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The effects of Color Contrasts on Users of Digital Environments

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Abstract

In this paper, we examine the need for usability methods for game design and argue that we need to research ways of guiding players through a digital environment, known as player guidance. We propose to do this through color, since it is a core component to any digital environment. In order to do this, we review the color contrasts as defined by Itten, J., in an experimental setting to find out whether the presence of contrasts can influence either the decision making of a player or the effects of the contrasts on the viewing behavior of a player. Furthermore, we examine the effects of two color circles, one based on CMYK values and the other based on RGB values, to see whether different color circles yield varying effects. The goal of this paper is to find out whether color is suitable for player guidance and, if it is, to distill new player guidance techniques for use with game design.

Keywords: Visual Perception, User Experience Design, Interaction Design

1 Introduction

Within the game design discipline, level design is a fairly new practice. At first it was a task delegated to other developers but, when video games started to become more technically advanced, specialized level designers became a necessity. It could be argued that for modern game design, level design is of utmost importance [1,2]. However, as of yet there is no real formal understanding of what makes for good level design, apart from rules of thumb and design lore [3]. Furthermore, we feel that the current design lore for level design mostly requires a medium to high game literacy, possibly alienating less experienced players. Therefore we postulate that it is necessary to create a body of formal knowledge in regards to level design.

The aim of this study is to create new methods to make progression through game environments more intuitive for players of games. Our research focus is on how the user perceives the environment visually and how the user deals with this information. Past studies in interior design have proven the effectiveness of color on visitors [4,5]. However, a weakness of these studies is that they mostly relied on the psychological effects of color, which can be argued to have different effects depending on culture. Therefore, we seek to find whether color at its most basic can influence user behavior. We therefore researched how users would perceive contrasting colors (based on the definitions by Johannes Itten [6]) and whether these contrasts had any effect on their viewing behavior as well as decision making.

In prior research, we examined how color could have effect on the behavior of participants [7], both in their decision making as well as their viewing behavior. However, since the stimuli were designed to simulate a game environment more closely, a lot of noise persisted in the data, which made it hard to determine whether it was the color that affected the participant. Hence, we deemed further testing necessary. To analyze our results, we opted for dynamic Areas of Interest (AOI). AOI are fields of supposed interest to the user, used in eye tracking, which are used to determine how often and how long the user looks at each defined area. Dynamic AOIs are animated AOIs. Due to this, we were limited to using the video output generated by the eye tracking hardware. Due to this, the accuracy of our data was decreased from 60 samples per second to 10 samples per second, impacting the reliability of the data.

Another weakness of the previous study is that it relied on a single CMYK based color circle. Since games make use of a screen that outputs RGB color values, it is of essence that an RGB based color circle is constructed to see whether this yields different effects in influencing players' viewing behavior and decision making.

2 Usability for games

One could argue that usability is not an inherent necessity for games. It is true that games, unlike other interactive products, seek to challenge their players in order to create satisfaction. However, just because something is difficult, does not necessarily make it enjoyable. In earlier research, we have argued that defining challenge through its difficulty is rather problematic [8], as there are more factors at play with challenge rather than just its difficulty.

Furthermore, Koster, R., [9] argued that having fun is all about the brain releasing endorphins into our system, and that the way to do that is to learn something new or master a task.

Games in this sense are ideal for the task, since they are largely about mastery and comprehension. He referred to the rules within games as patterns and argued that once the player fails to see any patterns whatsoever, he will experience noise and become frustrated with the game.
Game creators have already developed a few methods of ordering this noise into information that is easier to understand. For instance, Isbister, K., [10] noted that the character Link from the game The Legend of Zelda The Wind Waker has large eyes that makes tracking his gaze easier. During the game, the character will often look at objects that may be of interest to the player. There are other games that employ this particular technique of the main character look at objects of interest, such as in the game known as Fatal Frame, a horror themed game developed for the PlayStation 2.
In order to make sure games do not become frustrating to the players, to both experienced and inexperienced players alike, it is necessary that usability for games is explored and researched.

3 Participants

The experiment was conducted with a total of 15 participants. The average age of the participants was 27.4 years, with a standard deviation of 7.1. There were a total of 9 males and 6 females. The participants were from varying nationalities.

4 Equipment

We experimented with two different color circles. The first color circle was based on CMYK values, to closely emulate the color circle that Itten, J., used in his experiments. The second color circle was based on RGB values, using the same means of creating the color circle as the CMYK circle.
For the paints used to construct the CMYK color values, we used the Holbein Artists Gouache G651 Primary Magenta, Holbein Artists Gouache G652 Primary Yellow and Holbein Artists Gouache G654 Primary Cyan. We used 218GSM paper for the color samples. To convert the colors to waveform values, the Konica Minolta CM2600d spectrometer was used. Recordings were made using the SAV setting while using F2 light source data. Since the experimental prototype was designed on a digital platform, there was a need to convert the color waveform values to digital values. To do this, the Konica Minolta Spectroradiometer CS-1000 was used. The colors were converted to hexadecimal values for usage in the experimental prototype. These results of the conversion to RGB are shown in table 1, together with the codes we will use to refer to them in this paper. The CMYK circle codes will be in uppercase letters.

Code	Color mixture	R	G	B	Hexadecimal
C	Cyan (C)	80	126	186	507E8A
Y	Yellow (Y)	255	235	0	FFEB00
M	Magenta (M)	170	84	99	AA5463
CYY	C(25%) Y(75%)	142	170	0	8EAA00
CY	C(50%) Y(50%)	107	149	72	6B9548
MYY	M(25%) Y(75%)	217	128	61	D9803D
MY	M(50%) Y(50%)	195	97	75	C3624B
CMM	C(25%) M(75%)	129	91	109	815B6D
CM	C(50%) M(50%)	114	92	123	725C7B
MCC	M(25%) C(75%)	106	98	140	6A628C
YMM	Y(25%) M(75%)	181	90	83	B55A53
YCC	Y(25%) C(75%)	87	137	99	578963

Table 1 Digital CMYK color values used for the experimental prototype

Furthermore, the first experiment had as a limitation that it only used the CMYK colors to check whether color could influence the behavior of the participants, since the color circle developed by Itten J., was also based on print colors. Since monitors primarily use RGB values instead of CMYK, using a color circle not native to a digital environment could be construed as a limitation of the study. For this reason, we opted to include an alternate color circle based on RGB values for this experiment, so we could analyse whether there was a difference of effects between the CMYK and the RGB based color circles. However, since we are using the color contrasts of Itten, J., we had to convert the RGB circle to fit Itten, J.,'s color circle as to not upset the workings of certain color contrasts. The results of the RGB circle are shown in table 2, together with the codes we will use to refer to them in this paper. The RGB circle codes will be in lowercase letters.

Code	R	G	B	Hexadecimal
c	0	0	255	0000FF
y	255	255	0	FFFF00
m	255	0	0	FF0000
cyy	128	192	0	80C000
cy	0	128	128	008080
myy	255	192	0	FFC000
my	255	128	0	FF8000
cmm	192	0	128	C00080
cm	128	0	128	800080
mcc	64	0	192	4000C0
ymm	255	96	0	FF6000
ycc	0	128	192	0080C0

Table 2 Digital RGB color values used for the experimental prototype

To get colors mixed with black and white for either circle, we overlayed an additional layer of black or white over the colors of the color circles and adjusted the transparency as needed.

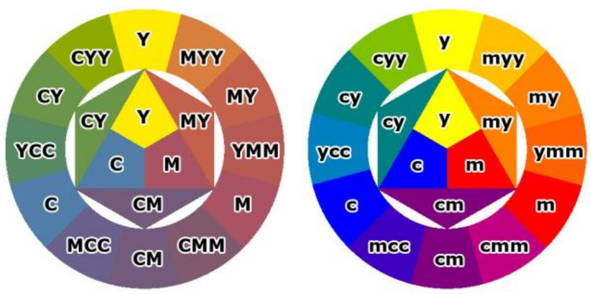

Figure 1 The CMYK circle and the RGB circle respectively

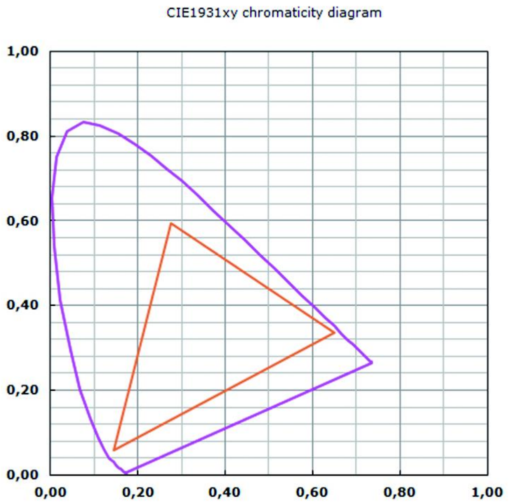

Figure 2 BENQ G2400WDLCD gamut range

A BENQ G2400WDLCD monitor was used for the experiment. Its gamut range is shown in figure 2. The entire color range is visualized by the purple enclosed area. The gamut range is the possible range of colors a monitor can output, which for this monitor is visualized by the area within the triangle with the red outline. For all CMYK values that reported one or more of the RGB values to be more than 255 (i.e. outside of the range of the monitor), we used the max value of 255. The computer used for the experiment was an Intel Core i5-2400 3.10GHz, with 4.0 GB RAM and an AMD RADEON HD 6450 1.00GB. The operating system used was Windows 7 Enterprise (64 bits). Additional hardware to control the experimental prototype was used in the form of a Microsoft Wireless XBOX360 Controller for Windows. For the eye tracking hardware, we used a Mirametrix S2 eye-tracker, model MRS2.

5 Preparation

For this experiment, 5 contrasts will be reviewed.

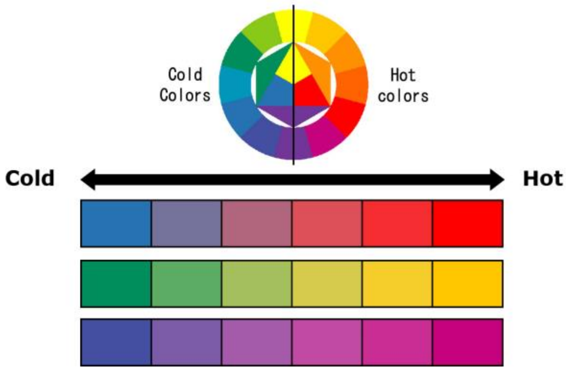

Figure 3 Hot and cold contrast

To determine which color is considered hot and which color is considered cold, the color circle is split in half. Every color on the right side is considered to be a hot color, whereas everything on the opposite side is considered cold.

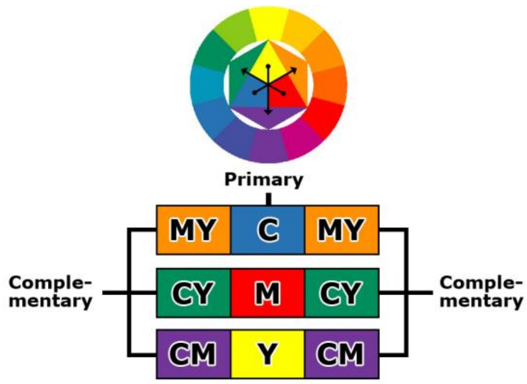

Figure 4 Complementary contrast

Within a complementary contrast, a primary color (the inner triangle of three colors) are combined with the secundary color (gotten by mixing two primary colors) that are polar opposite of them. According to Itten, J., the secundary color will strengthen the primary color.

Figure 5 Saturation contrast

The contrast of saturation relies on the purity of a color. The more a color is mixed down, the less saturated it becomes. A saturation contrast relies on the difference between a more saturated color and a less saturated color.

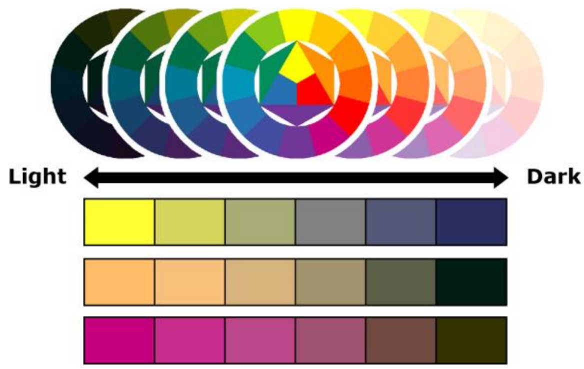

Figure 6 Light and dark contrast

For the light and dark contrast, a color is mixed with either dark or light colors (generally black or white) to make it lighter or darker.

Figure 7 Contrast of hue

According to Itten, J., the closer a color was to being a primary color, the stronger it was. A primary color is a color that cannot be gotten through mixing colors. Secondary colors are created by mixing two primary colors with one another. To get tertiary colors, a secondary color needs to be mixed with a primary color. For this reason, in this contrast, the primary colors are the strongest hue whereas the tertiary colors are the weakest. Secondary colors are of average strength.

For each contrast, we will use 2 sets of 3 stimuli (3 stimuli of each color circle). The remaining two color contrasts, namely the simultaneous contrast and the contrast of extension, shall not be reviewed. The simultaneous contrast relies on optical illusions which can be argued whether this constitutes as a proper contrast. The contrast of extension, according to Itten, J., was dependent on each individuals' personal preference.
In order to house the stimuli, an experimental prototype was designed using the game development software known as the Unreal Development Kit (we used the July 2012 Beta version of the software). The prototype takes the form of a side scrolling action type game, where the game camera is always fixated to the side of the environment (see figure 9). The in-game camera always remains stationary. The prototype features only the most basic controls to allow for interaction with the environment. The user is able to move left, right and run. The player can enter doorways through a special button, but this process is automated once the player presses the button.
30 stimulus rooms were prepared, for a total of 6 stimuli per contrast. Of these 6 stimuli, 3 use the CMYK circle and 3 stimuli use the RGB circle. Each stimulus room has got two entrances the participant can choose from. The entrances are surrounded by one of the colors of a particular color contrast, which have also been designated as the AOIs (see figure 8 and figure 9). AOIs (Areas of Interest) are the areas of which we want to know how they impact the participants' eye behavior.
Furthermore, a tutorial room to teach the participant the basic operations of the game was prepared. A final room was also prepared, for when the participant had completed all the stimuli. This tutorial room as well as the final room where not used for data analysis.

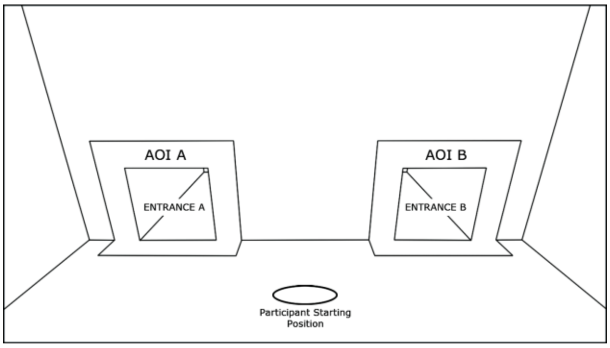

Figure 8 Stimulus room setup

AOIs were set up to have the following colors;

Contrast	AOI A	AOI B
Hot and cold	Hot	Cold
Complementary	Primary	Complementary
Saturation	Most saturated	Least saturated
Light and dark	Light	Dark
Hue	Strongest hue	Weakest hue

Table 3 AOI color setup

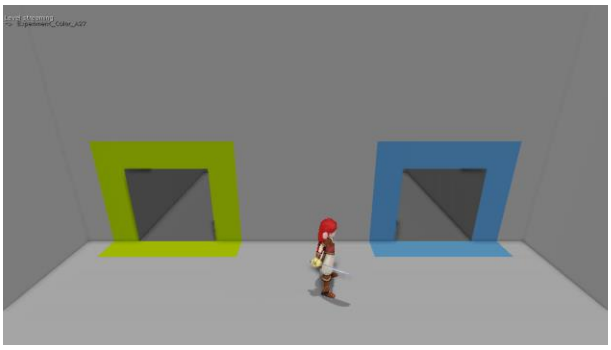

Figure 9 In-game screenshot of the experimental prototype

6 Protocol Design

Experiments were conducted in a room lit by white TL lighting. Depending on the circumstances, lights were turned on or off to get a good result during the calibration of the eye-tracking hardware. Participants were requested not to wear glasses or make-up, due to interference with the eye-tracking hardware.
Participants were explained the contents of the experiment, after which the examiner would proceed to calibrate the eye-tracking hardware. In order to get accustomed to the controls, participants would first play a tutorial room during which the examiner explained how to operate the XBOX360 controller. After the tutorial room was finished, the participants would move onto the stimuli.
The stimuli would appear in a randomized order (with the position of AOI A and AOI B being randomized as well), until the participant had finished all of them. After finishing all of them, the participant would be taken to the finish room. At this point, the participant was required to fill in a questionnaire to inform about their color preferences. Once the questionnaire was finished, the experiment was concluded.

7 Data Analysis

Out of the five contrasts used for the experiment, we were able to establish goals for two. Both the complementary contrast as well as the contrast of hue were clearly defined by Itten, J. For the complementary contrast, we defined the goal as the entrance that had the primary color as opposed to the entrance that had the secondary color. Furthermore, in the contrast of hue it is regarded that the more pure a color is, the stronger it becomes. That means that a primary color is dominant over a secondary color and that a secondary color is dominant over a tertiary color. For the remaining contrasts however, there was not a clear definition, so we will conclude their effects by the frequency of which entrances are being chosen.

For the AOIs we concentrated on the total time of the participant's fixations within the AOI (total dwell-time) as well as the average fixation time within the AOI (average dwell-time).

To determine what constituted as a fixation, the factory settings of the Mirametrix Eye-tracker were used. Furthermore, according to Holmqvist, K., & Nystrom, M. [11], a typical fixation is anywhere between 200-300ms, whereas saccades and glissades are only 30-80ms and 10-40ms respectively. Therefore, everything below 200ms was not considered a fixation but a saccade or a glissade instead. This data was not included in the analysis, as the main focus are AOI average and total dwell times, for which fixations were necessary. Furthermore, eye-tracker data created after the player had made a choice was not recorded either; as the data that leads up to the decision was all we needed. We consider a decision to be made the moment the player has pressed a button to proceed to the next room, as this action is irreversible and the act of entering a room is automated. Once the transition between two rooms is finished, if the player's gaze happened to be inside of an AOI but had not moved since before the transition was finished, the faze is not considered a hit, but a coincidence.

Samples that were returned as invalid by the eye-tracker were not used for the analysis of the data. On top of that, it was found that the RGB values on 6 stimuli were erroneous, making it hard to determine whether they could still constitute as a contrast. While they will be considered for future luminosity and radiance analysis, they will be ignored for the current analysis. ANOVA was used to analyse the significance of the eye-tracking data, whereas the Wilcoxon signed-rank test was used to determine the significance of the choice data. For both tests data that had a p-value of less than 0.15 was considered insignificant.

8 Hot and Cold Contrast Results

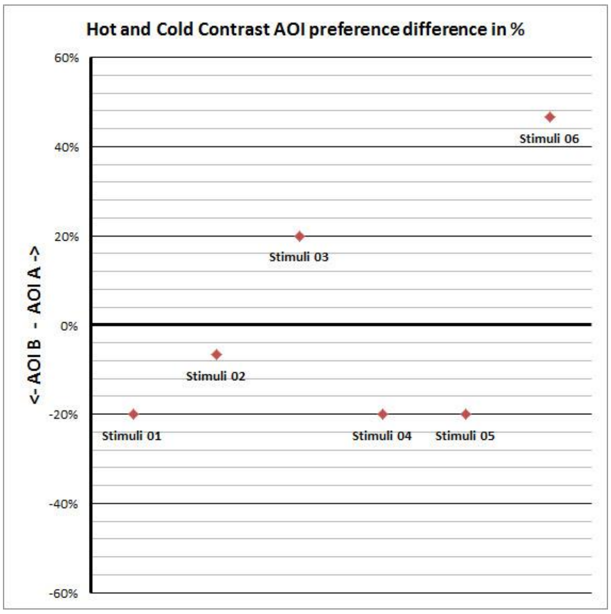

Figure 10 Hot and cold contrast choice data

	AOI A	AOI B
Stimulus 1	M	C
Stimulus 2	MY	CY
Stimulus 3	YMM	MCC
Stimulus 4	m	c
Stimulus 5	cmm	cyy
Stimulus 6	myy	mcc

Table 4 Hot and cold contrast stimuli colors

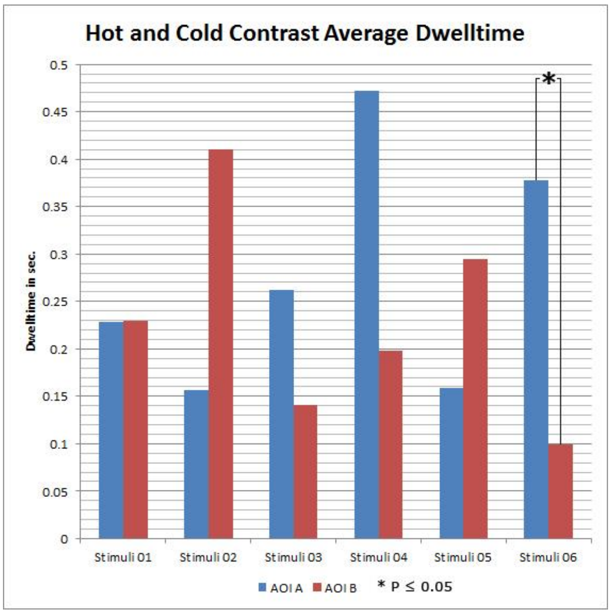

Figure 11 Hot and cold contrast average dwell-time data

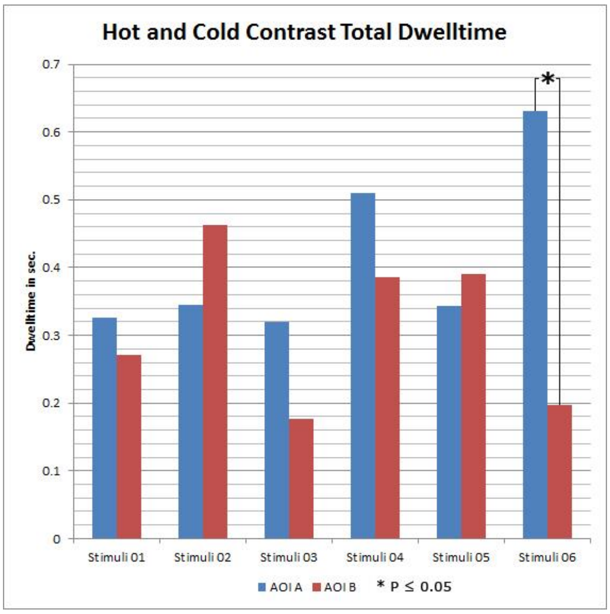

Figure 12 Hot and cold contrast total dwell-time data

Using the color codes from table 1 and table 2, the values of the colors used in the hot and cold contrast stimuli are shown in table 4.

While, with the exception of 1 stimulus, the effects of the hot and cold contrast can be largely considered insignificant, there was a very slight preference towards warm colors, in both the decision making (see figure 10) as well as in total dwell times (see figure 12). In both instances, the RGB based stimuli show more difference in performance as compared to the CMYK based stimuli, whose differences between AOI A and AOI B are largely minor.

9 Complementary Contrast Results

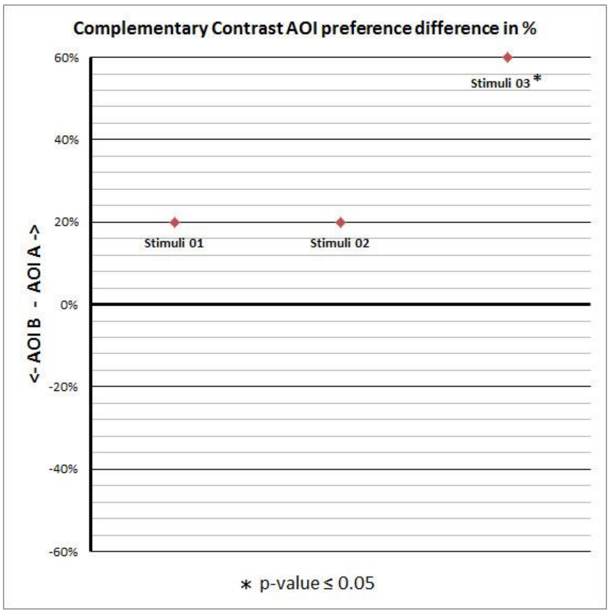

Figure 13 Complementary contrast choice data

	AOI A	AOI B
Stimulus 1	M	CY
Stimulus 2	C	MY
Stimulus 3	Y	CM

Table 5 Complementary contrast stimuli colors

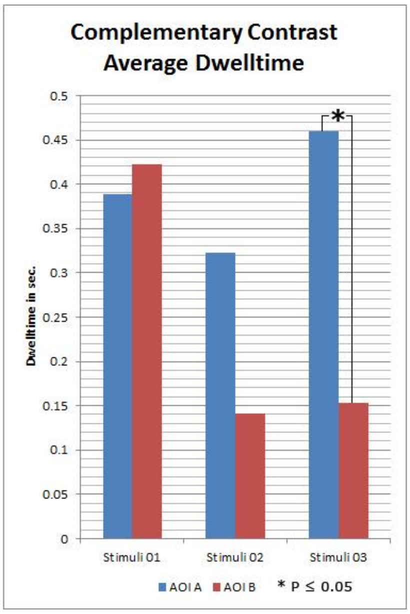

Figure 14 Complementary contrast average dwell-time data

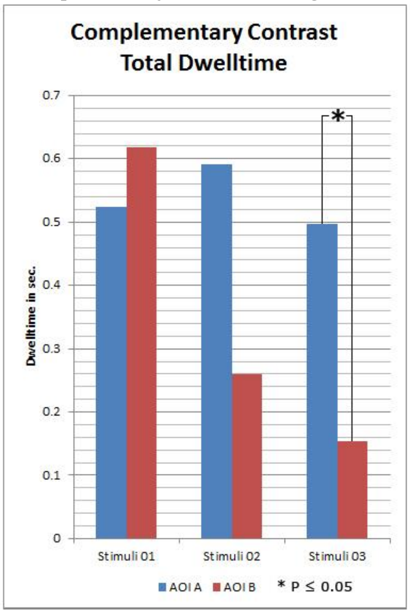

Figure 15 Complementary contrast total dwell-time data

Using the color codes from table 1 and table 2, the values of the colors used in the hot and cold contrast stimuli are shown in table 5.

In 2 out of 3 instances, in either decision making (figure 13), average (figure 14) and total dwell-times (figure 15), the primary color beats out the secondary color, a rather surprising result as prior research reported opposite results for the same contrast. However, despite this only the results of the third stimuli were of any significance.

10 Saturation Contrast Results

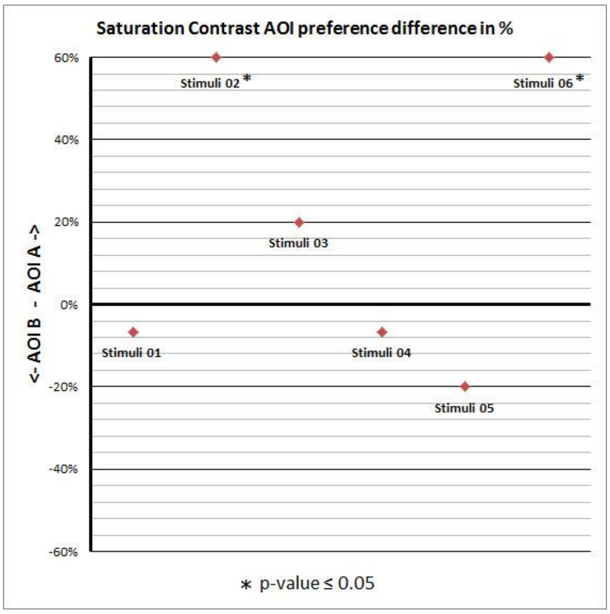

Figure 16 Saturation contrast choice data

	AOI A		AOI B	
Stimulus 1	YMM	(0% white)	YMM	(50% white)
Stimulus 2	MCC	(0% white)	MCC	(20% white)
Stimulus 3	CYY	(0% white)	CYY	(60% white)
Stimulus 4	mcc	(0% white)	mcc	(30% white)
Stimulus 5	cmm	(0% white)	cmm	(50% white)
Stimulus 6	y	(0% white)	y	(20% white)

Table 6 Saturation contrast stimuli colors

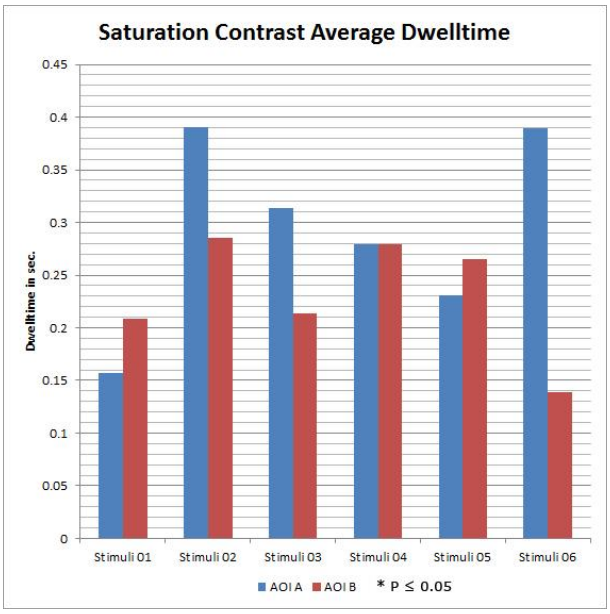

Figure 17 Saturation contrast average dwell-time data

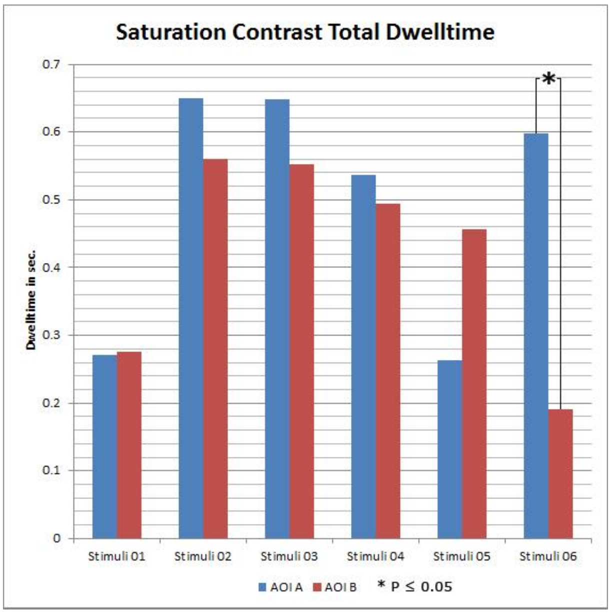

Figure 18 Saturation contrast total dwell-time data

Using the color codes from table 1 and table 2, the values of the colors used in the hot and cold contrast stimuli are shown in table 6. In these stimuli we overlayed the colors with a transparent layer of white to create lighter hues. The percentage of the transparency has been recorded next to the color code.

The saturation contrast gave mixed results, with the decision making (figure 16) being divided in-between AOI A and AOI B. Both the average (figure 17) and total dwell-times (figure 18) showed a very minor preference towards the more saturated colors. The difference was especially striking in stimulus 6, which also reported a significant difference on the total dwell time.

11 Light and Dark Contrast Results

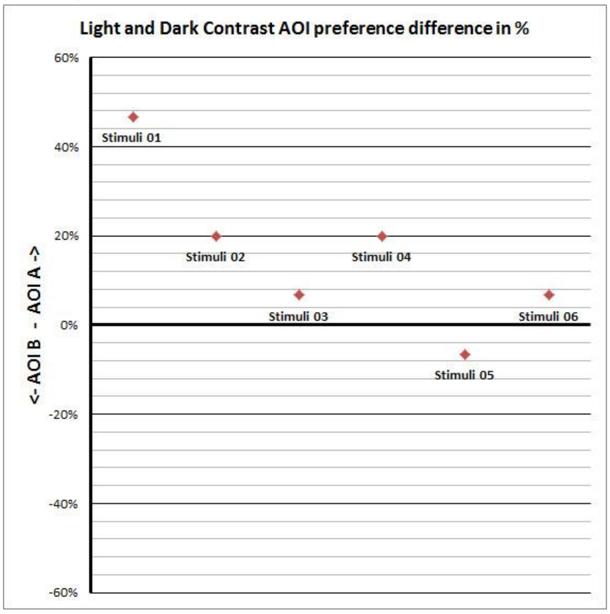

Figure 19 Light and dark contrast choice data

	AOI A		AOI B	
Stimulus 1	Y	(40% black)	Y	(80% black)
Stimulus 2	MCC	(10% white)	MCC	(20% black)
Stimulus 3	CYY	(20% white)	CYY	(40% black)
Stimulus 4	m	(20% black)	m	(70% black)
Stimulus 5	cy	(50% white)	cy	(60% black)
Stimulus 6	mcc	(60% white)	mcc	(40% black)

Table 7 Light and dark contrast stimuli colors

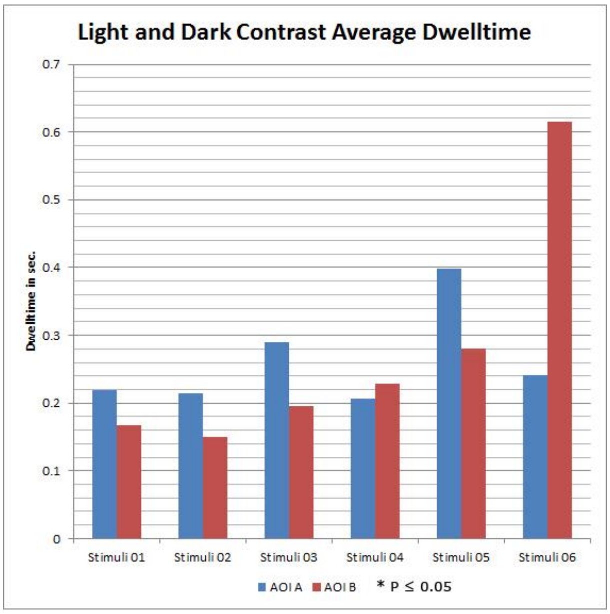

Figure 20 Light and dark contrast average dwell-time data

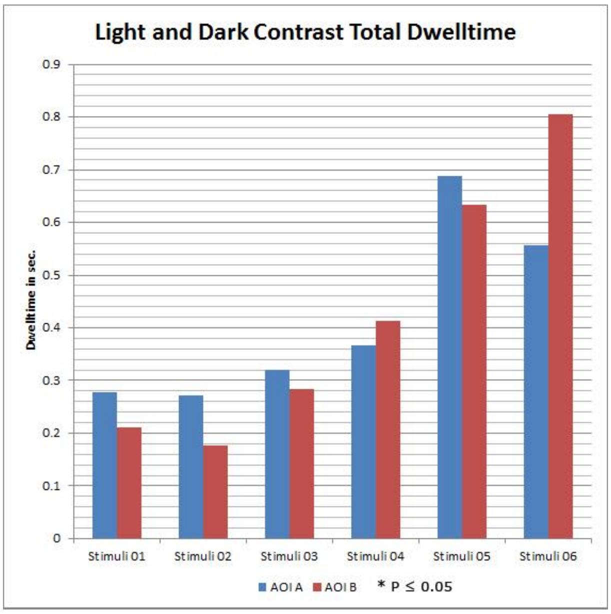

Figure 21 Light and dark total dwell-time data

Using the color codes from table 1 and table 2, the values of the colors used in the hot and cold contrast stimuli are shown in table 7. In these stimuli we overlayed the colors with a transparent layer of either white or black to create light contrasts. The percentage of the transparency as well as the color used has been recorded next to the color code.

There was a preference towards the lighter color, even if the preference was rather slight. The lighter color got the highest decision rate (figure 19). 5 out of 6 stimuli recorded a preference for the lighter color, though the choice data itself turned out to be insignificant. With the average dwell times (figure 20) there was also a slight preference towards the lighter color. However, none of the stimuli returned significant results. The total dwell-times (figure 21) showed no significance.

12 Contrast of Hue Results

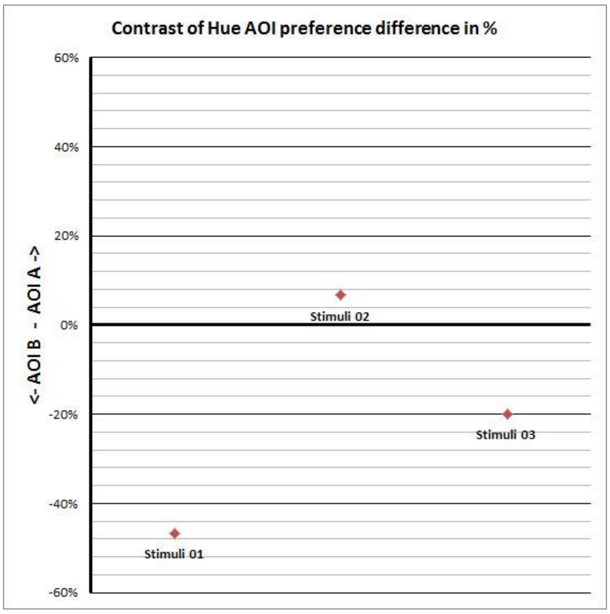

Figure 22 Contrast of hue choice data

	AOI A	AOI B
Stimulus 1	M	MY
Stimulus 2	CM	CYY
Stimulus 3	C	CYY

Table 8 Contrast of hue stimuli colors

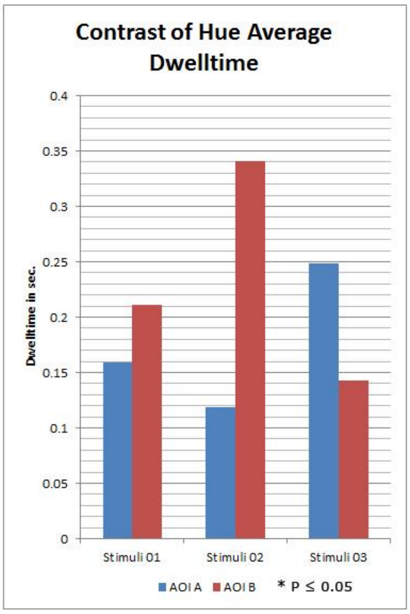

Figure 23 Contrast of hue average dwell-time data

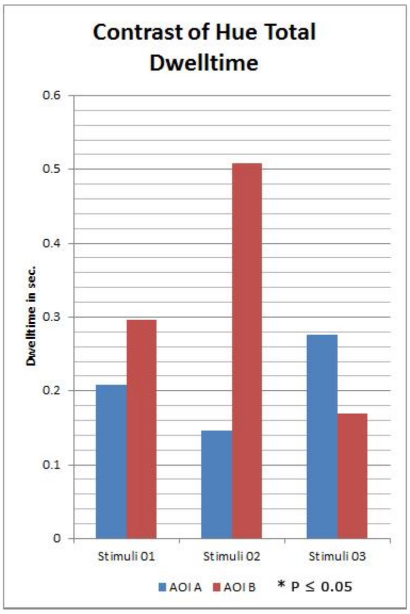

Figure 24 Contrast of hue total dwell-time data

Using the color codes from table 1 and table 2, the values of the colors used in the hot and cold contrast stimuli are shown in table 8.

The contrast of hue performed extremely poorly, with the supposedly stronger hue losing out to the weaker hue 2 out of 3 times. The results are consistent however, even if they are not significant, with the stimuli reporting the same findings in decision-making (figure 22) as well as average (figure 23) and total dwell times (figure 24).

Looking at all the results, we can conclude that there is no significant effect on viewing behavior of the participants. There's only very few stimuli that returned significant results. There are also no real differences between the significance values of either the CMYK and the RGB stimuli, meaning that what kind of color circle is being used does not have a distinct effect on participant behavior either.

13 Limitations

A possible limitation in this experiment is that the stimuli are not designed to emulate an actual game environment. Though the first experiment was designed to have an environment more closely emulating a game environment, it caused a lot of noise in the data. While this experiment was designed to eliminate that limitation, we could argue that players would behave differently if the environment was more structured like a game. Furthermore, the handedness of the participants could also be a potential limitation, as can be seen in table 9.

	AOI A	AOI B
Left handed	71.1%	29.8%
Right handed	48.9%	51.1%

Table 9 Difference of choice data between left and right handed participants

While the right handed people were equally likely to choose either the left or the right entrance, left handed people showed a distinct preference for the left entrance. However, since there was a lack of left handed people among the participants (only 20% of all participants were left handed), we cannot conclude with certainty that handedness has an effect on what people are more likely to choose, which constitutes as a limitation to the current study.

14 Conclusion

In order to create an enjoyable game experience for users of varying levels of game literacy, it is necessary that new methods to accommodate these players in a digital environment are researched. Game environments that confuse players will end up being frustrating to them, giving weight to the idea that usability is necessary to games as well.

However, even though color remains a core component to any digital game environment, this experiment has shown that color, at least when used in contrasts, have no significant effects on player behavior. The few exceptions can be considered coincidences. Seeing both the CMYK color circle and the RGB color circle return results that are of no significance, tells us that using different color circles does not yield a satisfactory difference in results either.

15 Future Works

While out of the scope of the current paper, we wish to further examine whether the luminance values used in the current experiment had any influence on player behavior. This shall be examined in a future paper.

References

[1] Bezinsky, C., *The Art and Science of Level design.* Session 4044 at GDC 2000, 2000.

[2] Co, P., *Level Design for Games,* New Riders, 2006.

[3] Hullet, K., Whitehead, J., *Design Patterns in FPS Levels*, FDG '10 Proceedings of the Fifth International Conference on the Foundation of Digital Games, ACM New York, Computer Graphics Proceedings, Annual Conference Series, ACM, 78-85, 2010.

[4] Brengman, M., Geuens, M., *The Four Dimensional Impact of Color On Shoppers Emotions*., Advances in Consumer Research 31, 122-128, 2004.

[5] Lam, S.Y., *The Effects of Store Environment on Shopping Behaviors; a Critical Review*, Advances in Consumer Research 28, 190-197, 2001.

[6] Itten, J., *The Art of Color*, John Wiley and Sons, 1997.

[7] Brandse, M., Tomimatsu, K., *Using Color Guidance to Improve on Usability in Interactive Environments.* HCI International 2014, to be published.

[8] Brandse, M., Tomimatsu, K., *Empirical Review of Challenge Design in Video Game Design*, HCI International 2013 – Posters' Extended Abstracts, 398-406, 2013.

[9] Koster, R., *A Theory of Fun*, Paraglyph Press, 2005.

[10] Isbister, K., *Better Game Characters by Design,* Morgan Kaufmann Publishers, 2006.

[11] Holmqvist, K., Nystrom, M., *Eye Tracking, a Comprehensive Guide to Methods and Measures.* Oxford University Press, 201