihara test.

3.4.2. Usability Testing through Game-based applications

This method evaluates the usability of adaptive versus non-adaptive settings by using games to implement color recognition tasks.

3.4.3. Usability Calculation: Using effectiveness, efficiency, and satisfaction metrics, a comprehensive assessment is carried out to shed light on the usability enhancements that adaptable interfaces provide.

3.4.4. Comparative Evaluation

Showing how adaptive interfaces benefit users with color blindness and CVD by contrasting the usability metrics between adaptive and non-adaptive environments.

This article provides useful suggestions for creating adaptive interfaces that will work in upcoming mobile technologies and applications. It makes recommendations for how to modify user interfaces to improve overall user experience and account for different color vision impairments [35-36].

4. Results and Discussion

We have calculated the effectiveness, efficiency, and satisfaction scores for in this area. Individuals with color-blindness and those with color vision deficiency (CVD). Additionally, usability metrics have been computed separately for color-blindness conditions including Protanopia, Deuteranopia, and Tritanopia, as well as for color vision deficiency conditions such as Protanomaly, Deuteranomaly, and Tritanomaly.

4.1. Effectiveness

Figure 5 compares the effectiveness of non-adaptive versus adaptive environments for individuals with Protanopia, Deuteranopia, and Tritanopia.

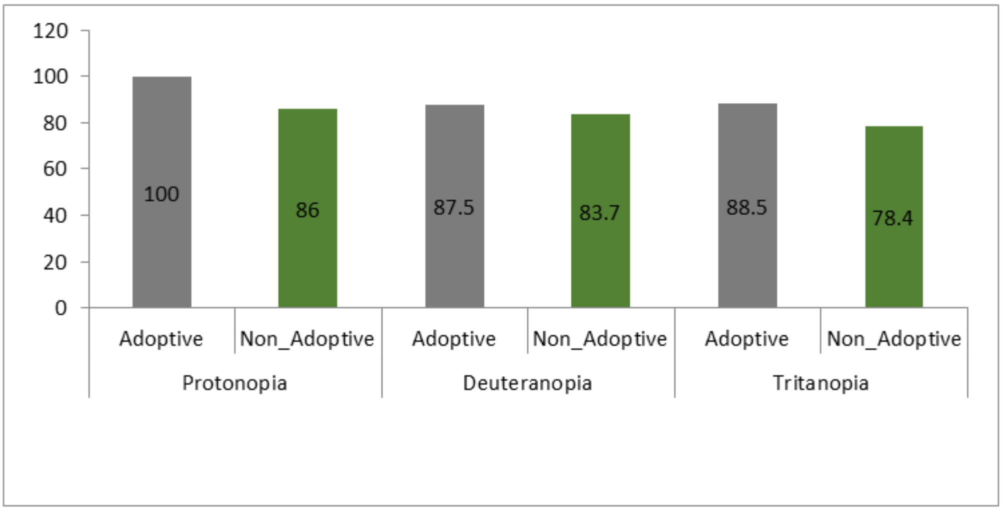

Figure 5. Effectiveness of colorblind in both adaptive and non-adaptive environments.

In an adaptive area, the effectiveness scores were 100%, 87.5%, and 88.5% respectively. Particularly, Protanopia exhibited an exceptionally high level of adaptability, while it was relatively good in the non-adaptive environment, though not as pronounced. Interestingly, both Deuteranopia and Tritanopia demonstrated similar effectiveness scores in both adaptive and non-adaptive environments. Overall, the findings suggest that the effectiveness of an adaptive environment surpasses that of a non-adaptive one.

Figure 6 illustrates the effectiveness of color vision deficiency (CVD) in both non-adaptive and adaptive environments. In the case of Protanomaly and Deuteranomaly, the effectiveness remained consistent at 100%, 87.7% and 78.3%in the adaptive environment. Respectively in non-adoptive 84.4% 78.3% and 78.3%. Overall, the effectiveness in adaptive environments exhibited a significant difference compared to non-adaptive environments. There was an approximately 12% difference in effectiveness for Protanomaly and Tritanomaly in CVD in the non-adaptive environment. According to the results, there is a significant difference in the efficacy of non-adaptive and adaptive modes for color-blind and CVD users. For all forms of color blindness, the efficiency of adapted surroundings is often higher; however, for CVD, the effectiveness varies. Non-adaptive and adaptive behaviors differ by around 12%. Color Blind and CVD modes. These findings suggest that smartphone users with color-blindness and CVD prefer adaptive environments for enhanced usability and comfort.

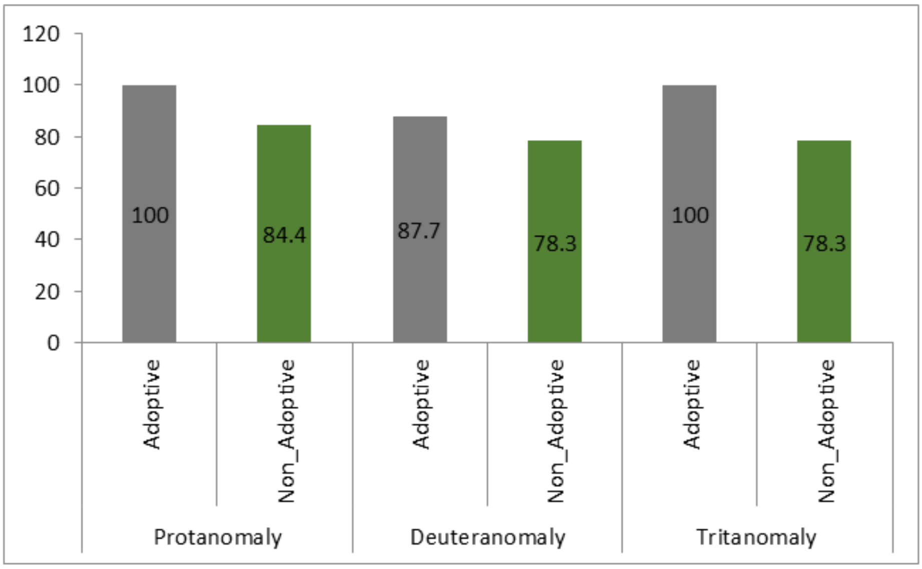

Figure 6. Effectiveness of CVD for non-adaptive and adaptive environment.

4.2. Efficiency

Figure demonstrates the efficiency of both non-adaptive and adaptive modes using the formula with N=tasks. Additionally, it illustrates the efficiency of individuals with color-blindness in both non-adaptive and adaptive Environments.

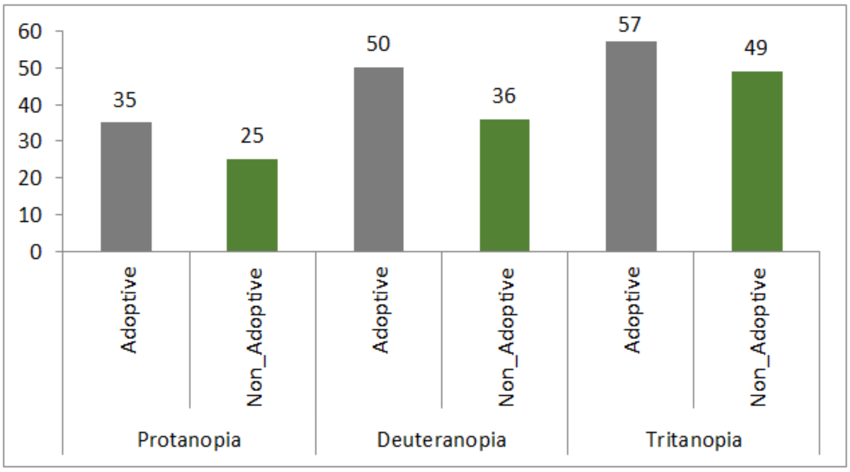

Figure 7. Efficiency of CVD users in both non-adaptive and adaptive environments

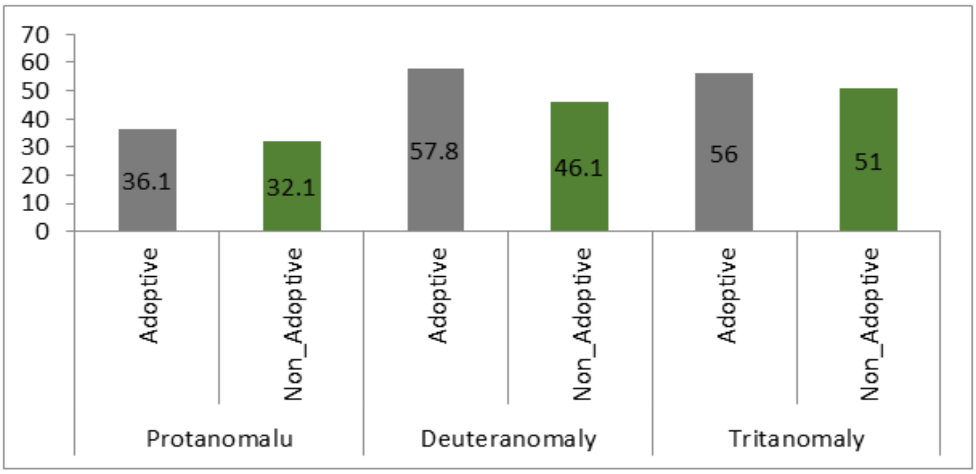

Figure 8. Efficiency of individuals with color-blindness in both non-adaptive and adaptive environments.

The outcome demonstrates that adaptive characteristics have a better efficiency for color vision defects (Protanomaly, deuteranomaly, and Tritanomaly).

4.3. Satisfaction

To gauge participant satisfaction, the ASQ for Protanopia, Deuteranopia, and Tritanopia has been used in the evaluation process. It shows that in a non-adaptive environment, the satisfaction of Protanopia, Deuteranopia, and Tritanopia, ranked as6.4, 6.1, and so on, is lower than in an adapted environment.

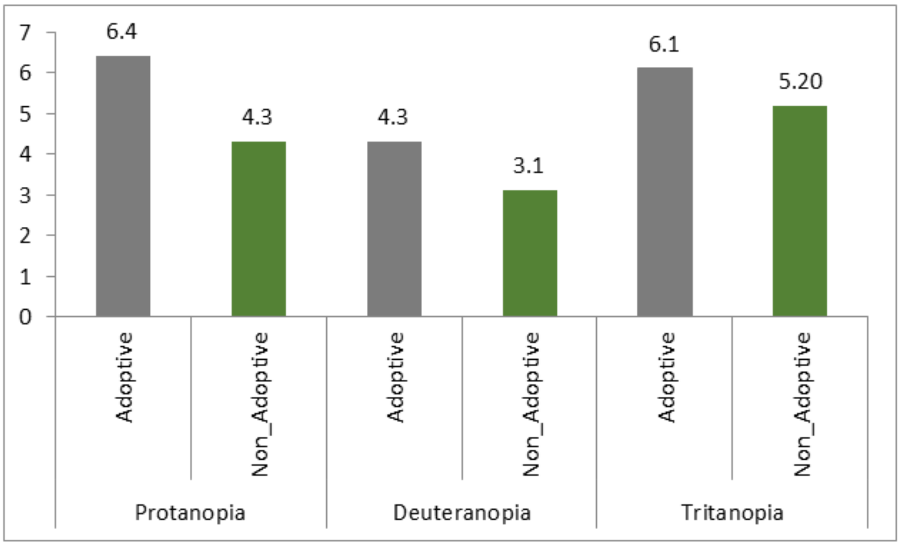

Figure 9. Participant Satisfactions in non-adaptive and adaptive environments

4.4. Image Correctness and Satisfaction Level

Apply different brightness functions and contrast adjustments to the input image. Generate an adjusted version of the image based on these modifications. The adjustments enhance visual clarity and quality. Return the processed image for further use or display.

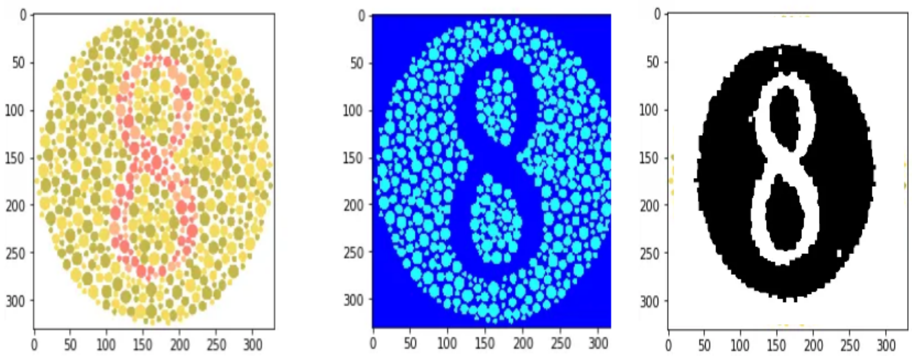

Figure 10. Image Adjustments

After trying out different image segmentation methods on the same dataset then we got better results.

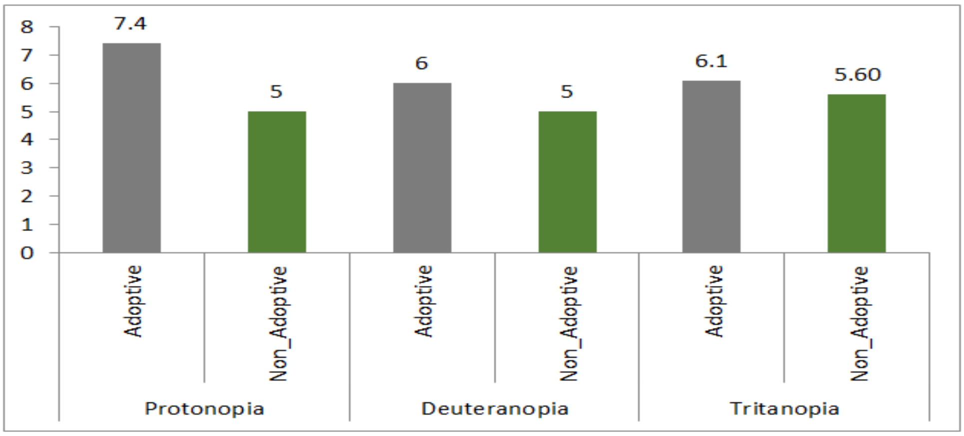

Figure 11. Participant Satisfactions in non-adaptive and adaptive environments after Image Adjustments

5. Conclusion

Information and communication technologies (ICT) by themselves do not ensure accessibility. For those with mild visual impairments, many ICT services provide accessibility challenges. Experiments reported in this paper show that careful interface design that takes human restrictions and context into account can considerably increase user satisfaction. In this study, we propose a revolutionary approach to smartphone applications: instead of changing user behavior, they adapt to their user contexts. With a 40% reduction in Color Vision Deficiency (CVD) and a potential 27% gain in efficiency, the results show a significant boost in task completion effectiveness.

As a result of better performance, user satisfaction rates were significantly higher in adaptable interfaces, as demonstrated in the Protanopia and Tritanopia examples. In contrast to other forms of color deficits, Deuteranomaly users experienced less significant increases in effectiveness and efficiency in adaptive environments. However, there was a general preference for adaptive interfaces, indicating better levels of overall satisfaction. Efficiency gains are shown in Figure 7, where they can reach up to 50% in cases of Protanomaly and double in cases of Tritanomaly. Adaptive interfaces reduced anxiety and promoted confidence by blending in seamlessly with user experiences. By creating user class ontologies and contexts, future research could build on this study and provide more customized interfaces.

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