Modern boardgames: a colorimetric analysis from the point of view of color deficiencies

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Abstract

Color vision deficiency is a condition that impairs one's ability to see color or distinguish between different colors. In Europe, around 8.8% of the male population and 0.4% of the female population are color deficient. When playing tabletop games or board games, color blindness can prevent players from distinguishing between different game elements, leading to a reduced enjoyable gaming experience.

Color serves two purposes in board games: aesthetic and gameplay. The gameplay aspect is more critical as different colors are typically used to differentiate among game elements with different meanings or belonging to different players. While it is important for a color deficient player to fully enjoy the aesthetics design of the game, their difficulties to play the game can render it useless. Some games on the market are difficult or almost impossible for color deficient people to play, forcing them to come up with homemade solutions to play the game.

This study aims to explore the use of color in various board games by measuring the reflectance spectra of the many colored components of the game, such as board areas, cards, pieces, and other game resources. The spectra are acquired using a spectroradiometer and are then used to calculate the CIE xyY coordinates to determine whether the colors of each game fall or not on the daltonic confusion lines in the CIE chromaticity diagram. This paper presents the preliminary results of this investigation.

Keywords: Color blindness, color deficiency, board games.

Introduction

In recent times, there has been a growing emphasis on accessibility across a lot of different fields, and one of these fields is about color vision deficiency in board games.
Color vision deficiency, commonly known as color blindness, affects approximately 8.8% of the male population and only 0.4% of the female population (Birch, 2012; Hunt and Carvalho, 2016) and is the inability to distinguish certain shades of color. This condition is due to the fact that human color vision relies on the response of three classes of photoreceptors of the retina known as *cones* and sensitive to photons of varying wavelengths, corresponding to the long-wavelength (L), middle-wavelength (M), and short-wavelength (S) regions of the visible spectrum. Color vision deficiency typically results from either a complete absence of one of the three classes of cone pigments or alterations to one of them (Melillo *et al.*, 2017).
When discussing accessibility for individuals with color vision deficiency, it's important to note that many board games, both older and newer, have not been designed with color blindness in mind. This oversight often forces individuals with color vision deficiency to devise their own methods to enjoy these games. For instance, two tokens with the same shape but different colors may appear identical to a colorblind user, significantly impacting his gaming experience.

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The use of colors in board games differs a lot from game to game, serving both aesthetic and gameplay-oriented purposes. Even though it is essential for a colorblind player to appreciate the game's aesthetic design too, the challenges in playing the game can render it unenjoyable or impractical. Thus, in this research we studied the use of color in various board games focusing on gameplay characterization rather than the aesthetic. In particular, for each board game, we compared the colors of different components of the game (i.e., board areas, cards, paws, dice and other game resources) with the aim to identify board games that might pose challenges for colorblind users.
Among the different types of color blindness (i.e. *Monochromacy*, *Dichromacy* and *Anomalous Trichromacy*), the preliminary results of our research are focused on *dichromacy*, the most studied Color Vision Deficiency that includes *protanopes*, *deuteranopes* and *tritanopes* individuals. *Protanopia* (also known as *red Dichromacy*) is caused by the lack of the L cone, resulting in an inability to differentiate colors within the red spectrum, and in difficulty distinguishing between red, yellow, and orange hues. *Deuteranopia* (also referred to as *green Dichromacy*), attributed to the absence of the M cone, is characterized by a reduced sensitivity to green which causes deuteranopes to struggle to differentiate between colors in the red, yellow, and green regions of the spectrum. Finally, *Tritanopia* (also known as *blue Dichromacy*), linked to the absence of the S cone, involves a loss of sensitivity to blue, leading to an inability to distinguish between blue and yellow hues.
This paper shows the preliminary result of this analysis.

Board Game Selection

For this study, we analyzed the board games listed in Table 1. In the list, a couple of recurrent names of designers and artists are present. Among the designers, there are Emerson Matsuuchi, author of the *Century* series and Uwe Rosenberg for *Agricola* and *Seconda Chance*. Among the artists, there are Chris Quilliams, responsible for the *Century* series, *Beez* and *Blackout Hong Kong* and Klemens Franz for *Grand austria hotel* and *Agricola*.
The selection criteria behind the chosen games are twofold. Firstly, we received recommendations from colorblind individuals who enjoy playing board games and have encountered difficulties with some of the games on our list. As an example, the game *Earth* presents a notable challenge for individuals with color vision deficiency due to the presence of numerous distinct game pieces, many of which are various shades of green, a color that poses difficulties for many dichromats.
Secondly, the choice was influenced by the availability of these games in the market, including both well-known titles and more recent or lesser-known ones.

Board Game Analysis

For each game, we had to make decisions regarding what to measure and what to exclude from the analysis. We focused on the game elements whose color is necessary for the gameplay. To organize the analysis, we divided the different game components into four distinct categories: *Pawns* (all game pieces used to represent a player or the resources that a player can acquire) *Cards*, *Dices* and *Boards*. Each category can have a further subdivision based on the shape of the object or its function in the gameplay. For example, *pawns* can be divided for their shape and usage (such as hexagon or circle objects in *Brass Birmingham*) or for what they represent (such as resources or player tokens), *dice* can be differentiated for the number of faces, *cards* from the layout of the single card, etc.
As a result of this categorization, for each game, we created groups of elements with the same shape, aspect, and function but different colors. At this point, it is clear that for the discernment of these components, color plays a crucial role in gameplay. Therefore, given the importance of color discrimination, we conducted comparisons of these colors within each subcategory to explore whether discrimination is still possible also for dichromat players.

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Table 1. - List of the board games with authors and artists (*BoardGameGeek*, 2023). Some titles are not in English since we kept the language title based on the local version available.

Game	Authors / Designers	Artists
Brass birmingham	Gavan Brawn, Matt Tolman, Martin Wallace	Gavan Brawn, Lina Cossette, David Forest, Damien Mammoliti, Matt Tolman
Kamisado	Peter Burley	Peter Burley, Peter Dennis, Steve Tolley, Yoojung Lee
Grand austria hotel	Virginio Gigli, Simone Luciani	Klemens Franz
Beez	Dan Halstad	Chris Quilliams
Zanzibar	Franz-Benno Delonge	Claus Stephan, Mirko Suzuki
Carcassonne	Kalus-Jürgen Wrede	Marcel Gröber
Bitoku	Germàn P. Millan	Edu Valls
Coatl	Pascale Brassard, Etienne Dubois-Roy	SillyJellie
Century– Eastern Wonders	Emerson Matsuuchi	Atha Kanaani, Chris Quilliams
Bonfire	Stefan Feld	Dennis Lohausen
Agricola	Uwe Rosenberg	Klemens Franz
Blackout Hong Kong	Alexander Pfister	Chris Quilliams
Euphoria	Jamey Stegmaier, Alan Stone	Jacqui Davis
Calico	Kevin Russ	Beth Sobel
Chakra	Luka Krleža	Claire Conan
It's a wonderful world	Frédéric Guérard	Anthony Wolff
Tajuto	Reiner Knizia	Maxence Burgel, Damien Colboc
Hanabi	Antoine Bauza, Gérald Guerlais	Antoine Bauza, Gérald Guerlais
I colori delle emozioni	Josep M. Allué, Dani Gòmez	Anna Llenas
Tentacolor	Davide Panizza	Cécil Le Brun
Seconda Chance	Uwe Rosenberg	Justine Nortjè, Max Prentis
Colorfox	Martin Nedergaard Andersen	Katie Burk
Mandala Stones	Filip Głowacz	Zbigniew Umgelter
Atlantis Rising	Galcn Ciscell	Vincent Dutrait
Florenza dice game	Danilo Festa, Stefano Groppi	Ivan Zoni
Clever Hoch Drei	Wolfgang Warsch	Leon Schiffer
Earth	Maxime Tardif	M81 Studio, Conor McGoey, Yulia Sozonik, Kenneth Spond
SerpentinGiro	Katrin Abfalter	Irinia Pechenkina
Century - la via delle spezie	Emerson Matsuuchi	Chris Quilliams, David Richards, Fernanda Suàrez
Schonbrunn	Tommaso Bagnoli	Francesco Mattioli, Maichol Quinto

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We acquired the reflectance spectra of each different colored object for each subcategory. For this purpose, we used the portable spectrophotometer CM-2600d by Konica Minolta that inspects a circle area of 3 mm in diameter. The instrument was calibrated by measuring the supplied white calibration plate as a reference for white and a shaded area as a reference for black. Through the auto-average parameter, each spectrum was obtained as an average of three consecutive measurements. The spectra were acquired considering the UV component and in SCE (Specular Component Excluded) mode, which subtracts the specular component of the light source from the sample when calculating the amount of reflected light. The spectra obtained ranged from 360 nm to 740 nm with a sample step of 10 nm.
For each colored element, we typically acquire a single reading. However, in certain exceptional cases involving transparent or semi-transparent tokens, it was necessary to sample color readings twice, capturing data from different points on the piece to ensure a more comprehensive and accurate acquisition of the color.

Starting from the obtained spectra, we then calculated the XYZ and xyY coordinates of each sample using the *colour-science* package of Python (Colour Developers, 2015). In particular, the coordinates were calculated using D65 as the illuminant and the CIE 1931 (2°) observer as the standard observer following the CIE guidelines in (CIE TC 1-85, 2018). For each subcategory of colored object, we plotted the colors to be discriminated on the 1931 CIE Chromaticity Diagram along with the various confusion lines for the three different types of dichromats, that originated from the confusion points specified in the book (Wyszecki and Stiles, 2000): the xy coordinates for *protanope*, *deuteranope* and *tritanope* individuals are respectively (0.747, 0.253), (1.080, -0.080) and (0.171, 0.000).
Since all the colors along a confusion line are perceived as identical by a color-blind person, plotting all the colors used in a particular subcategory can allow us to discern which pairs of colors could be confused by a dichromat.

Results and discussions

Figure 1 shows an example of the result computed for the subcategory of dice in the board game *Florenza Dice game*, in which the discrimination of the color of the dices is necessary for the different uses in the various phases of the game.

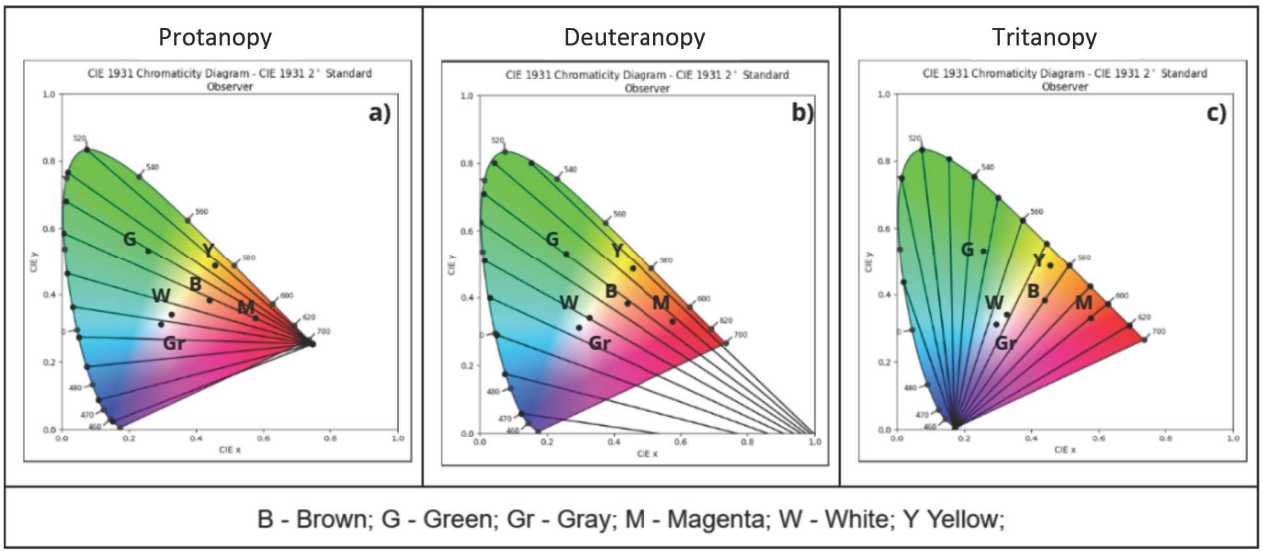

Figure 1. - Chromaticity Diagram and Confusion lines for Protanopy (a),Deuteranopy (b) and Tritanopy (c) for the *dice* category in the game *Florenza dice game.*

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From the chromaticity diagrams, red and brown could be challenging to discriminate for protanope players, brown and green for the deuteron individuals, while no problems should arise for Tritan users.
In Table 2 all the results for each subcategory of every game under analysis are summarized. In particular, along with the description of the subcategory (type, element, and number of colors), it can be seen the pairs or triplets of colors that can be respectively confused by protanope, deuteranope and tritanope individuals.

Table 2. - Results of the analysis. Every row represents a subcategory of the analysed game.

Game	Type	Element	Number of colors	Colors that can be confused		
				Protanope	Deuteranope	Tritanope
Brass Birmingham	Pawns	Resources	4	-	-	Yellow-Purple
	Pawns	Circles	4	-	-	Yellow-Purple
	Pawns	Hexagons	4	-	-	Yellow-Purple
	Pawns	Cubes	2	-	-	-
Kamisado	Board	Squares	8	Brown-Green	Purple-Blu, Brown-Green	Blu-Green, Yellow-Brown
	Board	Writings	8	Red-Green, Purple-Blu, Brown-Orange	Red-Brown-Orange	Green-Blu, Purple-Yellow, Red-Brown-Orange
Grand Austrian Hotel	Pawns	Circles	5	Purple-Light Blu	-	-
	Pawns	Cubes	4	-	-	-
Beez	Pawns	Big Circles	5	-	Purple-Light Blu, Red-Yellow	-
	Pawns	Small Circles	5	Red-Yellow	Purple-Light Blu, Red-Yellow	-
	Pawns	Hexagon	4	Cyan-White	-	-
Zanzibar	Pawns	Mercants	5	Orange-Yellow	Orange-Yellow, Red-Green	-
	Pawns	Scorekeeper	5	Orange-Yellow	Orange-Yellow, Red-Green	-
Carcassone	Pawns	Humans	5	-	Red-Green	-
Coatl	Pawns	Heads	5	-	-	-
Bitoku	Pawns	Onigiri	4	Green-Brown	Green-Brown	-
	Pawns	Animals	4	Green-Brown	Green-Brown	-
	Pawns	Samurai	4	-	-	-
	Pawns	Fish	4	Green-Brown	Green-Brown	-
Century – Eastern Wonders	Pawns	Cubes	4	Red-Brown	Red-Green	-
	Pawns	Houses	4	Light Blu - Pink	-	-
Bonfire	Pawns	Angels	8	Red-Wood, Cyan-Pink, Green-Yellow	-	Gray-Wood
	Pawns	Humanoide	5	Green-Yellow	-	-
	Pawns	Circle	4	Green-Yellow	-	-
	Pawns	Resources	6	Pink-light Blu	Pink-Gray	Gray-Wood
Agricola	Pawns	Plank	4	Purple-Light Blu,	-	-
	Pawns	House	4	Purple-Light Blu,	-	-
	Pawns	Humanoide	4	Purple-Light Blu,	-	-
	Pawns	Animals	3	-	-	-
	Pawns	Resources	5	Orange-Yellow	-	Yellow-Brown-Wood

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Blackout: Hong kong	Pawns	Circles	4	Orange-Green	Orange-Green	-
	Pawns	Cubes	4	Orange-Green	Orange-Green	-
	Pawns	Houses	4	Orange-Green	Orange-Green	-
	Dice	D6	3	-	-	-
	Cards	cards	4	-	Red-Yellow	-
Euphoria	Pawns	Heart	6	-	Purple-Blu	-
	Pawns	Star	6	-	Purple-Blu	-
	Pawns	Head	6	-	Purple-Blu	-
	Pawns	Resources	7	Green-Yellow, Gray-light Blu	Gold-Yellow-Orange	Gold-Yellow-Green
	Dice	D6	6	-	Green-Red	-
Calico	Pawns	Tassel	6	Purple-Blu, Magenta-Light Blu	-	Purple-Yellow
	Pawns	Dense tassel	6	Light Blu-Magenta	-	Purple-Yellow
Chakra	Pawns	Circles	8	Yellow-Green, Red-Orange, Light Blu-Purple	Yellow-Green, Red-Orange, Light Blu-Purple	Purple-Yellow-Black
	Pawns	Gems	8	Green-Orange, Purple-Blu	Red-Green-Orange, Purple-Blu	Green-Blu
It's a wonderful world	Pawns	Resources	6	Red-Yellow	-	Gray-Yellow
	Cards	Cards	6	Yellow-Green	Yellow-Green-Orange	-
	Cards	Resources	8	-	Red-Green	-
Tajuto	Pawns	Pagodas	8	Pink-Blu	Red-Green	Blue-Green, Pink-Orange- Red
	Pawns	Cubes	8	Green-Orange	Red-Green	Pink-Orange
	Pawns	Humanoide	4	Green-Orange	-	Green-Blue
Hanabi	Pawns	Token	1	-	-	-
	Cards	Cards	6	Red-Green	-	Yellow-Black
I colori delle emozioni	Pawns	Tokens	5	-	-	-
Tentacolor	Pawns	Tentacles	6	Purple-Red	Orange-Green	Yellow-Orange
Seconda Chance	Cards	Cards	8	Green-Orange, Purple-Blue	Yellow-Orange	-
ColorFox	Pawns	Sticks	6	-	Red-Green	-
	Cards	cards	6	Yellow-Green	Yellow-Green	Pink-Yellow
Mandala Stones	Pawns	Pawns	5	Black-Pink	Purple-light Blue	Purple-Yellow
Atlantis Rising	Pawns	Pawns	9	Clay-Green	-	Purple-Grey-Silver
	Pawns	Gems	5	-	-	-
	Dice	Dices	1	-	-	-
Florenza Dice Game	Dice	Dice	6	Red-Brown	Green-Brown	-
Clever Hoch Drei	Dices	Dices	6	-	-	Brown-Yellow
Earth	Pawns	Trees	4	-	-	-
	Pawns	Resources	3	-	-	-
	Pawns	Tokens	2	Green-Brown	Green-Brown	Green-Brown
	Pawns	Leafs	4	Purple-Blue	-	-
	Cards	Cards	20	Orange-light Brown-Green, Brown-Teal	-	Blue-Green, Brown-Orange
SerpentinGiro	Pawns	Pieces	4	Green-Orange	-	-
	Dice	Dice	4	Pink-Blue, Orange-Green	-	-
Century – la	Pawns	Cubes	4	Red-Brown	-	-

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via delle spezie	Pawns	Coins	2	-	-	Gold-Silver
	Cards	Points	4	Red-Brown, Green-Yellow	Green-Yellow	-
	Cards	Mercants	5	-	-	Gray-Green
Schonbrunn	Pawns	Numbered	6	-	-	-
	Pawns	Gentlemen	6	-	-	-
	Pawns	Military	6	-	-	-
	Pawns	Circles	7	-	-	-

Conclusions

In this study, we investigate the use of color in different board games in the context of accessibility. We conduct a comparative analysis of colors across different subcategories of resources (being them pawn, card, dice, or boards elements) that can be differentiated only by color. Colors positioned along the confusion lines of the chromaticity diagram cannot be discriminated by protanope, deuteranope, and tritanope players. The preliminary results confirm that various games from different authors and artists may pose potential challenges for users with color vision deficiencies. This study lays the foundation for further investigations aimed at analyzing and developing the accessibility of board games.

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