Using Digital Game as Clinical Screening Test to Detect Color Deficiency in Young Children

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ABSTRACT
Digital games as education tools for children have been studied in the past. However, the use of digital games in clinical environments such as for children’s healthcare is still rare in the research community. This paper reports on the development of a digital tablet game called “Dodo’s catching adventure” which examines the use of games in visual color-deficiency screening for young children. A user study was conducted at a National Eye Centre. Results of the study show that the digital game demonstrates sensitivity and specificity on Red-Green color deficiency detection, and is comparable to the two gold standards in color deficiency tests, namely the Ishihara and Farnsworth D15. Furthermore, children found the game to be more enjoyable than the Ishihara test. This provides evidence for the feasibility of using such games as diagnosis tools for early childhood health conditions.

Author Keywords
Digital game, color deficiency test, children game

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H.5.2 User Interfaces, K.8.0 Games

General Terms
Colorblind, children game

INTRODUCTION
Computer and videogames can be very engaging for children [10]. Such games play a significant role in children’s development. A recent study showed that 82% of American children are avid gamers players, and by the age of two, a child has already has the capability to play many computer games [22]. Children appreciate computer games for their novelty, similar to other forms of entertainment such as comic books and cartoons, as such activities provide extreme experiences [10]. With their ability to engage young children, it seems that computer games have the potential to be used for situations for children in the healthcare settings, such as in eye health screening.

However, it is interesting to note that (to the best of our knowledge), none of the validated color vision tests for children are in the form of a digital game. The conduct of color screening tests for young children have traditionally been wrought with difficulty since it often requires advanced verbal or cognitive skills [9]. Such tests may also reinforce the social stigma regarding such color deficiencies, since children may become discouraged if they compare their performance with their normal vision peers. By using digital game technology via a screen-based activity, our game (“Dodo's catching adventure,” or Dodo game for short) is designed to detect color vision defects effectively in children from two and a half to six years of age, through a fun and relaxed manner.

THE NEED OF COLOR VISION DEFICIENCY TESTS FOR YOUNG CHILDREN AND ITS CURRENT LIMITATIONS
Congenital Dyschromatopsia affects 8% to 10% of males and 0.4% to 0.5% of females [5,7,17,18]. In Red-Green color deficiency (Deuteranopia or Protanopia) are relatively common, while Blue-Yellow color blindness (Tritanopia), are extremely rare [5,17].

Ishihara plates, arrangement tests, anomaloscopes, and lantern tests are commonly used in clinical practice today [2,20]. The Ishihara test and the Farnsworth D15 test are currently the most widely used screening tests. Ishihara is used to detect Red-Green color deficiency and total color deficiency. The test contains plates with circular dots of different colors forming a number character that would be invisible to a person with color deficiency but visible to a normal vision person, or vice versa. The D15 test is used...
worldwide to select applicants for employment in occupations that require good color vision. In the test, participants are asked to arrange sixteen color caps in a logical rainbow order [4, 11].

Color vision tests for young children are important [1,8,20]. However, approximately 40% of color vision deficient people are unaware of their condition [8]. Color vision testing for young children remains a challenge for clinicians because many screening tests require a relatively high cognitive demand on children, especially on those younger than 5 years old [6,9,19]. In fact, both the Ishihara and D15 tests are not suitable for children under the age of 5 [6,20]. Computer-based tests do not solve this cognitive limitation [1,17,23]. While there exist screening tests specially designed for young children, they are not as effective as Ishihara and D15, and they require special communication from the examiner, therefore the result may not be objective [9,15,17,18,21].

**DODO GAME DESIGN**

Dodo game’s main target users are young children. Hence, the game adopts a color matching game type with audio support, which is suitable for young children. The game is designed with bright color tones against a white background to ensure minimal interference with game object. It contains colorful graphics and interesting characters in order to engage young children. Dodo game is currently available on iPads and PC platforms (Figure 1).

In this game, players are asked to tap the screen to pick an object with similar color profiles. The Dodo game includes 4 sub-games: Sub-game 1 (Ladybug game) is designed to test total color deficiency. However, both Red-Green and Blue- Yellow color deficiency sufferers can also fail this game; Sub-game 2 (Fish game) is used for testing Blue- Yellow color deficiency, Sub-game 3 (Butterfly game) is used for testing Red- Green color deficiency and the Sub-game 4 (Owl game) is a classification test for two types of Red-Green color deficiency: deuteranopia and protanopia. Each sub-game consists of six quick stages where each player is asked to pick one object out of four objects that looks the most similar in color to the a sample object. Objects in each game can be grouped into four groups: a sample object, normal vision objects, color-blind objects and neutral objects. At the start of each sub-game, the blinking sample object (e.g., a butterfly) appears in a speech bubble next to the Dodo character with the “Pick This” text and audio. Then, four groups of objects appear on the screen for the player to pick the most similar one. The player will pick either normal vision selectable objects or color-blind selectable objects or neutral objects, depending on his/her color vision.

The game’s win-lose condition is independent on whether the players have color deficiencies. The player would be prompted to play the game again if his/her choices were the neutral (control) objects indicating that the player does not fully understand the rules of the game, or that the player is being uncooperative. Otherwise, the player will always win the game. At the end of the game the screen always displays the message “You Win!” This is designed intentionally to not discourage color deficient children. The color deficiency test results can be accessed by clicking on the information icon located on the top right of the screen.

**Design method**

Based on Gestalt principles, such as the law of similarity in visual perception, humans naturally tend to group similar objects by shape, color, size or brightness together [25]. The design method of Dodo game is based on the assumption that differences in hue and saturation of objects would direct players with color deficiency to group objects differently than those with normal vision.

When a color deficient individual cannot distinguish the hue of objects (since they look alike), they can only notice the difference of object’s saturation and brightness (Figure 4). The key feature of the game design is to compensate for the low resolution in the recognition of hues, as colorblind individuals tend to be more sensitive to the differences in saturation [16]. An individual with normal vision can hardly notice the difference of saturation between the sample object and the normal vision object, and will naturally choose this object when he/she is asked to pick an object similar to the sample object. Figure 4 shows a color

![Figure 1: Dodo game’s starting screen on a tablet computer](image)

![Figure 2: Sub-game 3 layout](image)

![Figure 4: Dodo game design concept](image)
profile of the sample object (2), the color-blind selectable object (3) and the normal vision selectable object (1) in sub-game 3. When being asked to pick the object similar to a sample object (2), a Red-Green color deficient person sees the hues of all objects are nearly alike, hence they will choose (3) with similar saturation. A normal vision person will choose (1) with similar hue. All the sub-games are designed based on the same principle for different types of color deficiencies.

The color design was adopted from the Ishihara PC based version with isochromatic data for Red-Green color deficiency established by Lakowski [15,17]. Vischeck color deficiency vision simulation was used to simulate the color rendering of objects to color deficiency color vision for color-blind selectable objects [13]. Figure 5 shows how Sub-game 3 appears when viewed by a normal vision person and the Red-Green color deficient person respectively, using the Vischeck computer simulation.

![Figure 5: Sub-game 3 in normal vision (left) and in Red-Green color deficient vision simulated by Vischeck (right)](image)

**Dodo game’s criteria**

Both Ishihara and D15 do not provide a clear grading and give little indications of severity based on the number of mistakes. Therefore, Dodo game follows this grading convention. In terms of the number of errors that a player is allowed to make, the percentage to distinguish between mild and strong color deficiency is set to be more than 50%. Therefore in Red-Green color deficient detection, if the ratio is above 10/18 errors, the player will be a strong color deficient. Players that make between 4-9/18 errors would be classified as having slight/mild color deficiency. Players that make between 4-9/18 errors would be classified as having slight/mild color deficiency.

**Pre-test on adults to verify design method**

A pre-test was conducted on six male adults, including three Red-Green color deficient individuals, and three normal vision individuals, all tested using the Ishihara test. The reason for this pre-test, was that adult players could comprehend and communicate with researchers directly, thus preventing any confusion or negative results caused by a lack of understanding. A pre-test result would be useful to determine if our current prototype was functional, and the pre-test would help researchers fine-tune the different elements. The tests were conducted under good room lightening, and both eyes were tested simultaneously. A PC version of Dodo game on a 13 inch Macbook laptop was used in this pilot study. Color calibration was performed before each participant was asked to play the game. All the participants were able to play the game from the start of the test. Dodo game was successful in detecting color deficient subjects with no false positives.

**Observation of Dodo game’s usability on toddlers and pre-school children**

In the game development process, we asked a small group of young children to play Dodo game. They were all detected as having normal color vision as indicated by the Dodo game. All of the children were able to play and win the game easily in the first trial with minimal instruction. None of the children realized that the Dodo game was a screening test.

**USER STUDY**

An ideal color vision test should reliably detect, categorize and grade the severity of color vision deficiencies. Currently, the two gold standard tests, Ishihara and the D15, are the most used color vision test in optometry clinics [7,11]. Dodo game’s target users were children from two to six years old. However, such young color deficient subjects were not available for recruitment because the current clinical practice usually does not ask children at that age to do colorblind tests at hospitals. Thus, as the two gold standard tests are not recommended for children under six years old, there did not exist a ground-truth to evaluate the game’s reliability with the target group. Optometrists at Singapore National Eye Centre suggested using Ishihara test and the Farnsworth D15 test (D15) to compare Dodo game’s effectiveness on Red-Green color deficiency detection. During the six-month user study, we were not able to recruit Blue-Yellow (Tritanopia) color deficiency participants due to the rarity of such sufferers.

A within-subjects repeated measures user study was supervised by optometrists at the National Eye Centre. Thirty-two subjects (N=32, Mean Age = 11.42, 1 Female) were recruited. All the tests were conducted under good indoor lighting in a clinical environment with both eyes tested simultaneously. The iPad version of Dodo game was used in this study. The screen brightness was kept balanced at the default setting (auto brightness). Sixteen of subjects were Red-Green color deficient, as detected by Ishihara test. The control group consisted of sixteen normal color vision participants. The average playtime of Dodo game was 3.14 minutes to finish four sub-games.

**Sensitivity and specificity**

Using the Ishihara test results as reference (which detected all sixteen colorblind subjects), D15 mis-classified four subjects as normal (25%), while Dodo game mis-classified three subjects as normal (18%). All tests classified the normal subjects correctly.

**Comparing enjoyment level of Dodo game to the two gold standard tests**

For enjoyment measuring, we modified a related sub-scale of Intrinsic Motivation Inventory (IMI) with 7 questions, using a seven-point Likert scale [12]. Three tests were counterbalanced to avoid order effects, with the same questionnaires administered after participants completed.
Using repeated measures ANOVA, we analyzed the results. In terms of Enjoyment, the results showed a significant main effect ($F(2,62) = 4.01, p < .05$).

Using paired samples $t$-tests between Ishihara and D15 ($t(31) = -1.24, p = .23$), D15 and Dodo game ($t(31) = -1.55, p = .13$), Ishihara and Dodo game ($t(31) = -2.925, p < .01$), Dodo game was significantly more enjoyable than Ishihara.

**DISCUSSION, CONCLUSION AND FUTURE WORK**

The results suggested that Dodo game had slightly better sensitivity than D15, but less than Ishihara. In terms of enjoyment, Dodo game was significantly more enjoyable than Ishihara, while being on par with D15. The results give support for the potential use of Dodo game as a new approach for the use of digital games to screen children at pediatric clinics or at home. As a new clinical tool for color vision screening, it is compatible with the two gold standard Ishihara and D15 tests in sensitivity and specificity. Portable, easy and fun - the game may be a good choice for color vision screening for children below the ages of five. Future work will involve the fine-tuning of Dodo game, and testing it with a larger population of young children.

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