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Visual Ergonomics for Colourblindness: Applying Universal Design Principles in Graphical User Interface to Provide Affordance to the Colourblind Users

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Abstract

With evolution of Graphical User Interface, the access to the computer interface was expanded to cater to the extreme user categories by providing accessibility features and making the computer interface more inclusive. One such extreme user category is colourblind, which has a special accessibility requirement from the GUI. This paper studies the iconography of the Microsoft Windows operating system interface with an objective to develop an inclusive icon design solution that is visually ergonomic for colourblind users to include them as a mainstream user category in a computer interface.

Keywords: human behaviour, user experience, human-centred design, visual ergonomics, colourblindness

1. Introduction

The Graphical User Interface (GUI) was developed with an aim to provide the benefits of computer systems to the general users, thereby making them quickly familiarize with the computer environment. It is a powerful tool comprised of various visual elements (WIMP) that defines its characteristics on a screen. In human-computer interaction, WIMP stands for "Windows, Icons, Menus, and Pointers" (van Dam, Andries, 1994). With technical advancements, the computer interface visually evolved according to users' needs as more people got involved as computer users and started accessing the GUI features. With further evolution of the GUI, the access to the computer interface was expanded to cater to extreme user categories by providing accessibility features and making the computer interface more inclusive. With evolution of the GUI, the access to the computer interface was expanded to cater to extreme user categories by providing accessibility features and making the computer interface more inclusive (Otachi, 2019). One such extreme user category is colourblind, which has a special accessibility requirement from the GUI. Although accessibility for colourblind users is provided in the GUI, it has to be customised from the settings. One solution to this problem could be redesigning the visual components of the GUI using universal design principles so they could be equally accessed by both colourblind users as well as users with normal colour vision. An icon is one such visual component that affects a computer interface's usability according to its appropriateness, communicating the intended meaning and its recognizability (Fullerton and Happ, 1993). With advancements in graphic technology, the focus of GUI designers had shifted towards bringing aesthetic appeal to the icons by using complex and detailed graphics to make the icons appear more realistic, thereby neglecting the issues faced by vision deficient users such as colourblinds. This has resulted in inconsistency throughout the GUI as there exists icon sets of multiple visual styles including fluent, skeuomorphic and pictorial. Appropriate use of visual style in the icon set of an operating system GUI not just helps mitigate the visual confusion caused but also make them feel confident accessing it. This paper tries to understand the problems faced by colourblind users in a desktop/laptop computer interface pertaining to the iconography of Microsoft Windows OS in terms of recognition, accessibility and engagement, in order to develop an inclusive icon design solution that is visually ergonomic for colourblind users and enhance their task performance efficiency thereby including them as a mainstream user category in a computer interface.

2. Review of Literature and Available Solution

A comprehensive literature review was conducted to understand colourblindness and how it affects the day-to-day life of people suffering from colourblindness alongside the literature review of extreme user categories. Also, a detailed study of the available solution pertaining to colourblindness in a computer interface was performed.

2.1. Background Study

Colourblindness is a disorder where an affected person cannot distinguish a particular colour shade against another colour shade. As a result, one affected is not familiar with the difference between colours evident to the people having Normal Colour Vision. This disorder occurs due to the lack of photopigments present in red, green and blue cone cells in the eyes. At the same time, there are two types of photoreceptors in our eyes, namely: rods and cones. The perception of brightness and darkness is due to the presence of rod cells, whereas colour perception depends upon the cumulative information retrieved through red, green and blue cone cells. Colourblindness is the abnormal behaviour of a particular colour cone resulting in a change of colour perception in a person. 8.59% of the population is colourblind (Natu, 1987). There are three common types of colourblindness: the lack of green cone cells in the eyes is called Deuteranopia, the lack of red cone cells in the eyes is called Protanopia, and the lack of blue cone cells in the eyes is called Tritanopia. Figure 1 shows the graphical representation of the colour spectrum of a) colour absorption curves for normal colour vision, b) colour absorption curves for Deuteranopia, c) colour absorption curves for Protanopia, d) colour absorption curves for Tritanopia (Gordan, 1998).

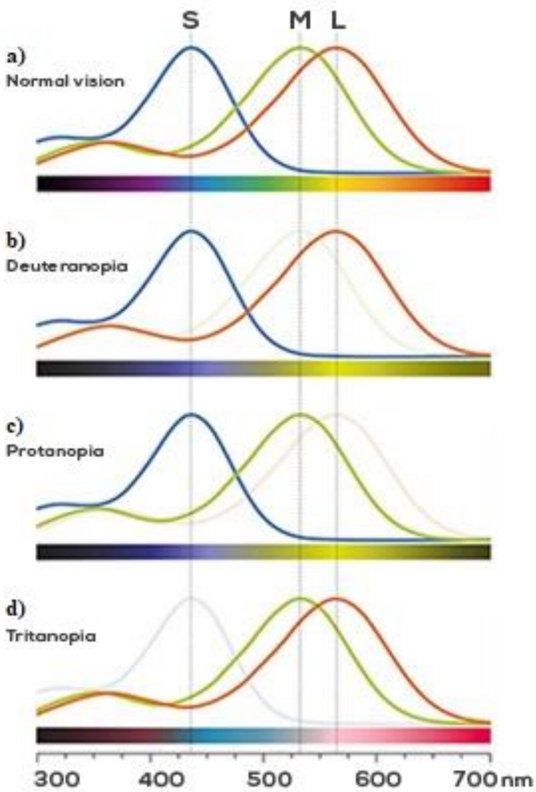

Figure 1. Colour absorption curves in colourblindness

People with colourblindness face many difficulties in their daily life such as reading traffic lights while driving; distinguishing between vegetarian and non-vegetarian food items while purchasing groceries; handling electronic and electrical devices; identifying flowers, fruits and vegetables and cooking; clothes selection while wearing and buying; analysing lab results of experiments; communicating with digital media such as computer interfaces and touch-based devices; and a lot more. Colourblindness being incurable, the people affected always have to adapt themselves according to tangible and digital products around them. Considering computer interface, if a computer interface is comprised of clashing colours in its visual components, a colourblind person would miss the essential information and have an unpleasant experience leading to ineffective communication and inefficient task performance.

2.2. Available Solution

The newer versions of computer operating systems now come equipped with colour correction accessibility settings for colourblindness. For example, Microsoft Windows 10 has 'Ease of Access' section under the Settings program, which provides colour correction filters as an accessibility option for colourblindness. Similarly, Apple also has colour filters under the Display section of accessibility settings in its macOS 12 operating system. These colour correction filters adjust the colour contrast between confusing colours for different colourblindness types in the computer interface to make it visually comfortable to the colourblind users.

2.3. Extreme User Bell Curve (Normal Distribution Curve)

The normal distribution curve or extreme user bell curve, as shown in Figure 2, is the diagrammatic representation to map the situation of the user groups. The majority of the user groups fall inside the centre of the curve, but there are still many user groups situated at the extreme ends of the curve who have special requirements from the product. Understanding these requirements become necessary to design a universal product that could include these extreme users alongside the existing mainstream user base as the insights collected from the extreme ends helps generate design concepts for both user categories (Basak and Roy, 2019).

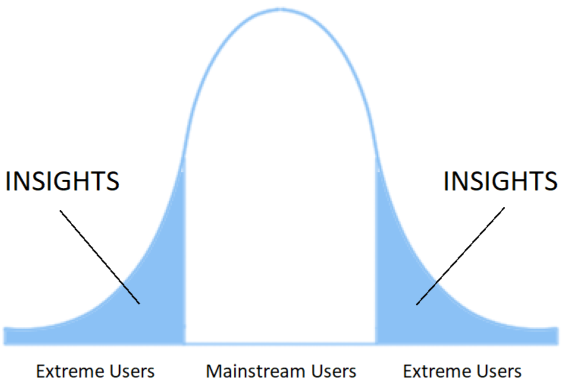

Figure 2. Extreme user bell curve

3. Purpose of Study

This study is conducted to understand the user experience of colourblinds in a desktop computer interface. Although this is evident that more people are shifting to touch-based mobile devices for their daily requirements with an increase in the task performing capabilities of touchscreen devices, there is still a lot of professional work, that demands a Desktop/Laptop computer interface due to their higher graphics and performance capabilities. According to research conducted in India, the users, on average, spend more than 6 hours daily on computers (Sharma, 2016). Moreover, this study is essential as it provides a scope to design a product or an interface accessible to all, thereby improving an individual's quality of life. Allowing people with different abilities to use an interface the same way as it is meant for normal users could decrease feelings of isolation and emotional pain (Khaliq and Torre, 2019).

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4. Research

In order to collect valuable user insights, qualitative research was conducted in multiple phases, which involved understanding of methodology to be used, proper planning and research design.

4.1. Research Methodology

Action research methodology is considered for this research since a solution was required for a defined problem and the research process had to be designed accordingly. The research begins with a survey that was circulated through various social media channels so that interested candidates can directly participate, allowing a more considerable number of people to respond. The survey was designed with an intention to discover colourblind subjects among respondents and gather basic information regarding colourblindness, such as awareness and consequences. If the survey yielded desired results, it would then be followed by an on-field sampling and detailed interview session with the participants diagnosed with colourblindness. The interview responses would then be analysed for extracting meaningful results through affinity mapping and thematic correlation methods.

4.2. Survey

A survey containing an online colourblindness test and a few basic questions such as age, gender, and current occupation was circulated in the initial stage of the research. The objective here was to discover people with colourblindness. Participants from all age groups above 15 years took part in the survey, and the ratios are as follows:

- 15-25 years……………25 respondents……………..…...41.7%
- 25-35 years……………31 respondents.……………...51.7%
- 35-45 years……..….…….2 respondents…………….…….3.3%
- Above 45 years…………2 respondents…….…………….3.3%

Total 60 participants responded to the survey, among whom 12 were found to be colourblind on taking the test, which is 20%, a more significant majority than that of 8.9% found in the secondary data. 56.7% of the respondents were students, and 43.3% of the respondents were working professionals. 76.7% male and 23.3% female participants responded to the survey, which is 46 male and 14 female. No female was diagnosed with colourblindness among the respondents of the survey. 56.6% of the respondents had never taken the colourblindness test before, 36.7% had taken the colourblindness test before, and 6.7% were not sure. It was surprising to learn that most participants, including those found to be colourblind, never took a colourblindness test. This shows a lack of awareness among people with colourblindness about their condition, let alone the awareness about colour correction accessibility settings provided in the GUI. On further verification through established secondary data, it was confirmed that there is actually a lack of awareness among the colourblind individual about their condition (Yu, 2015).

4.3. Field Research and Sampling

To validate the data collected from the survey, a detailed and separate sampling was done by following the cluster random sampling method where the researchers approached all the students, professors and staff members of the Indian Institute of Technology Kanpur in person, requesting them to take the test. Participation in the experiment was voluntary. Each participant was approached individually for the colourblindness diagnosis test. 100 college students consisting of 72 males and 28 females; and 65 working professionals consisting of 52 males and 13 females took the test. Enchroma test for colourblindness diagnosis was chosen to get accurate and detailed results. 13 out of 100 college students and 9 out of 65 working professionals were found to be colourblind, constituting 22 participants, which is 13.3% of the total sample size of 165. No female participant was diagnosed with colourblindness here.

4.4. Interviews

The 22 colourblind participants found in our sample were interviewed to collect valuable insights regarding the problems encountered in their daily activities. The interview started with fundamental questions on colourblindness and progressed, emphasising questions related to experience with GUI.

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4.4.1. *Interview Questions*

- Have you heard about the term colourblindness? If yes, what do you know about it?
- Do you know that you have colour vision deficiency? If yes, when did you first get to know?
- Do you know the type of your colourblindness?
- Have you experienced any problems with the colours? If yes, then with which colours?
- What problems do you encounter while working on a desktop computer/laptop?
- Are you aware of the presence of colour correction settings in a Windows computer/laptop? If yes, have you ever applied the colour correction settings?

4.4.2. *Interview Responses*

- 7 out of 22 respondents with colour vision deficiency had a basic idea of colour blindness. These were those people who had taken the colourblindness test before.
- 15 were unaware of their condition but had difficulty in perceiving certain colours correctly.
- No one among the respondents knew the type of their colourblindness.
- The Deuteranopes (Green colourblind) faced a problem distinguishing between shades of red and green, while Protanopes (Red colourblind) perceived the darker shade of red as black.
- When using a computer, they face multiple issues with colours while playing games, shopping online, watching a video, studying and working on data visualization infographics such as pie charts, graphs, maps and diagrams; working with slideshows, and so on.
- 3 out of 7 who knew about their condition were actually aware of accessibility settings being available. These 3 respondents had used the colour correction settings before but reverted to original colour settings because more than one person generally shared the device they used. So, it becomes a tedious task to toggle the colour settings back and forth.

4.5. Ethical Review

We ensured that the tests should be conducted ethically, and the data collected should be used solely for our research purpose. All the terms were shared with the participants prior to the test. The data collected was kept confidential, and the names of the participants diagnosed with colourblindness were not disclosed. While conducting an interview, permission for recording the interview and clicking pictures were sought. Incentives were arranged for all who took part in the interview for their time and effort.

5. Design Challenge

It is a process to identify and define a problem by analysing the research data as well as evaluating the existing interface and its trend for setting a scope for a design solution.

5.1. Data Analysis

Affinity mapping was the method used here for data analysis where the extracted interview data was categorized in clusters to identify the few most prevalent problems faced by colourblinds in GUI, and thematic correlation was used to put the recorded statements of the participants under relevant clusters.

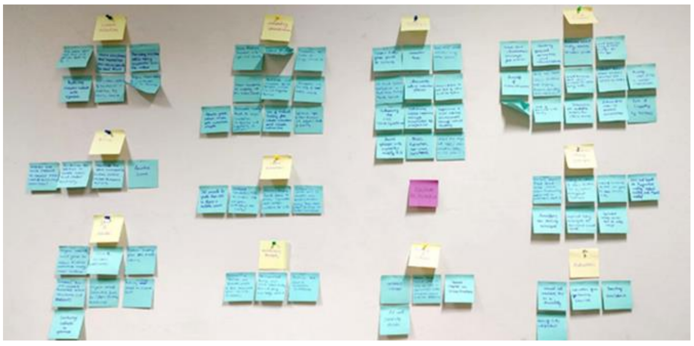

Figure 3. Affinity mapping of interview data

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5.2. Insights (Problem Identification)

The findings of the affinity diagram showed that most people with colourblindness are unaware of their condition. Also, it was disappointing to find that a negligible percentage of colourblind people use colour correction filters as they are unaware of the colour correction accessibility settings. Those aware of the provision of colour correction settings in a computer do not keep colour correction settings applied. This is because computers are also a part of sharable interfaces, which means multiple users can access each device at different time slots, making it more difficult for colourblind users to keep the colour correction settings applied. The fact that they have to change the settings every time after the alternate user turns off the setting discourages them from applying the settings next time. All participants were familiar with the Windows interface and had no major interaction with alternate operating systems.

5.3. Scope of Design

From the insights gathered, it was understood that colour correction accessibility does not provide a significant advantage to the colourblinds, as there are multiple issues that make the colour correction filters unusable. A universal design approach should be adapted to make the computer interface inclusive to colourblinds alongside the mainstream users without the requirement of accessibility customization.

5.4. Design Evaluation

To make the GUI visually ergonomic for colourblind users, several visual components were explored and studied to come up with a possible design solution. Icon sets used in GUI were found to be the most suitable visual component to enhance the users' experience. Therefore, iconography was chosen for design evaluation considering colourblind computer users as subjects. Microsoft Windows 10 OS was observed in this study as Microsoft Windows has much higher individual computer ownership than any other OS (Statscounter, 2021). A colourblindness simulation tool was used to simulate the colour vision of Deuteranopia (Green blindness), Protanopia (Red blindness), and Tritanopia (Blue blindness) to understand how the GUI appears to users with different types of colour vision deficiency.

5.4.1. Contemporary Design

The iconography manifested in Microsoft Windows 10 OS is comprised of several icon sets conforming to different visual design styles. The Desktop icons follow "fluent" design approach that uses an isometric, two-dimensional visual style (Warren, 2020).; The System Settings section uses pictorial icons, which are graphic symbols conveying meaning through their pictorial resemblance. These are simple outlines of the visual objects that are created using single-colour strokes. Whereas the Device icon set follows skeuomorphism, making the icons appear realistic and three-dimensional. The device icons are part of the icon set, first introduced with Windows Vista OS, and have not been updated yet. The same visual style is established in Windows Vista icon guidelines (Hickeys et al., 2021).

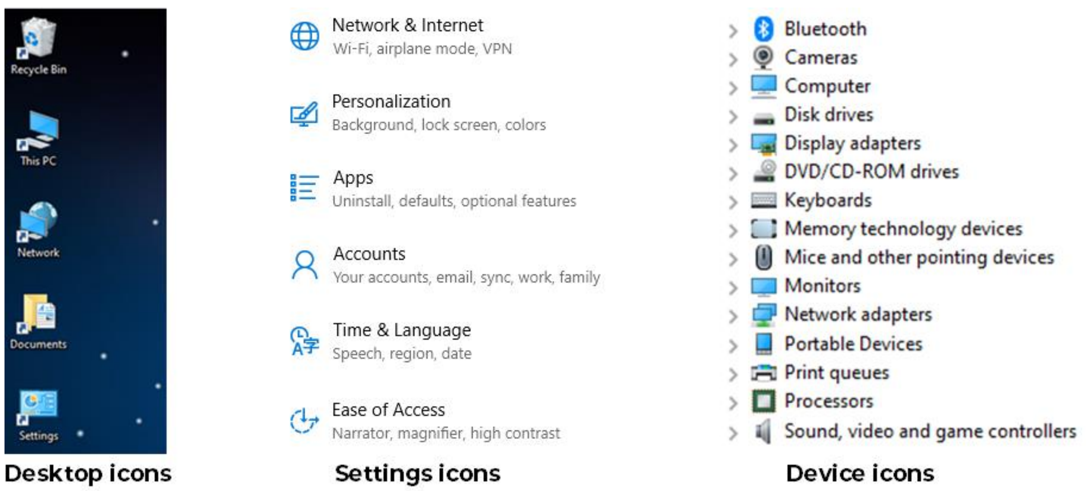

Figure 4. Different visual styles used for desktop, settings and device icons in windows 10

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5.4.2. *Trend Study*

It is essential to keep track of the current design trend so that the concept remains in line with the visual style and does not entirely mismatch while working on the design solution. The current trend in iconography was observed in this study, especially those followed by Microsoft in its various software. Microsoft has shifted to pictorial iconography, which could be observed in the user interface of the recent version of its word processing software - Microsoft Word, as shown in Figure 5. This visual style is prevalent throughout all Microsoft Office programs, including Microsoft PowerPoint and Microsoft Excel as well as other utility and communication software such as Microsoft Teams and Microsoft Azure. Icons used in these programs are symbolic icons created using a single colour.

Figure 5. Evolution of microsoft office word toolbar icons

Windows 10 already has an alternate application environment for configuring system functionality named 'Settings' present alongside 'Control Panel'. The Settings app uses pictorial visual style for its icons, as shown in Figure 6. Therefore, this is certain that Microsoft is putting efforts to make the Windows interface inclusive by revamping the visual environment with the assistance of icons.

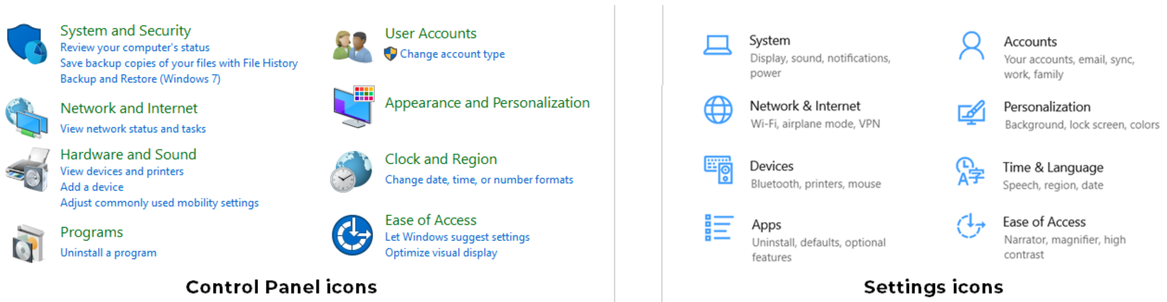

Figure 6. Comparison between control panel icons and settings icons in windows 10

5.4.3. *Review*

From the observation, it was found that Microsoft has started adopting pictorial style icons in most of its software platforms for all modern apps from Windows 10 onwards, e.g., Settings app. Despite this, Windows OS still uses fluent design visual styles for Desktop icons and skeuomorphism for Device icons. Windows OS has always suffered from a variety of different icon sets, and through Windows 10, Microsoft is putting on an effort to simplify the icons (Warren, 2020). The Presence of multiple icon sets in an OS creates visual inconsistency throughout the graphical user interface, which is bad for the efficiency of task performance. Furthermore, intricate details and contradicting colours in small visual components like icons make them unidentifiable for colourblind users.

Figure 7. Comparison of visual appearance of icons for users with different colour vision

Figure 7 shows the appearance of few selected icons from an icon set in normal colour vision and compares it with the appearance to users with deferred colour vision. A colourblindness simulation tool

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is used to show the colour vision of green and red colourblinds. Here we can see how it is actually confusing and difficult for a user with green blindness and red blindness to recognize icons such as default program, disk writing, defragmenter, etc. Figure 8 shows the appearance of the Windows Desktop icons and Device icons from the colour vision of a colourblind.

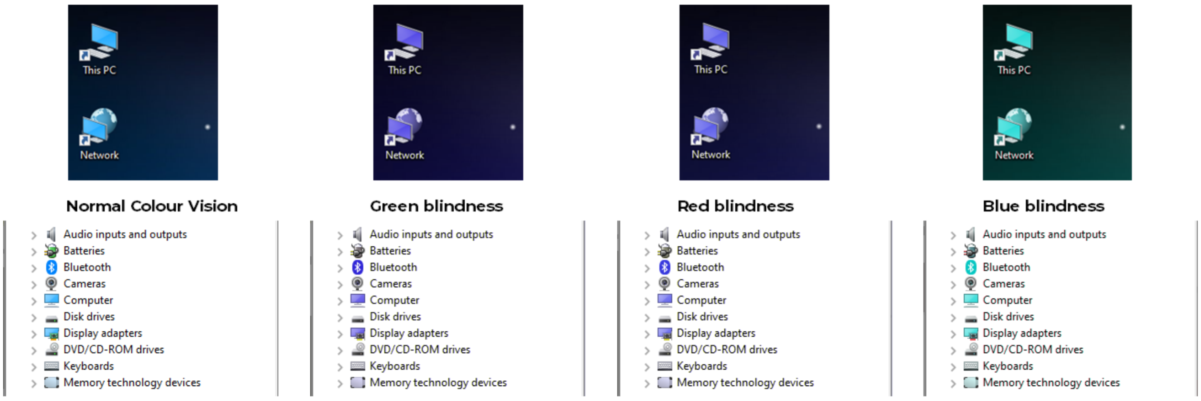

Figure 8. Visual appearance of desktop and device icons to users with different colour vision

While if we analyse the pictorial icons that have been used in the Settings app, they could be easily identified by colourblind users, be it any colour vision deficiency. Figure 9 shows how the Windows Settings icons would appear to users with different types of colour vision deficiency.

Figure 9. Visual appearance of settings icons to users with different colour vision

6. Concept Design

After thoroughly reviewing the existing design and current trend, a redesigned iconography design concept is proposed for Microsoft Windows OS so as to make the GUI inclusive to the colourblind users. Set of pictorial icons are designed to replace the multiple icon sets available in the Windows GUI while maintaining their aesthetic properties. Pictorial icons make use of symbols in graphical representation and they have long been used as a tool by video game manufacturers to make their interface friendly to their colourblind consumers. A unified icon scheme makes the icon design consistent throughout the interface, enhancing the task performance efficiency, as a single icon set would require less time and cognition to be recalled. Pictorial icons would make the visual appearance of Windows GUI more streamlined and provide visual affordance to colourblind users. Studies show that colour distinctiveness in icons does not affect task performance or learnability, but its shape does (Chajadi, 2020) and it is not colours but visual characteristics such as Closure, Continuity, Symmetry, Simplicity and Unity (Gestalt psychology) that makes a visual element appear beautiful (Easterby, 1970). As the pictorial icons consist of single solid colour, there is no possibility of a presence of another contradictory colour, thereby making the icons visually ergonomic to the colourblind users. Apart from providing visual ergonomics to the colourblind users, this will also enhance the visual experience of a user with normal colour vision, thereby making the GUI a universal design. Figure 10 displays the icons and their appearance when applied as Desktop icons and Device icons. Pictorial icons also have a high learnability index and are considered to be the easiest to learn among all other icon styles (Kunnath et al., 2007).

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Pictorial icon set | Desktop icons | Device icons

Figure 10. Pictorial icon set and its appearance as desktop icons and device icons

The icon set has a replacement icon for each of the icons present in the current icon sets and is therefore used as a default icon set (system icons). By default, the icon colour sets to the accent colour of the background image applied, as it presently happens with System icons. The accent colour is restricted so that the colour luminance is ≤ 100, and the RGB values of $R \leq 150$, $G \leq 150$, $B \leq 150$. This is done to maintain a good contrast between the icons and the background colour. The user also has an option to choose and customise the accent colour from the personalisation settings. If a user deliberately applies a same-coloured background and accent colour, the icons will still be recognisable, as shown in Figure 10, due to a white outline differentiating the icons from a similar coloured background. This is similar to the visual design of a mouse pointer, which makes it discoverable even against a similar colour background. To ensure that the icons are universally legible and could be used throughout the Windows GUI. The icons are designed in .ico format, conforming to the Microsoft Windows icons guidelines. These icons could be downscaled to as low as 16x16 pixels and upscaled to as high as 256x256 pixels.

7. Testing and Analysis

A high-fidelity prototype of the concept design was thoroughly tested with the 22 participants diagnosed positive with colourblindness and the resulting data was analysed to validate its effectiveness.

7.1. Usability Testing

To assess the performance of the design concept, two sets of a mock user interface of Windows Desktop and Device Manager was developed using a user interface prototyping tool. Each set of these mock interfaces had two prototypes, one with an existing icon set and the other with redesigned icon set, i.e.,

- a prototype of Desktop GUI with existing icons
- a prototype of Desktop GUI with redesigned icons
- a prototype of Device Manager GUI with existing icons
- a prototype of Device Manager GUI with redesigned icons

All the mock interfaces replicated the functionality of their original counterpart, but the icons' arrangement was disturbed, so the icons are no longer sorted according to their name or type.

The Desktop prototype consisted of 16 icons, whereas the Device Manager prototype consisted of 24 icons.

22 participants who were diagnosed with colourblindness participated in the experiment.

For the first part of the experiment, participants were asked to perform five tasks each on both types of Desktop prototype and for the second part, they were asked to perform five tasks each on both types of Device Manager prototype. Five random and non-repetitive tasks were assigned to the participants for both parts.

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Each task required exactly 3 clicks: Right-click the icon function, click on properties from the menu and click the 'OK' button. This experiment was conducted in controlled lighting conditions, and participants were allowed to interact with the user interface environment before each test to get familiar with it. Cumulative time (in seconds) was recorded after the completion of a set of 5 tasks. Table 1 shows the performance data of redesigned icons as compared to the existing icons.

Table 1. Performance comparison between existing icons and redesigned icons

Participant	Desktop GUI with existing icons (seconds)	Desktop GUI with redesiged icons (seconds)	Time difference (seconds)	%age incr-ease in efficie-ncy	Desvice manager GUI with existing icons (seconds)	Device manager GUI with redesiged icons (seconds)	Time difference (seconds)	%age incr-ease in efficie-ncy
1	30.01	28.12	1.89	6.29	28.24	24.24	4	14.16
2	60.39	59.54	0.85	1.40	38.15	32.78	5.37	14.07
3	29.83	29.34	0.49	1.64	24.67	21.85	2.82	11.43
4	34.35	33.93	0.42	1.22	35.28	30.01	5.27	14.93
5	28.75	28.63	0.12	0.41	26.82	24.04	2.78	10.36
6	48.97	47.84	1.13	2.30	33.75	30.52	3.23	9.57
7	31.22	31.78	-0.56	-1.79	23.16	21.17	1.99	8.59
8	35.19	33.98	1.21	3.43	28.92	25.37	3.55	12.27
9	30.57	30.28	0.29	0.94	26.7	22.19	4.51	16.89
10	29.62	29.04	0.58	1.95	35.51	31.29	4.22	11.88
11	40.96	40.74	0.22	0.53	25.93	22.25	3.68	14.19
12	42.21	37.87	4.34	10.28	32.44	27.21	5.23	16.12
13	37.45	37.02	0.43	1.14	27.89	22.69	5.2	18.64
14	36.16	36.08	0.08	0.22	29.88	23.74	6.14	20.54
15	36.35	35.59	0.76	2.09	23.56	22.03	1.53	6.49
16	37.52	39.07	-1.55	-4.13	27.2	27.9	-0.7	-2.57
17	45.45	44.82	0.63	1.38	37.59	31.56	6.03	16.04
18	52.21	51.76	0.45	0.86	28.21	25.97	2.24	7.94
19	29	28.42	0.58	2	25.43	20.89	4.54	17.85
20	47.08	48.26	-1.18	-2.50	36.23	32.09	4.14	11.42
21	32.68	32.1	0.58	1.77	29.78	26.08	3.7	12.42
22	38.23	37.65	0.58	1.51	31.45	25.37	6.08	19.33
Total	834.2	821.86	12.34	33.02	656.79	571.24	85.55	282.63
Avg.	37.91	37.35	0.56	1.50	29.85	25.96	3.88	12.84

7.2. Data Analysis

As it could be observed from the table that there is a significant performance boost while accomplishing a set of tasks in both desktop as well as device manager environment as the time taken to finish a task is decreased by an average of 0.56 seconds in case of desktop icons and an average of 3.88 seconds in case of device manager icons. The graph in Figure 11 shows increased efficiency when the participants performed the Desktop user interface tasks with redesigned icons. The efficiency further increases while performing Device Manager tasks with the redesigned icons. The performance comparison chart in Table 1 shows that there is a 1.5% performance increase of colourblind users when using pictorial icons against the fluent icon scheme on the Desktop environment, whereas there is a massive 12.84% performance boost for the colourblind users when using pictorial icons on Device Manager user interface against that of the existing icon set. This explains that the smaller icons with detailed graphics are much harder to perceive by the colourblind users.

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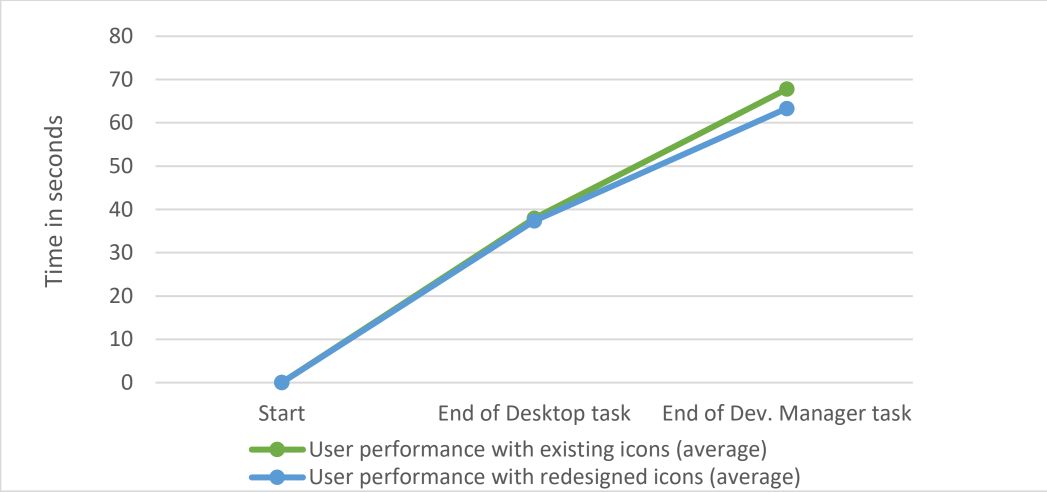

Figure 11. Performance comparison graph

7.3. Discussions

As analysed from the data, the pictorial icons do significantly increase the efficiency of the task performance. This increase in efficiency empowers colour deficient users by increasing their productivity. It is debatable that computer users seldom access device manager, so a redesign of device icons barely makes a difference, even if the user is colourblind and whether the efficiency is increased. However, considering an emergency situation where the device icons must be accessed, the enhanced visual ergonomics will help the same user to deal with the situation quickly and confidently. It is still difficult to comment on whether the familiarity with the windows interface influences the results obtained since all the participants invited were familiar with Windows OS with very little to no exposure to other operating systems. It would be interesting to conduct research based on the familiarity of the GUI.

7.4. Limitations

Universal design principles are applied in any product or interface to make it equally accessible to user categories that have different requirement from it. This may include users such as computer semi-literate or compute illiterate users, older adults, differently-abled users, etc. This research is restricted to cater to the requirements of colourblind computer users only. Another limitation is that the experiment conducted in this research only compares the performance of pictorial icons versus the skeuomorphic and the fluent icons when accessed by a colourblind user, and there is no direct user to user performance comparison between a colourblind user and a user with normal colour vision when accessing these icons. Furthermore, there was a limitation to experiment and task design as there is no possibility of tasks other than the one performed in this research since device manager is the only program that is currently making use of skeuomorphic icons while the fluent icons that are used outside the desktop environment maintain a good contrast with the background.

8. Conclusion and Future Scopes

A colourblind user faces many accessibility issues in their daily life while using the existing graphical user interface. The lack of awareness about their condition and the lack of knowledge about colour accessibility settings provided in the computer interface forces the colourblind users to use their computers with decreased efficiency. From all the tests and experiments conducted in the research project, it is clear that Pictorial icons can greatly help enhance the performance of users with colour vision deficiency. It provides an equal opportunity to colourblind users to achieve higher efficiency of task performance without customizing the interface while maintaining the aesthetics of the current interface design.

Extending this project to other operating systems such as macOS and Linux should be the prime scope from here onwards. Since the icon design guidelines change from system to system, it would be interesting to study and design an accessible iconography by introspecting the icon design guidelines of the other operating systems and the design trend their manufacturer is adopting. Consecutively, another

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research could be conducted to study the role the familiarity with the operating system plays in task performance efficiency by comparing the performance data of multiple operating systems with each other. The pictorial icon can be used in computer interfaces and more digital platforms as much as possible to make the system inclusive to colourblind users and provide equal accessibility to all. A follow-up study needs to be conducted which compares the task performance efficiency of colourblind users against that of users with normal colour vision using the same set of tasks as used in this research. It would also be interesting to conduct further studies to understand the requirements of other extreme user categories such as computer semi-literate and compute illiterate users, older adults, differently-abled users and so on to make the computer interface even more inclusive.

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