Exploring the Impact of Colour-Blindness on Computer Game Performance

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Abstract
We assess the effects of colour-blindness on casual computer gaming performance and experience. Participants played an online puzzle game in both an unmodified environment and in a colour-blind simulation. Some of our results suggest that the colour-blind filter did not negatively impact player performance. However, users perceived the game as more difficult and their performance as limited. These contradicting results highlight the importance of further assessing the impact of colour vision deficiency on performance, and the accessibility principles used in game design when colour coding operable cues.

Author Keywords
Accessibility; colour blind; online games; performance

ACM Classification Keywords
H.5.m [Information interfaces and presentation]: Accessibility design and evaluation methods

Introduction
Colour can capture game players' attention and guide decision-making. Research suggests that some colours can alter an audience's emotions and bodily reactions. These colours may not have the same degree of effectiveness on colour-blind individuals. In this study, ten participants played six levels of a casual, online puzzle game in its original state

and then in a colour-blind simulation. Key aspects of their performance, including mouse clicks and level duration, were not significantly different between conditions. Yet, participants perceived the colour-blind simulation as more challenging, and their performance as limited, due to a lack of easily differentiable operable cues. The results of this research can support the advancement of accessible interface design guidelines, including the W3C WCAG 2.0.

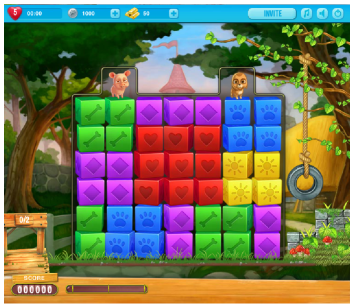

Figure 1: The unmodified interface players used in Phase 1 of the user study.

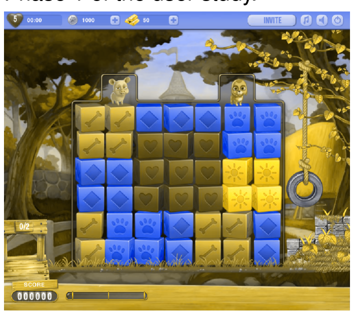

Figure 2: Phase 2 game interface with red/green colour-blindness, Deuteranopia, filter applied.

Background

Colour plays an important role in interface design. Wolfson and Case [11] suggest that players' brains are more alert and their performance is more successful when red dominate the screen [11]. Bonnardel's [1] users not only preferred blue and navigated blue websites faster than ones with green or grey colour schemes [1]. Plass et al.'s study [9] revealed that developers can elicit positive emotions and increase comprehension by incorporating preferred colours – blue and orange – in design [9]. Yet, all this research assumes average colour perception. Do colour-blind individuals have similar experiences?

Recent colour vision deficiency (CVD) literature aims to adapt computer outputs to remedy or correct the impairment (e.g., [4, 3, 6]) rather than evaluate the usability implications of colour-blindness [7]. In 2016, Reinecke et al. [10] began to consider how other external factors such as operating environment, available light, monitor brightness, and age can impact usability. They found that 88% of their study's participants, some with typical vision abilities, were unable to distinguish colour-cues included on popular websites.

Recent studies do not explore how colour-blindness affects information processing abilities and overall user experience. Our study explores the differences between CVD and non-CVD performances and user experiences through simulation methods. Empirical evidence describing colour-blind performance can help identify requirements for design accommodation for this user group.

Methodology

Hypotheses: We compare performance in an unmodified environment and in a simulated colour-blind environment. We hypothesize that: **(H1)** User performance will worsen within the colour-blind state. Poor performance will be measurable through lower scores, more overall clicks, and longer decision-making durations, and **(H2)** Users will perceive their performance as slower, and the game as more difficult, when playing in the colour-blind state.

Setup: Participants used a desktop Windows PC, standard computer mouse, and Google Chrome in a controlled lab setting. The space was lit with two standard sized panels of fluorescent lighting. The display monitor was not calibrated, 22 inches wide, and had a resolution of 1080ppi.

Computer Game: The participants played an in-browser version of "Pet Rescue Saga." The player must click on groups of matching blocks to destroy them, freeing the pets to "rescue" them. In its intended state, each blocks are categorized by five colours and corresponding over-lay patterns (Figure 1).

Simulating CVD: Due to the limited access to CVD individuals, few participants were expected to be colour-blind. Instead, participants played within a colour-blind simulation through the Spectrum Chrome plugin [5] to mimic a state of colour-blindness. We simulated a type of red-green CVD called Deuteranopia [8]. This filter reduced the range of visible colours to shades of blue and yellow. As a result, the block patterns became less stark, but were still visible (Figure 2).

Participants: We recruited 12 participants (9 female, and 3 male) and nine were between 21 to 39 years old. Eleven participants said they played video games less than five hours per week; the remaining participant played up to 10 hours. None had ever played Pet Rescue, but four had played games with similar rules and interfaces.

Procedure: Our study was cleared by the university's REB. Sessions lasted approximately 1 hour, including two 20-minute phases of gameplay and time for questionnaires.

Before gameplay, we measured each participant's ability to see colour with an online version of the Farnsworth-Munsell (1986) colour arrangement test [2]. Eleven participants were identified with average colour vision abilities. Only one participant, P12, was identified with "slight Deuteranomaly."

During each session, participants first played six levels of Pet Rescue in sequential order, then repeated the six levels with the Deuteranopia filter engaged, and finally completed post-test questionnaires about the game, their performance, and explaining how they used colour and other cues to make decisions.

Data Collection: We used screen-recording software to capture the game sessions and manually extracted the 1) player score as awarded by the game, 2) number of clicks (highlighted on the video by the screen-recording software), and 3) level duration. We excluded clicks that navigated between levels or closed dialogue boxes. We categorized each in-game click as follows: a "successful" click broke a block to help rescue a pet, and an "unsuccessful" click failed to destroy blocks, suggesting the player did not click on a group of matching blocks. Level duration was calculated as the difference between the first and last click within a level. We included any time (typically milliseconds) spent reading dialogue boxes as we considered this variance reflective of their individual abilities to process information within the unmodified and colour-blind conditions.

After reviewing the data, we omitted P4's results because they did not play all six levels in sequential order and P12 was diagnosed with mild CVD and therefore perceived the game differently than other participants. The data of the remaining 10 participants was analyzed.

Results

The study's conditions were not significantly correlated with changes in player scores, mouse clicks, and decision-durations. At times, participants performed better with the colour-blind filter than in the unmodified state. These findings challenge our original hypotheses as they suggest that players were not significantly impacted by the visual changes.

Conversely, the participants' feedback suggests that user perceptions of their own performance were better aligned with our original hypotheses. Post-test feedback suggests that the colour-blind filter forced players to change their gameplay strategies. Participants often associated this forced change with a decline in their performance. This dichotomy suggests further research should be made to reassess the effects of colour-blindness on player performance.

Player Scores: Average player scores were fitted to the trend lines illustrated in Figure 3; this graph suggests average player scores decreased per level over the course of the game. This may be due to an increase in difficulty as the game progressed. Between conditions, players scored lower when playing with the colour-blind filter ($M = 22565, SD = 5677$) than in the unmodified state ($M = 23259, SD = 5404$). A Pearson's product-moment correlation was run to assess the relationship between

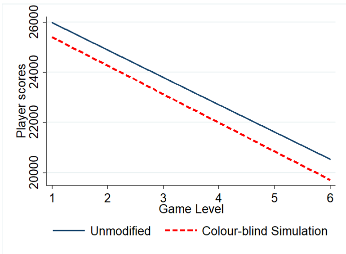

Figure 3: Average player scores.

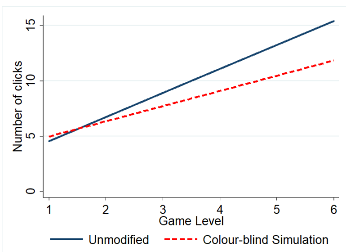

Figure 4: Average number of mouse clicks.

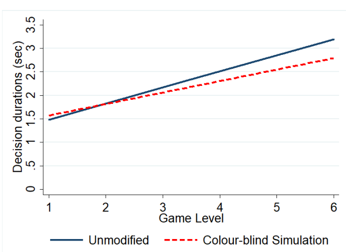

Figure 5: Average decision-making durations.

conditions and player scores, there was no significant correlation ($r(8) = -0.2, p = 0.5$).

Number of Clicks: As shown in Figure 4, the average number of mouse clicks per level increased as the game progressed. This graph also shows players clicked more in the unmodified state ($M = 9.9, SD = 7.8$) than when playing with colour-blind filter ($M = 8.4, SD = 5.2$).

A Pearson correlation test suggested a small negative correlation between conditions and mouse clicks ($r(8) = -0.1, p = 0.2$). This small negative correlation suggests users required less clicks to complete a level, and denotes slight player performance improvement in the CVD filter. However, this may not accurately reflect the effects of the filter because participants could have became acclimated with the game before the colour-blind simulation stage, and their performance may have naturally improved due to learning effects. This could be a limitation of choosing not to counterbalance conditions between participants, and will be discussed later.

Decision-making Durations: To measure decision-making durations, we divided the level durations by the total number of clicks (i.e., decisions) within the level to estimate how long it took players to scan the screen, strategize, and choose a block during gameplay. As reflected in Figure 5, average decision-making durations increased with game levels. Decisions also took longer with the unmodified interface ($M = 2.3s, SD = 1.4s$) than with the colour-blind filter ($M = 2.2s, SD = 1.2s$).

These results suggest that player performance decreased as the game became more difficult, but improved when given the opportunity to repeat the same level (i.e., playing the game a second time in the colour-blind condition). A Pearson correlation test suggests that the study's conditions had a negative, albeit insignificant, correlation with player decision-making durations ($r(8) = -0.1, p = 0.5$). As previously discussed, participant's improved performance may be due to acclimation for the game.

Perceived Performance: The results of the post-test questionnaires suggest that participants' perceived performance was consistent with our original hypotheses. It is important to understand any negative perceptions of game difficulty and performance as they may reveal aspects of poor user experience or usability.

After playing the game in an unmodified state, participants rated the game closer to "very easy" ($M = 3.6, SD = 0.5$) and their performance as "fast" ($M = 3.0, SD = 1.0$). In the short-answer sections, most players noted that the variety of colours allowed them to match related blocks easily, and execute their next moves quickly. After playing Pet Rescue within the colour-blind simulation, participants rated the game as "difficult" ($M = 3.0, SD = 0.5$) and their performance as "slow" ($M = 2.0, SD = 0.3$).

Several participants felt they made more errors within the colour-blind simulation than in the unmodified state. Most noted increased reliance on the blocks' overlay patterns, rather than obvious colour changes. Two participants noted that they focused on slight changes in colour shades rather than hues to group matching blocks. Often, participants associated any changes in their techniques with the changes in their ratings of game difficulty and personal performance.

The Colour-Blind Participant's Performance: P12 reported that she played games, such as Backgammon and memory training puzzles, for fewer than 5 hours a week on average. She was the only participant identified as having slight deuteranomaly.

When discussing the effects of the simulation, P12 noticed changes in the interface's saturation and contrast – "Everything looks less bright and greyer" – with the filter engaged. According to the post-test questionnaires, P12 focused on grouping blocks according to symbols rather than colours in both conditions. Also, there was no change in her rating of the game's difficulty (very easy), nor the perceived speed of performance (fast).

Unlike the other participants, P12's average score increased in the color-blind condition where she made fewer clicks and spent less time making decisions. This positive trend suggests that the colour-blind simulation did not impede her ability to learn the game, and decipher operable cues.

Discussion

The performance results contradicted our H1 hypothesis, by showing that performance did not degrade in the colour-blind condition. However, H2 was supported; participants thought that the colour-blind condition was more difficult and believed that their performance was worse as a result.

The Advantages of W3C's WCAG 2.0: Our results provide some insight on current accessible design principles. The Success Criterion 1.4.1 section in WCAG 2.0 addresses many ways to incorporate colour in accessible interface design. According to these guidelines, information that is conveyed through colour must be paired with different signifiers,including patterns, text, and selection tools to ensure clarity for any type of perception ability.

Pet Rescue Saga's interface is consistent with these suggested techniques; it uses colours, symbols, and a selection border to help visually organize the blocks. The performance results of this study allude to the effectiveness these colour-blind accommodations. The participants also used these design cues to cope with the CVD filter. As P6 described: *"In [the colour blind] version, I relied mostly on the symbols. I think I may have checked the colours, but as a secondary thing. I'm not even sure now whether the colours were unique for each symbol. I think decisions were slow at the beginning, till [sic] I got used to relying on the symbols rather than the colours..."*

Furthermore, colour-blind user P12's techniques disregarded colours entirely. Her ability to improve her performance over the course of the study suggests that the game's secondary cues were enough to ensure success. Further research exploring the techniques of colour-blind users could confirm the value of these secondary cues, and their effectiveness when playing casual puzzle games.

However, our results also showed that users *perceived* their performance to be worse in the colour-blind condition. Generally, users who are unsatisfied with an interface are less likely to use it, suggesting that additional attention to this aspect of the usability of colour-blind cues would be beneficial.

Limitations and Future Work: We intended to gather a fair baseline measure of performance by first introducing the game to participants in its unmodified state. However, we may have introduced ordering effects and indirectly advantaged performance within the colour-blind simulation. A between-participants design or counter-balancing should be considered in future studies.

Authentic behaviours and thought-processes are unique to individuals who have colour-vision deficiencies. The results of an induced colour-blind study may be argued as ecologically flawed. Yet, recruiting colour-blind individuals is difficult due to the relatively small population. Inducing colour-blindness through Spectrum did not seem to negatively impede on the colour-blind participant's performance but future studies should formally evaluate these tools' ability to mimic the colour-blind experience.

The effects of colour-blindness on gamer performance should be further assessed with other games. We also suggest comparing the effectiveness of specific secondary cues (such as overlay patterns) proposed in accessibility design literature.

Conclusion

Our analysis of the quantitative performance indicators does not suggest that colour-blindness has a significant impact on players' scores, successful decisions, nor decision-making times. However, we do not assume these results prove a null hypothesis. Our analysis also showed that perceived performance by users was significantly worse in the colour-blind condition. This disconnect between the objective and subjective measures suggest that further work is necessary to improve the usability of colour-blind cues.

Acknowledgements

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