Usability Aspects of Adaptive Mobile Interfaces for Colour-Blind and Vision Deficient Users

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Summary
Colour-blindness or Colour Vision Deficiency (CVD) is not a disability rather it is naturally challenging vision problem in which user feel difficulty in distinguishing different colours especially differentiating among blue and yellow or red and green colours. It has broader impact as 8% (1 in 12) men and around 0.5% (1 in 200) women are facing this challenge. Today the devices are becoming smarter in recognizing user limitations and operating systems in Mobile-phones are providing such services which help user in their own context to overcome their barriers in usage of information and communication technologies. This paper explores the possibility to transform static interfaces into adaptive user interface which automatically change its behaviour according to user requirements. A research application has been developed which detects the colour-blindness types and automatically switch to respective colour mode. To simulate the visual abilities of user, the Ishihara test is performed in start. Two separate groups consisting 30 colour-blind users and another same sample of colour deficient users performed three different tasks in non-adaptive and adaptive environment. The results indicated that adaptive environment enhanced user effectiveness in tasks completion up to 20% and increased their efficiency up to 8%. Moreover, the users improved their satisfaction level for adaptive environment, specially the substantial difference of satisfaction recorded 40.54% in Protanopia.

Key words:
Adaptive Interface, Colour-Blind, Human Computer Interaction, Mobile Interface, Usability, User Experience (UX), User Context.

1. Introduction

Colour-blindness is a deficiency that disables the patients to differentiate among some basic colours such as red, green, and blue [1] [2]. The colour-blindness is a physical disability with the colour vision deficiency. This disability can restrict the patient to distinguish specific colour from a particular colour combination [3]. Colour-blindness is not considered an immense problem apart from the situations where colour coded information in different combinations is carefully chosen. This problem is usually occurred with lack of decision making from low-ground contrast colour schemes [4]. The fault in retina is the major cause behind colour-blindness. The retina of the eye has two types of cells, called cones and rods which process images. Rod works in night vision and cone works in sunlight while both are responsible for the colour judgement. The cones are called photoreceptors which are responsible for colour vision. There are three types of cone cells exist which absorb the colour spectrum (i) L cone: long wavelength light (red), (ii) M cone: medium wavelength light (green) and (iii) S cone: small wavelength light (blue). The fault in one or some specific cone cells is responsible for partial colour-blindness which produces in appropriate results related to identification of matching colours [5]. Table 1, illustrates cone types L, M, S along with the frequency in male and female population. There are two main possibilities in colour identifications (i) Trichomats are determinable i.e. orange, yellow, blue coral, and canary yellow (ii) Dichromats are not determinable i.e. red and green [6]. Most of patients are affected by Dichromacy which are further divided in to three following sub-categories such as Deuteranopia, Protanopia and Tritanopia. Protanopia contains around 0.02% female and 1.0% male population which is provoked by the deficiency of the L cone [7] [8].

Table 1: Three kinds of cones and their frequency in male and female

Kind of Cone	Cause	Frequency in Female	Frequency in Male
Monochromic	Missing all cones	0.00001%	0.00002 %
Dichromacy Protanopia Deuteranopia Tritanopia	Missing L cone M cone S cone	0.02 % 0.1 % Very rare	1.0% 1.1 % Very rare
Anomalous-Trichomacy Protanomaly Deuteranomaly Tritanomaly	Abnormal L cone M cone S cone	0.02% 0.04 % Very rare	1.0 % 4.9% Very rare

As shown in Table 1 [9], Deuteranopia involves around 0.1% female and 1.1% male population and it is provoked by the deficiency of M cone.

In certain spectrum of colour, the patient feels difficulty in identification of red, blue and green colours. Third type of blindness, Tritanopia, is due to lack of S cone which rarely exists in female but has comparatively more percentage in male population i.e. 0.0001% [5] [9] [10] [11]. The recent version of famous mobile operating systems e.g. iOS and Android have embedded function for Colour Vision Deficiency (CVD) to assist colour-blind users. Usability problems still persist for such users due to rigid modes, low functionality options and complex interfaces to approach facilities to overcome CVD [12] [13]. GoldenShores

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technologies LLC have developed an interface named ColourFind, featured by one camera view along with the quit button. As an output a simple line draws colour name in the middle of camera view. There are multiple interfaces exist that provide different features and functions to overcome or reduce colour deficiency. These attempts are good in terms of functionalities but do not support third party applications [14].
The adaptive user interfaces (AUIs) can be used to overwhelm the restrictions imposed by interfaces used in colour vision deficiency. To simulate the normal colour vision deficiencies, the regular camera of smartphone is used. However, still needs a great work to identify such colours that are user friendly for colour vision deficiency viewers [15]. The adaptive user interface (AUI) detects the user context to adapt a different display such as action and visualization to manage the user's goals according to requirement [16]. AUI supports such type of interface that should be adaptive as per user's needs rather than the users are being adaptive according to interface. Basically, adaptive user interface provides a platform with large potential to improve interactivity with systems [17]. People are facing many difficulties due to complex feature such as large information system, office suits and integrated applications with static interfaces, smaller screens and ability to handle the user feedback [18]. These difficulties in the mobile device interfaces can cause the low satisfaction level amongst the people [19]. A study has been conducted on the usability of mobile phone applications. It showed 59% task completion within given sample size. Moreover, there were three usability problems identified such as efficiency, text insertion and screen size [20]. The better usability is an important concern of users in smartphone applications but recent problems with the development of applications leads towards dissatisfaction [21]. In the mobile interface for an effective usability, the planned tasks should be mapped according to user's mental model. Adaptive user interfaces are directly used to enhance the level of the user's satisfaction and usability [22]. Still there are many applications facing usability problems because of their non-contextual user interfaces. Therefore, adaptive user interfaces try to improve the usability of applications by providing the user requirements by considering their level of ability [23]. This study is structured in different phases such as background describes the latest addition in literature regarding CVD. After that methodology section describes criteria of experimentation and usability assessment. Results and discussion sections illustrate the difference in usability produced by adaptive environment. Finally, conclusions and future work provide direction for future research in colour-blindness.

2. Background

Colour-blindness is a type of physical deficit where the subject is not able to recognise particular or whole colours. People having normal colour vision are considered as Trichromats and can recognise multiple types of colours such as yellow, navy blue, coral, orange, blue and canary yellow. Any of these colours is distinguished by red-green Dichromats. Accordingly, red-green Dichromats are not fair purely colour deficient, but they are colour-blind [23]. When the subjects have total colour-blindness, they can suffer from decreased visual acuity. Consequently, bright environments can cause different problems [2]. The work introduced in [24], indicated the difficulty of map reading for colour-blind users. The results reported that the 96% of whole participants were normal in colour vision deficiency whereas only 8% men were vision colour impaired. The cartographer should be responsible to manage the process of tuning the colours.
Pearson [25] described that 8% of Caucasian men are colour-blind. In particular, the Protanopia, which are red-blind, are only 1%, the Deuteranope, which are green-blind, are only 1.1%, the Dichromats, which are red-insensitive, are only 1%, and the Trichromats, which are green-insensitive, have the highest percentage of 4.9%. The author also stated that 0.003% men were found completely colour-blind and blue-blind were only 0.002%. It also indicated that only 0.4% women were characterised by any type of colour vision problem, where the red or green forms are predominant. Another interesting study was performed in [26] which designed three computational tools for supporting colour-blind people. In particular, the severity of the colour-blindness was evaluated by three tools in order to improve the visual quality according to adaption of fuzzy logic and to simulate the red and green colour-blindness. Histogram equalisation in RGB analysed all correction variations. Accordingly, there were 46% better people found in the evaluation while 14% were found tested worst. Also, histogram equalisation in L, M, S colour model was performed. The result evaluated that there were 17% people found better during testing and only 7% recorded as worst. Lastly, an image retrieval task based on features of colour co-occurrence was analysed in [27] where two cases were discussed for normal vision and three for colour-blindness. The conversion of 12000 images into 3 Dichromatic versions was performed by Vischeck simulation tool to discover the results of 48000 queries asked from colour-blind users. The result showed that in the top 20 retrieved images in competition with the normal vision using colour features was only 32% to 35%. Accordingly, work in [28] designed and implemented a physiological based model for simulating colour perception. The model can represent an effective support for the simulation of vision for the subjects with deficient and normal visual colour systems. A limitation of this model is that it only considers the

conditions approximately up to 99.38% for all CVD cases in Dichromacy and Anomalous Trichomacy. Also, the work in [29] realised a new model of discrimination of the human colour, called ICD-2, to overcome the limitations of CVD. The colour space adopted by the new model was better customised to the human colour vision versus the RGB colour space employed by old situation-specific models. From an empirical comparison of the two models, it was discovered that the old model was 24 times slower than the new ICD-2 model. A new wearable improved vision system based on augmented reality was introduced in [30] for increasing the colour vision in a subject affected by CVD. The experiment included 24 subjects with CVD, in particular 18 male and 6 female subjects of mean age 37.4 years. The obtained results from proposed system determined an improvement in the Ishihara Vision Test, with a mean value from 5.8 without correction to 14.8 with correction. Also, a colour compensation vision system for CVD subjects was proposed in [31]. It was based on Gaussian Mixture Model (GMM) for modelling the image colour distribution. An image of 300×300 pixels was re-coloured in less than 5 seconds by proposed approach without strain to improve the speed of optimization. The work in [32] proposed a fast re-colouring approach for CVD people which was based on preserving the image information. At the same time, re-coloured image was kept as quite natural by proposed colour transform for a subject with normal view. Also, a new algorithm was proposed for detecting unperceivable colours to be re-coloured for the CVD subjects. The results obtained by the experiment showed that proposed approach was able to keep images as natural for a normal viewer. At the same time, it was able to create more understandable images for CVD people. A re-colouring tool (SSMRecolor) based on concept of situation-specific modelling was developed in [33]. According to this model, the re-colouring process was performed. An experiment was performed with the involvement of multiple subjects with and without congenital CVD in a controlled study. The colour matching performance of SSMRecolor and other two methods were evaluated in different environmental contexts. The obtained results showed that the proposed SSMRecolor was more accurate and fast in colour-matching tasks. It demonstrated that using a situation-specific method to re-colouring was able to improve the usability of colour displays for different types of subjects. Also, the work in [34] developed a new algorithm of video re-colouring for people affected by Dichromacy. Four Internet videos were tested by the proposed algorithm. More specifically, the experiment was composed of 11 subjects with one subject affected by Protanopia to which the original videos were showed by first. Then, the tested subjects assessed the re-coloured videos. An evaluation based on contrast, naturalness and performance was performed on the four videos by the Protanopia subject. The obtained results showed that the proposed method can achieve a better visual quality on the re-coloured videos. The computer based version of the Ishihara colour plate test has been evaluated through algorithms based on adaptive interfaces. Also, a simulator for evaluating assistive interfaces was proposed in [35]. Searching icons application used by mobility impaired, visually impaired and able-bodied was used for evaluating the simulator. An experiment was conducted with 18 subjects which were chosen with the target according to icon and caption for the clicking of candidate matching. A total of 72 tasks were searched and pointed by each subject. A correlation of 0.7, a relative error within ±40% in 56% of the trials, and an average relative error of 16% with a standard deviation of 54% were obtained as a result of the experiment. An average relative error of 6% with a standard deviation of 42% was achieved for the 90% of the trials where the model correctly worked. Two prototypical colour-blind approaches, called ColorBless and PatternBless, were introduced in [11]. In order to improve the visual information for colour-blind subjects, a binocular luster with stereoscopic-3D was employed to analyse their usability and practicality. The experiment consisted in comparing these prototypes and other existing approaches. It was conducted on 10 colour-blind and 10 normal colour vision subjects with the age between 21 years and 30 years. To evaluate the effects of colours and contrast polarity on three dependent variables, ANOVA measures were adopted. From obtained results, it was shown that the contrast polarity influenced the noticeability of the luster effect. The development of dynamic interfaces based on the user's context can be considered as a valid support for improving the usability of user interfaces. In this context, the work in [36] developed the Tukuchiy framework for automatically generating AUIs. It was characterised by a rule system and obtained a greater usability on the basis of the preferences of users. On the other hand, this system considered colour-blindness and myopia in place of physical difficulties. For testing the rules, the Midiku application was designed for supporting the diagnostic process run by radiologist. Device assesses the rules using the Mock-ups of digital prototypes. The evaluation was realised by presenting Mock-ups to a team of radiologist including one expert and two novice radiologist. The screen organization and data fields view were positively evaluated, while the buttons, characters visualization and terminology were negatively evaluated. Furthermore, a usability study of online assistance was conducted in [37] for semi-literate users with four different interfaces. The study was conducted in the Republic of Rwanda where four groups were created from 180 participants with low literacy in order to make online tasks. The presented results of semi-literate users were significantly increased and improved the percentage of completed tasks from 52% to 94%. Another analysis of effectiveness, efficiency, and satisfaction was performed in [38] for usability evaluation of adaptive features in smartphones. In particular, screen rotation, voice commands, LED notifications and kid mode were considered as adaptive features for android and iOS platforms. The experiment was conducted with 128 subjects. Interesting patterns of usability were visible from the presented study, in particular a lower usability characterised screen rotation and voice commands. Whereas, LED notifications appeared to be dominant feature with almost 88% of effectiveness comparative to non-adaptive environment. Another usability study was conducted for semiliterate users by using online interface in Republic of Rwanda. The User Centred Design (UCD) lifecycle was used to improve the user's experience while System Usability Scale (SUS) was used to evaluate the interfaces which were translated in Swahili language. The results indicated that average subjective usability score was increased from 39 to 80 [39]. In another study, SUPR-Q model was proposed to measure the web usability for user's trust. The results indicated that usability of daraz.pk is better than other websites. Users showed better results in effectiveness and efficiency on daraz.pk i.e. 91% and 82% [40]. Furthermore, the work in [41] presented a new usability method by taking the limitations of existing systems. This model evaluated to support indirect and direct adaptation for considering the user feedback according to user environment for context identification. The QUIS questionnaire was used to evaluate the overall satisfaction of proposed methology. The obtained Alpha score is higher than 0.7 for all the scale except terminology and system information due to misinterpretation. An application was presented in [14] for increasing the usability of mobile interfaces in the context of CVD. The type of colour deficiency could be easily recognised by the proposed application. Hence, for supporting the affected people, application listed the unrecognizable colours. For simulating the colour vision problems to normal people, the smartphone's camera captured the image. The work in [42] introduced new approaches for developing adaptive interfaces as a valid support for interfacing CVD subjects with web systems. The proposed framework was showed through the development of prototypes and different scenarios. As a result, from the framework, the most suitable re-colouring approaches could be determined and automatically employed in order to adapt the interfaces for CVD people.

The aforementioned works analysed and studied the CVD accessibility and adaptivity in mobile applications. It is worth noting that many algorithms, approaches, models and applications have been designed for re-colouring, identification and contrasting of colours for CVD people. Nonetheless, these adaptive models are not particularly focused on the user needs. In fact, selection of colours that are visually friendly for CVD viewers still takes a lot of effort. Also, the adaptive features are designed for specific purpose/context and specific environment.

3. Methodology

Multiple experiments are performed to analyse the usability aspects of adaptive mobile interfaces for colour-blind and deficient users. In this regards an application with adaptive features was developed for colour-blind users. This application reads the user context with some initial colour-blind tests and switch to the specific mode accordingly. Ishihara test was used to identify the colour-blind users that will change user interface automatically. The usability evaluation was performed to measure the effectiveness, efficiency and satisfaction for adaptive and non-adaptive environment. Furthermore, the comparative usability analysis between colour-blindness and colour vision deficiency was presented for both adaptive and non-adaptive environments.

3.1 Adaptive Environment for Colour-blind Users

The mobile device interface provides a comfortable medium of communication between devices and users.

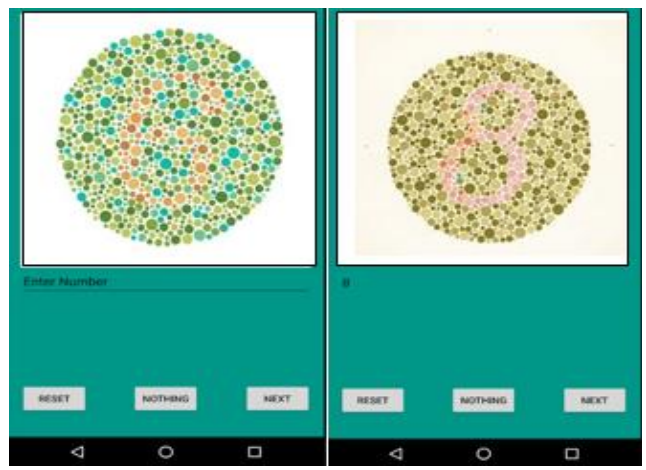

Fig. 1 Ishihara test for normal and colour-blind user.

A dynamic environment was simulated through an overlay application to perform usability evaluation. This application provides multiple styles of user interfaces having specific colour palettes. Dislike recent adaptable static developments, this dynamic environment switches to specific context just by sensing it. To sense the user context, every user has to perform Ishihara test at least once so that device can be familiar to the user and their visual abilities. Figure 1 shows the example of test, that is being performed for user's vision types identification. It presents the visual observations of test screen for normal vision user and for user having colour-blindness. Depending on the Ishihara test results, application switches to specialized interface style. This application uses a colour scheme that can be easily operated by users with any kind of colour-blindness. All the known users do not need to perform the test but will be directly logged in to their specific interface style. The figure 2 presents the login screens for normal and colour-blind user.

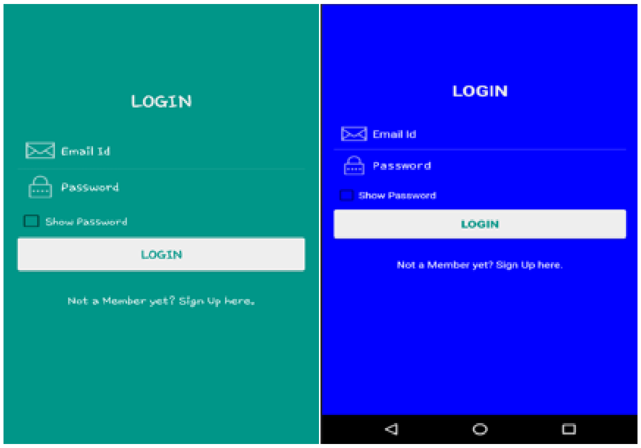

Fig. 2 Login screens for normal and colour-blind user.

3.2 Experimentation

The sampling for a usability evaluation needs simple group of users from targeted domain. Here the target domain of user is population of colour-blind and colour vision deficient users. The study preceded experimentation with 30 users. This is a standard and ample sample size for the users from specific geographic locality having specific vision impairments [43]. The sample set includes groups of users having colour- blindness and colour vision deficiency with more than one-year experience of smart phone usage. Thirty members including 23 males and 7 females are chosen on the basis of global ratio of male/female population with colour vision problem. In the experiment, participants were in the range of 18 to 30 years of age. Three tasks were given to users in non-adaptive and adaptive environment. All the participants attended a small training session in which they were briefed about tasks they have to performed. These tasks include playing three different colour based games. These games were selected based on two reasons, first different colour combinations are used in these games and second user needs to identify colours to play in changing combinations. Each task can be attempted maximum three times to successfully stand ground in the game for the allocated time of 5 minutes.

Fig. 3 The interface of color switch game.

Color Switch (Task-1): In this game the player needs to take a jumping ball across multi-colour, rotating, open and closed shapes through matching colour region of the shape. With every new shape the jumping ball changes its colour too. Figure 3 shows some sample combination and shapes used in Color Switch.

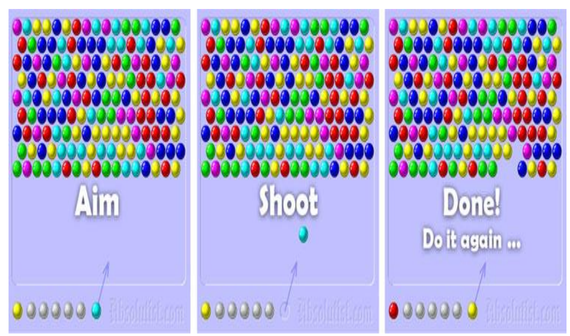

Fig. 4 Screen shots of bubble shooter game.

Bubble Shooter (Task-2): In this game, user need to shoot down different coloured hanging and increasing balloons until they touch the bottom of play screen. User has to shoot them only with matching balloon provided in the canon. Figure 4 presents some screen shots of task.

Fig. 5 Screen shots of baby xylophone game.

Baby Xylophone (Task-3): User has to play two specific tunes using a rainbow coloured Xylophone by hitting the colour music notes appearing on different keys.

3.3 Evaluation of Usability

The usability evaluation is performed according to the ISO 9241-11 standard with the measurement factors of Effectiveness, Efficiency and Satisfaction. These measurements can be calculated as follow [44]:

$$Effectiveness = \frac{Total\ tasks\ completed}{Total\ tasks\ undertaken} \times 100\ \%$$

The resources such as time, money or mental efforts that need to be extended to achieve the intended goals are called efficiency and can be measured as:

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

Where;

N=Number of tasks

R=Number of participants

nij=Result of task i by user j (completed Task results nij=1 otherwise nij=0)

tij =Time by user j to complete the task i

In this study, After Scenario Questionnaire (ASQ) is used to measure the satisfaction. ASQ is based on short questionnaire on post task usability evaluation technique. ASQ is easy to understand and also takes less time to evaluate the satisfaction of user. It contains three questions where first question is related to ease in task completion, second question shows the completion time of a task and third question is about satisfaction level against provided support information. Each question is ranked on seven-point Likert scale which varies from strongly disagree (0) to strongly agree (6) with equal distance on each point [45].

4. Results and Discussion

In this section the results of effectiveness, efficiency and satisfaction have been calculated for colour-blind and CVD people. The usability has been computed for colour-blindness (Protanopia, Deuteranopia, Tritanopia) and colour vision deficiency (Protanomaly, Deuteranomaly, Tritanomaly).

4.1 Effectiveness

The figure 6 shows the comparison of effectiveness between non-adaptive and adaptive environment. The effectiveness of Protanopia, Deuteranopia and Tritanopia for non-adaptive environment is 80%, 60% and 60% respectively.

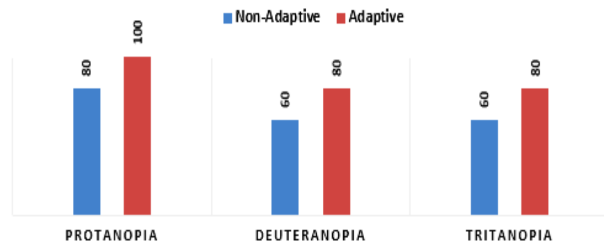

Fig. 6 Effectiveness of colour-blindness for non-adaptive and adaptive environment.

In adaptive environment the effectiveness is 100%, 80% and 80% respectively. Protanopia has extremely adaptive environment while it is close to good in non-adaptive environment with respect to effectiveness. The result shows that Deuteranopia and Tritanopia has equal effectiveness for non-adaptive and adaptive environment. Overall the results illustrate that effectiveness of adaptive environment is greater than non-adaptive environment.

The effectiveness of colour vision deficiency is elaborated in figure 7 for non-adaptive and adaptive environment. The effectiveness of Protanomaly and Deuteranomaly remained same which is 80% for non-adaptive environment. Likewise, Deuteranomaly shows the equivalent effectiveness for non-adaptive and adaptive environment. Overall the effectiveness of adaptive environment has significant difference than non-adaptive environment. Moreover, the effectiveness for Protanomaly and Tritamomaly in CVD shows the substantial difference (20%) for non-adaptive environment.

The considerable difference has been shown in the results of effectiveness for colour-blind and CVD users in non-adaptive and adaptive mode. The effectiveness is higher in average for all types of colour-blindness in adaptive environment while it varies for CVD. The difference shows between non-adaptive and adaptive mode in CVD for Protanomaly is 20% and for Tritanomaly is 40%. The above results represent that the users of smartphones with colour-blindness and colour vision deficiency feel comfortable with adaptive environment.

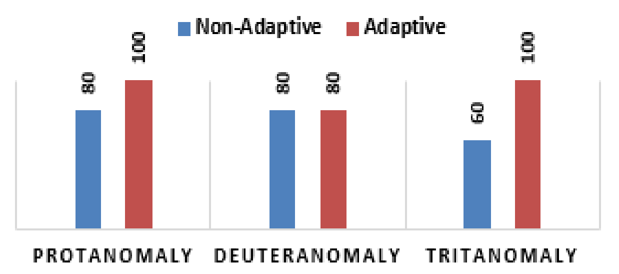

Fig. 7 Effectiveness of colour vision deficiency for non-adaptive and adaptive environment.

4.2 Efficiency

The efficiency of non-adaptive and adaptive modes has been proven in the figure 8 by using N=goals in formula. It also represents the efficiency of colour-blind people for non-adaptive and adaptive environment.

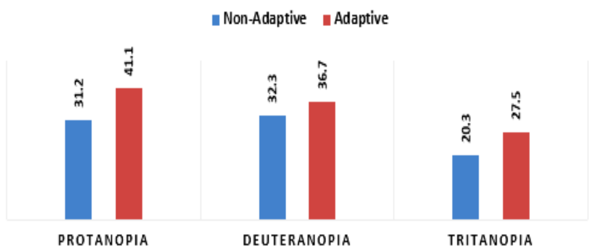

Fig. 8 Efficiency of colour-blindness for non-adaptive and adaptive environment.

It shows that efficiency of adaptive features for Protanopia is higher. It illustrates that the efficiency of Protanopia, Deuteranopia and Tritanopia is lesser in non-adaptive environment (31.2 %, 32.3%, 20.3%). Overall the efficiency of adaptive environment is better than non-adaptive environment.

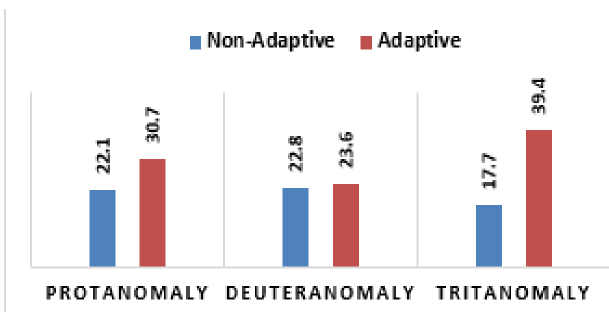

Fig. 9 Efficiency of colour vision deficiency for non-adaptive and adaptive environment.

The figure 9 denotes the efficiency of colour-vision deficiency for non-adaptive and adaptive environment. The result shows that the efficiency of colour vision deficiencies (Protanomaly, Deuteranomaly, Tritanomaly) is higher for adaptive features. Moreover, highest efficiency is 39.4% for adaptive and lowest is 17.7% for non-adaptive environment in Tritanomaly. The Deuteranomaly CVD type has not much difference between the efficiency of adaptive and non-adaptive mode.

Overall the efficiency shows the impressive results in adaptive environment for colour-blindness and CVD. The difference in efficiency for Protanopia is 9.9% for colour-blind people. The highest efficiency for adaptive features is reported 41.1% in protanopia for colour-blindness while 39.4% in tritanomaly for CVD. The efficiency of colour-blind and colour-vision deficient users improves when they perform in adaptive environment.

4.3 Satisfaction

The figure 10 shows the usability comparison in terms of user satisfaction for non-adaptive and adaptive environment.

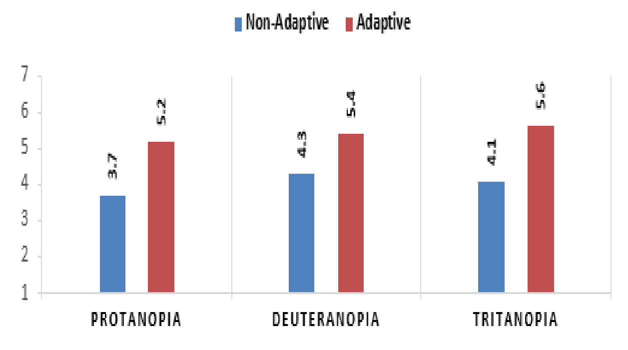

Fig. 10 Satisfaction of colour-blindness for non-adaptive and adaptive environment.

The evaluation has been taken through ASQ for Protanopia, Deuteranopia and Tritanopia to measure the satisfaction level of participants. It illustrates that the satisfaction of Protanopia, Deuteranopia and Tritanopia ranked as 3.7, 4.3 and 4.1 respectively for non-adaptive environment is lesser than adaptive environment. Likewise, the Protanopia users contain minimum satisfaction for non-adaptive (3.7) and adaptive (5.2) environment. The highest satisfaction rate is 5.6 which gained for Tritanopia in adaptive environment.

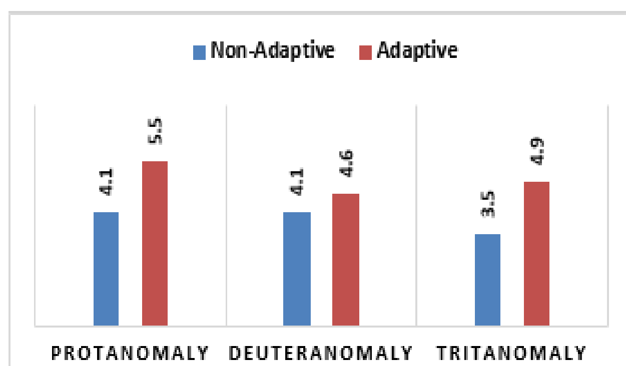

Fig. 11 Satisfaction of colour vision deficiency for non-adaptive and adaptive environment.

The figure 11 shows the satisfaction of colour vision deficient people for protanomaly, deuteranomaly and tritanomaly. The result clarifies that satisfaction is greater in adaptive environment than non-adaptive environment. The satisfaction level of protanomaly is ranked as 5.9 in adaptive environment which is higher while 5.5 is lower in protanomaly. Protanomaly and deuteranomaly shows equal satisfaction level (4.1) in non-adaptive mode.

5. Increase in Usability by Adaptive Mode

The results show that adaptive environment has better usability measures than non-adaptive environment. This section calculates the increase percentages of usability measures w.r.t. the non-adaptive environment. It presents comparative result analysis for users with colour-blindness versus users with colour vision deficiencies. The overall results show that the adaptive environment has mix advantageous for the users with colour-blindness and CVD. The increase in effectiveness, efficiency and satisfaction has been calculated by using following formulas.
Overall the satisfaction level of adaptive environment is much better than non-adaptive environment for colour-blindness and CVD. The difference is ranked same as 1.5 between satisfaction level of protanopia and tritanopia. Identically, the usability satisfaction for colour vision deficient users shows highest limit (4.9) for adaptive environment while lowest limit (3.5) for non-adaptive environment in tritanomaly. Furthermore, the result elaborates the feeling, comfortability and usability of participants during the experimentation in adaptive environment.

$$Increase\ in\ Effiecincy = \frac{Efficiency_{(Adaptive)} - Efficiency_{(Non-Adaptive)}}{Efficiency_{(Non-Adaptive)}} \times 100$$

$$Increase\ in\ Satisfaction = \frac{Satisfaction_{(Adaptive)} - Satisfaction_{(Non-Adaptive)}}{Satisfaction_{(Non-Adaptive)}} \times 100$$

$$Increase\ in\ Effectiveness = \frac{Effectiveness_{(Adaptive)} - Effectiveness_{(Non-Adaptive)}}{Effectiveness_{(Non-Adaptive)}} \times 100$$

The figure 12 shows the capable view and increase in effectiveness. It presents the effective comparison to identify the effectiveness between colour-blind and colour vision deficient mobile users.

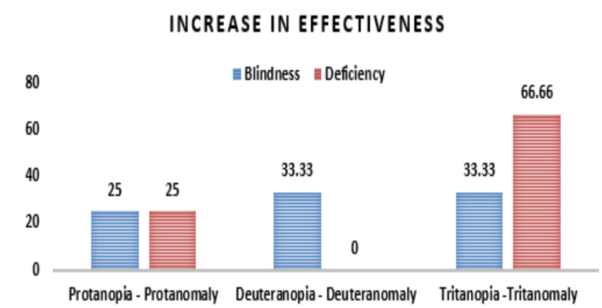

Fig. 12 Increase in effectiveness of colour-blindness and colour vision deficiency.

The vital difference recognises in Tritanopia and Tritanomaly for colour-blind and CVD users. It shows that colour-blind (Deuteranopia) people has 33.33% increase in effectiveness while there is no increase in effectiveness for colour vision deficient (Deuteranomaly). Furthermore, the equal increase in effectiveness is noticed for (Protanopia) colour-blindness and (Protanomaly) CVD.

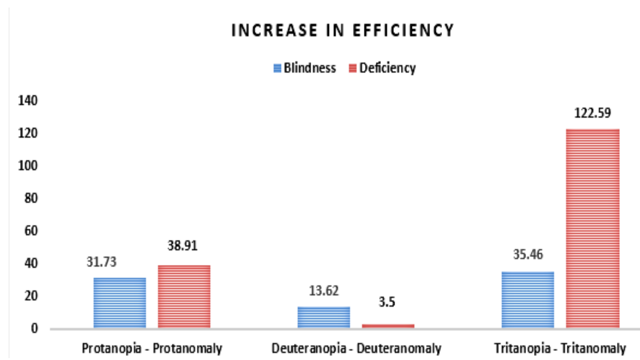

Fig. 13 Increase in efficiency of colour-blindness and colour vision deficiency.

The excellent efficiency is shown in figure 13 for mobile users in adaptive environment of Tritanomaly. It elaborates that Protanomaly has 38.91% efficiency while Deuteranomaly has minimum efficiency for CVD. It expresses the highest efficiency of colour-blind users in Tritanopia is 35.46%. Likewise, Protanopia has efficiency 31.73% while Deuteranopia has lower efficiency for colour-blind users. Moreover, major difference appears in Tritanopia and Tritanomaly for colour-blind and CVD users. The comparison between colour-blind and CVD people gives the expression of enhancement in efficiency of mobile users.

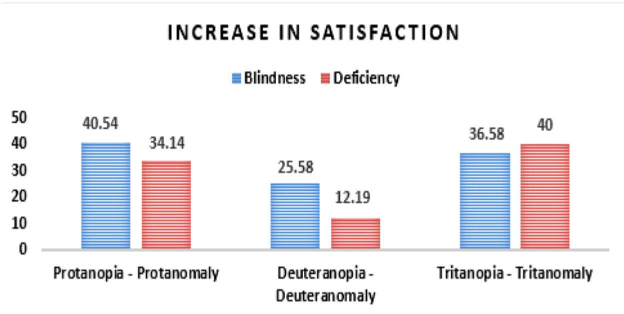

Fig. 14 Increase in efficiency of colour-blindness and colour vision deficiency.

The figure 14 shows comparison of satisfaction between colour-blindness and colour vision deficiency for mobile users. The result interprets the percentage of satisfaction for Protanopia (40.54%) and 34.14% for Protanomaly. The substantial difference is shown between the satisfaction of Deuteranopia and Deuteranomaly. Moreover, the users are significantly satisfied for Protanopia in colour-blindness and Tritanomaly in CVD.

6. Conclusion

Mere availability of information and communication technologies (ICT) not means accessibility. Many ICT services pose an accessibility barrier for those who have minor vision deficiency. If interfaces are carefully designed by keeping in view user limitations and their context, then it will raise their satisfaction level as observed in experiments. The paper presents a novel approach in which the behaviour of users is not altered according to the smart phone application rather the application changes its behaviour according to user environment through adaptive interface. The results showed a significant improvement in task completion rate (effectiveness) which is increased 40% in case of Tritanomaly users in CVD, furthermore their efficiency also increased up to 22%. The satisfaction rate of colour-blind users in adaptive interfaces were higher especially in case of Protanopia and Tritanopia which was also evident by their performance. It is pertinent to mention here that in case of Deuteranomaly in CVD the effectiveness and efficiency of users in adaptive environment was not much improved if compared to other types of colour deficiency but overall satisfaction on adaptive interfaces proved them preferred choice. The figure 13, shows that increase in efficiency in case of Tritanomaly in CVD was twofold while in case of Protanomaly it was up to 40%. The adaptive interfaces provided seamless integration in which the user felt more confident and less scared. In future, the work expanding this study by defining the ontology of user classes and their context to design more personalized user interfaces.

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