Early Detection of Colour Blindness Using Video Games

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Abstract: This paper presents research into the detection of colour blindness in children and young adults through the use of modified video games. Existing gamification in this area has primarily considered very young children (under 7) and so more advanced games are necessary for the attention of older children and young adults. Initial testing with 50 participants shows significant potential for the detection of colour blindness using adapted retro games.

1 INTRODUCTION

Colour blindness affects around 4% of the population and can have a significant impact on learning. For example, in the UK "80% of pupils with a colour vision deficiency (CVD) arrive in" secondary school undiagnosed (Albany-Ward, 2015), despite or perhaps because "Routine screening for color blindness was quietly removed from the Healthy Child Screening Programme in 2009" (Difolco, 2024).

Given it's prevalence, there is a clear need for early diagnosis of colour blindness/deficiency. This research attempts to provide a simple mechanism to automatically identify colour blindness/deficiency by building tests into commonly played computer games. In this manner it should be possible to identify the condition much earlier.

2 BACKGROUND

The section provides an overview of Colour Blindness (often referred to as Colour Vision Deficiency), considers the most common current tests for Colour Blindness and finally presents some work on the use of video games as diagnostic tools .

2.1 Colour Blindness

Colour blindness affects approximately 1 in 12 males and 1 in 200 females (Difolco, 2024). Around 99% of colour blind people suffer from a type of "red-green" deficiency, although this is really a generic term for a deficiency in either their L cones (those sensitive to long wavelengths such as red light) or their M cones (those sensitive to medium wavelengths such as green light). There are four associated conditions:

1. **protanomaly** – Malfunctioning L cones.
2. **protanopia** – Missing L cones.
3. **deuteranomaly** – Malfunctioning M cones.
4. **deuteranopia** – Missing M cones.

There are also (relatively rare) occurrences of "blue-yellow" colour blindness, but these are actually deficiencies in the S cones (those sensitive to short wavelengths such as blue light). There are two associated conditions:

5. **tritanomaly** – Malfunctioning S cones.
6. **tritanopia** – Missing S cones.

Unfortunately the majority of colour blindness is not being diagnosed early enough and this late diagnosis "can lead to children becoming disillusioned with learning or feeling that they are stupid or less able than others" (Albany-Ward, 2015).

2.2 Current Tests for Colour Blindness

Several standardised tests have been developed to detect and classify colour blindness. These methods range from quick screening tools used in schools and clinical settings to highly specialised instruments and digital applications:

The **Ishihara Test** is a widely used screening method for identifying red–green colour vision deficiency, the test consists of a series of circular plates, each filled with a pattern of coloured dots.

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Within these dots, numbers or shapes are embedded using a colour that contrasts with the background for individuals with typical colour vision but becomes indistinguishable for those with specific colour vision deficiencies.

The **Farnsworth D-15 test** is a diagnostic tool designed to detect moderate to severe colour vision deficiencies and to distinguish between different types of colour blindness. It provides detailed insights into the nature of the deficiency, including whether it affects the red–green or blue–yellow spectrum. The test consists of 15 coloured caps (or tiles), each varying subtly in hue. The participant is asked to arrange these caps in a sequence that forms a smooth gradient starting from a fixed reference colour. Individuals with normal colour vision typically arrange the caps in the correct order. However, those with colour vision deficiency often make specific patterns of errors, known as "confusion lines," that reveal the type and axis of their colour discrimination problem.

The **Farnsworth-Munsell 100 Hue Test** is a highly detailed diagnostic tool used to evaluate an individual's ability to perceive subtle differences in colour hues (which makes it useful for both clinical assessment and occupational screening). The test comprises four separate trays, each containing a sequence of coloured caps with subtle gradations in hue. Each tray has two fixed endpoint caps, and the participant is asked to arrange the remaining caps in a continuous hue progression between those endpoints. The more accurately the colours are arranged, the better the person's colour discrimination.

The **Lantern Test** is a colour vision screening method traditionally used to assess whether individuals meet the colour perception requirements for certain occupations, particularly in fields such as aviation, maritime navigation, railways, and the military. It is designed to simulate real-world conditions in which quick and accurate colour recognition is critical for safety.

The **anomaloscope** is a highly specialised instrument used to diagnose and quantify red–green colour vision deficiencies with precision. It is considered the gold standard for distinguishing between protan and deutan anomalies and for determining the severity of the deficiency.

The **Cambridge Colour Test** is a computer-based diagnostic tool designed to assess colour discrimination thresholds with a high degree of precision. It is widely used in both clinical and research contexts to evaluate congenital and acquired colour vision deficiencies. The test is based on a modified version of the Ishihara principle, presenting the subject with a series of pseudoisochromatic plates composed of small dots that form numerals. Unlike the traditional Ishihara test, however, the CCT dynamically adjusts the chromaticity of the stimuli and background using the CIE colour space.

Recent advances in technology have led to the development of digital platforms and mobile applications that can screen for colour vision deficiency. These tools replicate traditional tests like Ishihara plates or D-15 arrangements and often include interactive elements. Examples include EnChroma's online test, EyeQue's VisionCheck, and various mobile apps such as Color Blind Pal (https://colorblindpal.com) and Color Vision Test (https://www.eyeque.com/products/visioncheck/). While these tools increase accessibility and can raise awareness among undiagnosed individuals, their accuracy can vary depending on the display device, lighting conditions, and calibration. Therefore, they are best viewed as preliminary tools that may prompt further clinical testing.

(Arnold, 2021) presented dynamic colour test games for the Nintendo 3DS, although these appear more like colour tests than actual games.

2.3 Video Games as Diagnostic Tools

Video games have been used in medical diagnostics in a number of areas. For example (Tunçgenç, 2021) presented a one-minute video game to diagnose autism called Computerized Assessment of Motor Imitation (CAMI). Using Kinect the system asks children to mimic the movements of a character on a screen, with a reported eighty per cent success rate from the study involving 180 children between seven and thirteen.

In colour blindness diagnosis, (Nguyen, 2014) presented a game called "DoDo's Catching Adventure" in which players have to do simple tasks like matching a coloured butterfly to one of several shown on the screen. This allowed the system to identify 14 Red-Green deficient children out of 28 children tested.

(Tang, 2021) presented a system called ColourSpot where the children (aged 4-7) had to click on coloured targets revealing an animation. By changing the colours of the targets it was possible to distinguish protan, deutan and tritan colour blindness limitations in the children. In testing (on quite a large cohort of children) it was found to be potentially more successful that the Ishiharda Unlettered standard.

3 GAME DESIGN

The aim of this research was to create an interactive and engaging web-based application that utilises gamification as a novel method for screening for colour blindness in young people ranging in age from 8 to 23. Built using React Native with the Expo framework, the application features three retro-style arcade games—Pong, Space Invaders, and Tetris—designed to evaluate user visual performance under dynamically changing colour conditions. By utilising gamification during testing, it is intended to eliminate the feeling of being tested for the user to relieve any stress or tension that can arise from various current screening methods to give the most accurate results as possible.

3.1 Dynamic Colour Shading

A key feature of the application is the integration of dynamically cycling colour palettes, each carefully chosen to simulate colour pairings known to be difficult to distinguish for individuals with various types of colour blindness, namely protan, deutan, and tritan. These palettes were informed by medically accepted guidelines and visual confusion data obtained from the Colour Blind Awareness website (https://www.colourblindawareness.org/). See Figure 1.

Figure 1: Tetris with a colour combination designed to detect deutan anomalies (left) and a filtered version of the same screen showing how it would be perceived by someone with deuteranopia.

As users interact with the games, the application unobtrusively alters the colour scheme according to a predetermined sequence. By tracking performance metrics such as reaction time, score, and accuracy across different colour modes, the system seeks to infer whether the user may exhibit difficulty distinguishing specific colour combinations, thereby offering potential insights into their type of colour vision deficiency.

3.2 Eye Tracking

WebGazer.js (an open-source JavaScript library that enables real-time gaze estimation using standard webcams) was integrated into to system to allow it to measure how precise the user's focus is in relation to certain game entities (e.g. Pong ball, Space Invader aliens) on the screen during gameplay as the colours change.

The percentage of time that the target (ball, bat, etc.) and the eye tracking were well aligned was found to be a reliable measurement, and bonus point were awarded within the game as a measure of this alignment. See Table 1.

Table 1: Potential for eye tracking alignment with game entities to identify users with colour blindness.

Users	% Bonus Points
with no Colour Blindness	96% +/- 4%
with Deutan	61% +/- 1%
with Deutan and Protan	30% +/- 1%

3.3 Game Play

Each game starts in greyscale. As gameplay progresses, the colours of each game entity (such as paddles and the ball), as well as the game background, are cycled through the predefined palettes corresponding to each type of colour blindness. This transition occurs gradually (using interpolation) and without user notification to avoid influencing behaviour or drawing attention to the visual alteration. By avoiding abrupt colour changes, user immersion is maintained. The transitions are subtle enough to prevent user distraction, while still allowing the system to log reactions, performance, or gaze data under different colour conditions. This allows developers to gather evidence of potential colour vision deficiencies without the user being explicitly aware of the test. See Figures 2 and 3.

Each colour palettes is used for only around 3 second, and the full cycle through all colour palettes takes around 3 minutes.

During each game session, the application logs performance data, including score, bonus points, object interactions, timing data, and the colour mode active at the time. These metrics are exported for later analysis. A sustained decline in performance during a particular colour mode may suggest a correlation

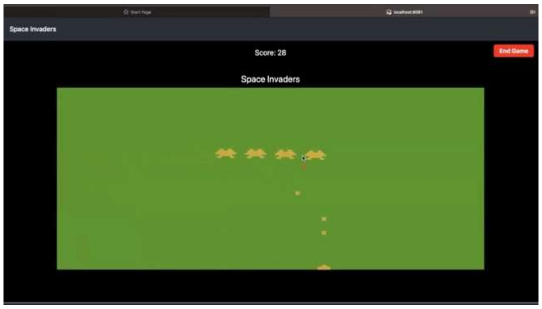

Figure 2: Space invaders shown with a colour combination designed to detect protan anomalies.

Figure 3: Pong screen shown with a colour combination designed to detect deutan anomalies (top) and one designed to detect tritan anomalies (bottom).

between the user's visual perception and a specific type of colour blindness.

This system offers a novel, engaging and non-intrusive method of screening users for potential colour vision issues while maintaining the integrity of gameplay and user experience.

4 EVALUATION

50 adult participants (mainly university students), 10 of whom had previously been diagnosed with deuteranopita, played all three games and were diagnosed (by the system) as having no colour blindness, or having protan, deutan and/or tritan anomalies. See Table 2.

From Table 2 we can see that in all cases the system diagnosis corresponded with the previous diagnosis. The only slight anomaly was that 2 of the participants who previously had been diagnosed as having protanopia, were also found to exhibit protan anomalies.

Table 2: Previous diagnosis of 50 participants in on the vertical axis and the diagnosis from this study is shown on the horizontal. These test results were identical for all three games (Space Invaders, Pong and Tetris). *Two of the participants are recorded twice as they were determined to have both protan and deutan colour blindness (CB).

	No CB	Protan	Deutan	Tritan
No CB	40			
Protan				
Deutan		2*	10	
Tritan				

4.1 Verbal Feedback from Participants

Verbal feedback was also collated and non colour blind participants commented on the ease of play of the games, saying they were very enjoyable and easy to pick up. They were impressed by the logic behind subtly changing game colours to identify colour blindness types. Some of these participants did suggest making some colour transitions less sharp on the eyes for brighter shades like yellow, but overall they were pleased with the presentation of the games.

One common comment from colour blindness participants was their surprise regarding the accuracy of the results given the simplicity of the games. Many of them were shocked when they were unable to identify game entities on screen as they know the retro games used in their standard format and would have no issues playing them beforehand. They enjoyed playing the games and never stated that they felt they were being tested. Due to the smooth and quick transition of the games through the colour shading cycles, none of the participants were left too long unable to effectively play the game, as each shade pair only lasted three seconds. The majority of colour blindness participants were unaware how quickly the screening had occurred.

5 CONCLUSIONS

This paper has presented a proof of concept of the colour blindness testing embedded into well known computer games (Pong, Space Invaders and Tetris).

This will allow the diagnosis of different forms of colour blindness, providing a stress free mechanism to test older children and young adults.

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