MEASURING EMOTIONAL RESPONSES TO COLOR IN VR EXPERIENCES THROUGH BIOMETRIC SENSORS

An analysis of color associations through user performance in a VR Target Shooting game

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Abstract. Color design is an integral part of the ever advancing world of architecture. Color schemes can drastically change the overall atmosphere of a structure. While color preference is subjective, it is often influenced by factors such as cultural backgrounds, age and gender. Moreover, communication between client and architect is key to an efficient design process. Therefore, this research aims to propose a solution where such preferences could be statistically measured. Through a Virtual Reality experience, users complete a basic target shooting game while under a heavily colored environment. Data from biometric sensors, measurements such as accuracy, session time and heart rate were recorded. Gathering data through various tests under contrasting colors, the results will undergo comparative analysis to draw conclusions on an individual or group test subject, determining their mental reaction towards various colors. This experiment when applied to an architectural design process could increase the effectiveness of client and architect communication, thus increasing efficiency.

Keywords. Emotion: Biometrics; Virtual Reality; Color Psychology; Client Interaction.

1. Introduction: Research Aims and Motivations

Ambiguity is a problematic issue that can lead to mistrust and damage communication (Norouzi 2015 p. 635). Communication between client and architect is vital to an efficient design process. Communication that is not clear can result in unsatisfactory design results for the client (Ayodele Elijah Olusegun, 2008). A recent study regarding this issue points out multiple reasons for communication difficulties between client and architects. (Norouzi 2015 p. 636). The few most notable points were as follows.

- The client's viewpoint was not fully considered
- Design requirements were not sufficiently managed
- There is a lack of feedback from the client

Developing an understanding for the client's needs require both parties to communicate effectively through interfaces of varying media types. As technology advances over time, common practices evolved from traditional written documents and two-dimensional drawings to three-dimensional rendered models, animations and simulations (Norouzi 2015 p. 637). However, these methods of communication and visualization ultimately result in the client and architect's verbal or written conclusions to drive iteration changes. In the event of either party not fully conveying their desired changes, it would lead to insufficient iterations, thus wasting time and resources. This is highly detrimental to client and architect relationship, especially in the modern deadline driven workplace.

Color design is an integral part of architecture, and is a highly subjective matter with various factors that influence color choices. These factors, while not limited to, are cultural background, general health, gender and age (Connor 2011 p. 230). Although these are important to take into consideration when developing design iterations, color preference is ultimately personal preference.

Therefore the proposed method is a tool measures a client's reaction to different colors on a subconscious level. Through statistical information, architects can understand the client's preferences and better apply colors based on the structure's intended purpose. This reduces the risk of design intentions being lost in translation, thus achieving client target satisfaction with fewer iterations required. By implementing this method at the start of the design process, the project could potentially be completed before the anticipated deadline, saving time and resources.

2. Research Observations and Objectives

The objective of this research is to understand the basics of color psychology and its significance from an architectural standpoint. Demonstrating an understanding of physiological and mental changes a person goes through when operating under different colored environments. To achieve this, research and data gathering is done to tie connections of these changes and draw conclusions. Understand what certain responses are feasible to measure and incorporate into this research and how these responses could be varied or interfered based on factors such as cultural background, general health, current mood and prior VR experience. The conclusion from gathered data is evaluated to understand how it is applicable to a more efficient design process in an architectural project.

3. Research Questions

There are multiple steps to understanding color psychology and measuring it in statistics, and conclude how this data is valuable to assuming preference. The following research questions will be addressed throughout this paper.

- In what ways does color affect humans on an emotional level?
- How does Virtual Reality compared to other forms of media consumption be more immersive and mentally impactful?
- In what ways do biometric readings represent mood and emotion?

4. Methodology

In order to develop a successful analytic tool, extensive research on color psychology is required to develop an understanding on how colors affect humans on an emotional level.

4.1 RECORDING PHYSICAL CHANGES AS DATA

The human body undergoes physical changes when affected by certain emotions. An understanding of how physical changes correlate to emotional changes is essential for the basis of this research. This ensures the data analysis to be accurate and strengthens the validity of the tool.

4.2 DATA GATHERING APPROACH

Once an understanding on physical changes are established, following is to determine the best approach to take in order to capture the most reliable data. The proposed media format has to be reasonably convincing to evoke

emotional response in order for the measurements to demonstrate significant trends and obvious indications. A range of options such as two-dimensional illustrations, three-dimensional rendering to full room-scale simulation will be considered.

4.3 DEFINING VARIABLES

To ensure accuracy of the recorded data, strict variables will need to be established. In the case of my experiment, the only variable that should change would be the environment color. This ensures the result comparison would only show differences of physical and emotional changes in reaction to colored environments. Other aspects of the experiment such as tasks the test subject are required to perform needs to be identical across all test trials. Randomness of generated content has to be kept minimal to avoid inconsistency.

4.4 DATA ANALYSIS

To properly draw conclusions from data analysis, data is gathered during multiple test sessions in different environmental color. Any extreme irregularities are removed from the data to produce more accurate trends. The data omitted will be declared and evaluated as to what caused such irregularities.

4.5 FACTORS OF INTERFERENCE

As emotional reactions to colors are greatly subjective that varies from person to person, it is unavoidable that biometric readings of physical reactions will show inconsistency in performance of the analysis tool. Interfering factors such as, cultural background, age, gender and general health are common in research that involves a high degree of subjectivity. Such factors will be considered during data analysis and any additional anomalies will also be addressed. It is important to note that these interfering factors causes less impact to results with an increased test pool.

5. Background Research

5.1 COLOR PSYCHOLOGY IN POPULAR CULTURE

The term color psychology refers to a range of affective, cognitive and behavioral responses to specific colors (Connor 2010 p. 230). It is not a foreign topic as the psychological effects of color has been documented with varying credibility ranging from mainstream media such as magazines and

blog posts to extensive scientific research. However as more researches are published over the years it may seem more recent articles contradict preceding claims. For example, studies suggested that red has a greater capacity for arousal than blue (Connor 2010 p. 230), while recent studies suggest that it might be the hue of the colors instead of saturation that causes arousal. Additionally, more recent studies claims that responses to color may vary depending on age, gender, culture and most importantly preference (Connor 2010 p. 230).

A rising issue with color psychology in popular culture is over generalization and credibility of claims (Connor 2010 p.229). These claims are often presented in a way similar to a scientific research, proposing in an authoritative manner while failing to address variance with subjective factors such as preference (Connor 2010 p.299). The underlying issue with color preferences lies mostly within social norms and modern trends. Mass marketing plays a significant role in setting current trends in fields such as fashion. For example, addressing the interference of gender, the color pink is considered feminine and fitting for female while blue is for males (Paoletti 2012). However this was not true up until the 20th century in the United States, as Paoletti suggested up until the end of World War II around 1950 that "There was no gender-color symbolism that held true everywhere." In addition to the social norms surrounding the color pink, it is considered to be a symbol of homosexuality as adopted by the LGBT community (Pullen 2010 p.101), which could sway color preferences in a design process. However in current trends it is sometimes seen as an elegant color on males, as demonstrated by various celebrities, thus swaying the general sentiment of the color in popular culture.

In the case of this research, and for demonstration purposes, colors chosen for the experiment should be contrasting as to increase the visible difference in gathered data. It is important to understand that certain colors have opposite psychological effects on different people. The meaning of color and associations are often mentioned along with a range of psychological effects along with biological and behavioral responses (Connor 2010 p.231). It is important to note these biological responses as it is the focus of this research's data gathering to draw conclusions on validity of the tool's ability to measure color preference. Examples of color association with biological response by Van Wagner, Logan Clarke, Appleby and Rewell are as follows.

- Red
    - Bright, warm color that evokes strong emotions

    - Intense or even angry color that creates feelings of excitement or intensity
    - Color of courage, strength and pioneering spirit
    - On the contrary, it is the color of anger, violence and brutality (e.g. the color of blood)
    - Red is energising and excites the emotions, and can stimulate the appetite
    - Stimulates the physical and adrenaline, raising blood pressure, heart rate and respiration
- Blue
    - In contrast to red, blue is described as a peaceful and tranquil color
    - However it can also create feelings of sadness and aloofness
    - It is calming, relaxing and healing
    - Blue causes the body to release tranquilising hormones (e.g blue sky) and is believed to lower blood pressure, slowing heart rate and decreasing body temperature

It is evident that the color red and blue are not only visually contrasting but evokes opposite biological changes, therefore it would be beneficial to include in the color pool of this research's experiment.

5.2 DESIGN RESEARCH METHOD

Since the purpose of this research is to propose and create a solution to the problem of client ambiguity, which lies within the issue of misleading color associations in popular culture. As mentioned above, color is a highly subjective matter in design, and while generalization can be made to a certain degree, it is still essential to understand the client's preferences on a minimum level. Referring to the above example, color association is often tied with biological reactions in both negative and positive ways. Therefore by designing a tool to statistically measure these positive and negative reactions, a conclusion can be drawn to accurately assume preference.

5.2.1 MEDIA FORMAT OF PROPOSED SOLUTION

Virtual reality for architectural visualization has become increasingly popular due to its versatility and ability to fully immerse the user in a virtual environment. However, to create an effective VR experience that properly evokes emotion, it has to be immersive. "The goal of immersive virtual environments (VEs) was to let the user experience a computer-generated world as if it were real—producing a sense of presence, or "being there," in the user's mind."(Bowman 2007) In the project's case, the goal is to direct

focus on the environment colors and not the level geometry, it is important to control these variables in testing. It is also important to note that "a realistic experience is no longer immersion's sole asset."(Bowman 2007) Immersion is a very broad term and different people immerse in environments more than others. Neither two-dimensional or even three-dimensional renderings of environments offer full peripheral vision coverage, as it has to be viewed from a screen or print out. VR surrounds the user's vision with full scale geometry and renderings, allowing for a higher level of engagement. The chosen experience will be a basic VR target shooter game, it requires little VR experience to fully grasp its intuitive controls. This is to eliminate any stress caused by confusing mechanics, producing a more accurate reading. The level design of the game will also be basic and bare-bones, reducing chances of the user reacting to the geometry and distracting elements instead of color, issues such as claustrophobia and acrophobia will also be addressed.

The concept of target shooting as a sport or a recreational activity such as carnival games and video games has existed for decades (Martin 2013). General game modes and rules are but not limited to accuracy, time trial and high score (Martin 2013). Playing a target shooter in a bare-bones form requires minimal prior knowledge to its mechanics, since the user is to only perform one task throughout the session, aiming and shooting. The fundamental purpose of a target shooter is to gauge player performance with statistical evidence. Given the simplicity of game mechanics and the long history of target shooting, it has seen widespread popularity across the world.

This research draws inspiration from various target shooting video games on their methods of measuring performance. The most notable example was Point Blank (also known as Gun Bullet), an arcade game developed by Namco in Japan. The game operates by having players use light guns to shoot targets, emphasizing on speed, accuracy and fast decision making. The game theme consists of cartoony aesthetics, being non-violent and all age friendly. This is an important aspect to consider when developing for this research, elements of the game ranging from targets to the player shooting device has to avoid interfering with the player's emotions.

6. Case Study

As stated above, the project design is a Virtual Reality target shooter experience, this section will address the following aspects of development.

- Hardware decisions
- Software decisions
- Game flow setup
- Game element decision
- Elaboration of project variables
- Data gathering and analysis

6.1 HARDWARE DECISIONS

Virtual Reality Head Mounted Displays, also known as VR HMDs have existed for decades with varying levels of graphical fidelity. In recent years VR technology has seen rapid advancement with the release of computer tethered units. This allows heavy tasks such as rendering and processing to be done externally on the computer, increasing graphical fidelity and decreasing bulk on the headset. The most widely adopted computer tethered HMDs currently are the Oculus Rift and HTC Vive. Both HMDs offer precise tracking and high fidelity displays, with the differentiating factor being software title exclusivity and 3rd party support. Therefore the Oculus Rift is chosen for its wide software compatibility and ease of use.

Figure 1. Oculus Rift Headset

Biometric sensors range from hobbyist to medical grade hardware, for demonstration purposes of this project, a hobbyist grade hardware is sufficient. The chosen sensor is a pairing of the Arduino Uno and the Pulse Sensor Amped. The Arduino offers high versatility with its open source ecosystem, allowing compatibility for various modules and software. This enables future upgrades and additions to the project such as sensing user

muscle activity via modules such as the MyoWare Muscle Sensor and electrodermal activity via the Grove GSR module.

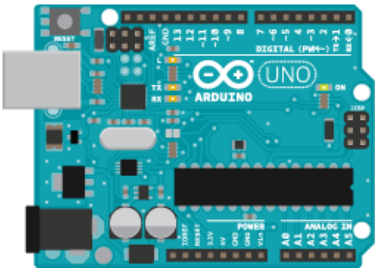

Figure 2. Arduino UNO chipset

Figure 3. Pulse Sensor Amped module

6.2 SOFTWARE DECISIONS

The software decisions for this project was a straightforward process. Unreal Engine offers native support for VR development and has numerous tutorials and support available. Therefore it was chosen for development of the VR experience.

The Arduino company offers the Arduino IDE, an open-source software for users to easily write and upload code to the supported Arduino boards. In addition, the software includes an output log for accessing measurements, therefore it has been chosen as the primary method of measuring biometric data.

6.3 GAME FLOW SETUP

The general game flow is separated into three stages. Preparation, action and conclusion. The preparation stage starts when the user puts the headset on and is given time to familiarize themselves with the controls. Once the user is ready to start, they aim at the start button on a nearby user interface and fire, starting the game. The user is then to shoot 30 targets that spawn with a 2.5 seconds interval, there is no time limit and once all 30 targets are

destroyed the game ends. Data is then collected and inputted into a spreadsheet in the conclusion stage. The duration action phase of the experience has to last long enough to gather enough data for an accurate calculation of average sums, as well as short enough to not cause fatigue to the user, posing potential risk to skewed results. 30 targets with a 2.5 seconds interval totals to 75 seconds of minimum game time, which allows for an accurate reading of heart rate BPM and ample time for user to prepare for the next target spawned.

Previous variations of the game displayed the user statistics next to the control buttons, this was later removed as it was not necessary for the user to see their performance statistics in real time, reducing any chance of distraction from the target shooting.

6.4 GAME ELEMENT DECISIONS

The game elements has been chosen carefully to remain as emotional neutral as possible to avoid causing interference.

Level design is the most important of all as it takes up the majority of the user's peripheral vision in the game. It is also the only changing factor across testing of different colors. The skybox consists of a solid color and a matching color is set for the ground. It is important to note that the ground color has to strike a difference from the sky to ensure the user feels "grounded" as to eliminate the risk of acrophobia, a common problem with VR experiences in general. The chosen skybox colors for this research is limited to blue and red for demonstration purposes. As mentioned above in the background research section, blue and red are contrasting colors in terms of psychological associations, and as such it should provide easily distinguishable differences in data analysis.

Figure 4. Chosen skybox colors for testing

User controls involve 2 Oculus Rift Touch Controllers to interact with the virtual environment. Each controller is mapped with either the shooting device or a virtual hand. It is important that the user is able to see both hands or at the very least visual representations in VR, this is to give the user a sense of "presence" as mentioned above in background research. Immersion

is an important asset in evoking emotion from the user. The shooting device is also carefully chosen to avoid hoplophobia, a term coined by Jeff Cooper to describe the "fear of guns and firearms" (Eimer 2013). Although the chosen model still resembles the shape of a firearm, the fictional sci-fi appearance should lower the risk of triggering the user.

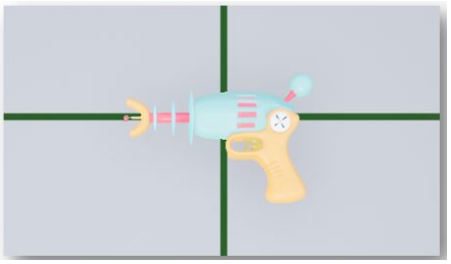

Figure 5. Chosen shooting device model

The targets model are designed to be simplistic and easy to see, chosen color is yellow as it is a color that draws natural attention and is easy to notice from a long distance, as evident in daily objects such as warning signs and traffic lights. The targets have to stand out to the user during gameplay, it should draw attention but at the same time not overwhelm the player.

Figure 6. Chosen model and color of targets

6.5 ELABORATION OF PROJECT VARIABLES

Variables are separated into three categories, dependent variables, independent variables and controlled variables.

- Dependent Variables: accuracy, session time, heart rate (BPM)
- Independent Variables: Skybox color, ground color

- Controlled Variables: Number of targets, all models used, game flow setup

The dependent variables are chosen to fully gauge user performance during the session. Each variable correlates with another for a much stronger analysis as each individual measurement provide vague or even misleading readings when focused on alone. Accuracy and heart rate has a direct correlation while total session time gives a general understanding of the session performance. When a person's heart rate increases, there are physiological changes such as increased adrenaline that affect motor function, causing accuracy to decrease. Session time allows for an overview of performance, whether the user is slowly shooting accurate shots or clearing targets faster but with increased missed shots.

Independent variables are limited to skybox color and ground color as the purpose of the experiment is to understand user reaction to color. As such these are the only variables that will be changed across different testing sessions.

Controlled variables consists of all other game elements as it is important not to have variance between testing sessions, eliminating the risk of the user reacting to changed game elements such as target shape and color.

6.6 DATA GATHERING AND ANALYSIS

In the case of this research, the data gathering is separated into a course of 5 days with 3 entries for each color per day, totaling to 15 sessions per color. Testing is performed on 1 subject only. Data gathering is distributed into multiple days on purpose to account for possible interference such as fatigue, current general mood and mental wellbeing. Accuracy is calculated using the formula below.

$$\textit{Accuracy in percentages} = \textit{total score} / \textit{total score} + \textit{shots missed} \; x \; 100$$

Shots missed is only recorded if the user misses a target, and begins counting when the user fires at the start button. Shots fired at in-game interfaces such as the start and quit button are also omitted from the counter.

Heart rate is calculated in Beats Per Minute and is updated every 2ms as written in the Arduino script. An initial reading is taken for 10 seconds during idle time before the user puts the headset on for before and after comparisons. An average is taken for both idle and session readings to consolidate results.

6.6.1 Analysis

For this research, gathered data is plotted onto frequency charts to demonstrate trends for comparison purposes. Each dependent variable is plotted onto separate charts for both blue and red tests.

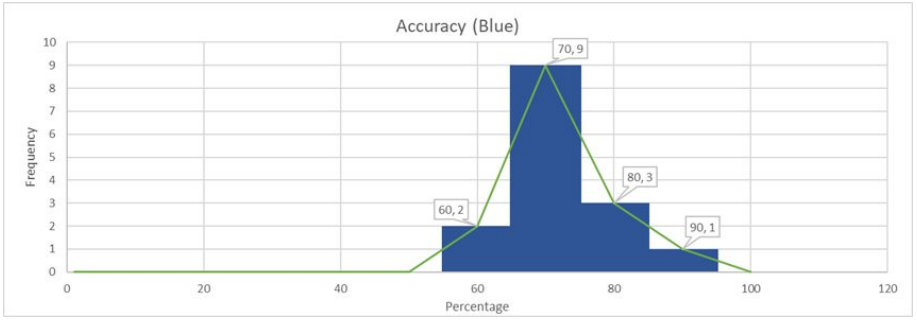

Figure 7. Accuracy in Blue skybox

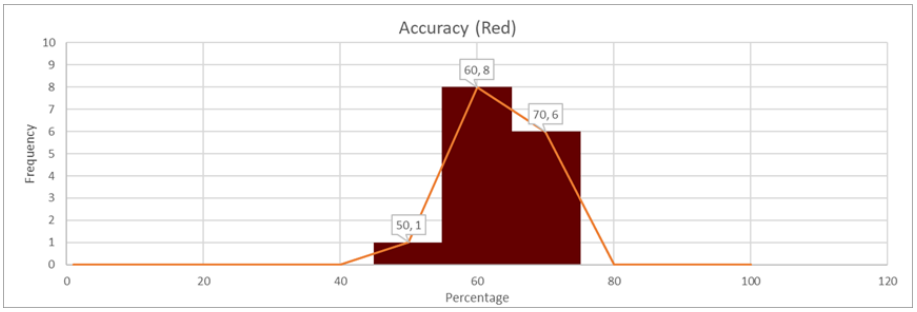

Figure 8. Accuracy in Red skybox

On initial observations, the average accuracy for blue skybox is around 70% while red skybox is around 60%. Although there is a sizable difference between the two, there are many interfering factors that could have affected results.

Figure 9. Idle Heart Rate in Blue skybox

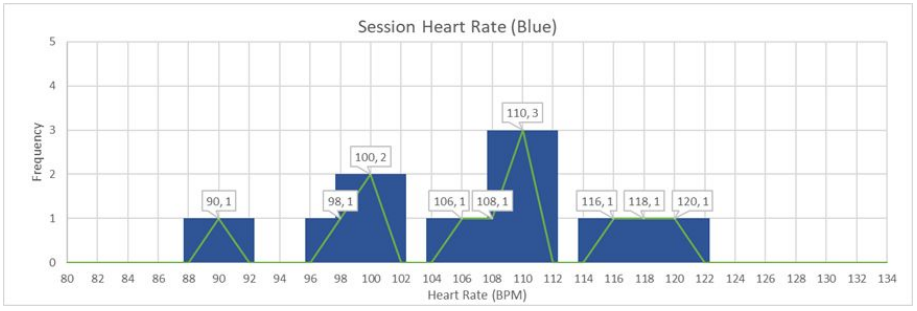

Figure 10. Session Heart Rate in Blue skybox

The increase of heart rate between idle and during session was evenly distributed between 90 to 122, where several sessions had overlapping results.

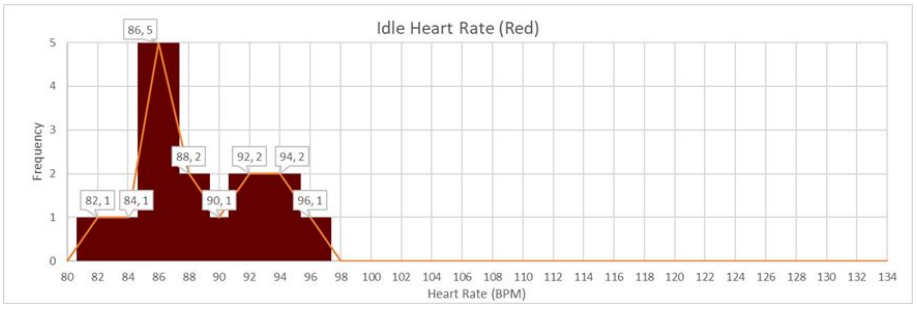

Figure 11. Idle Heart Rate in Red skybox

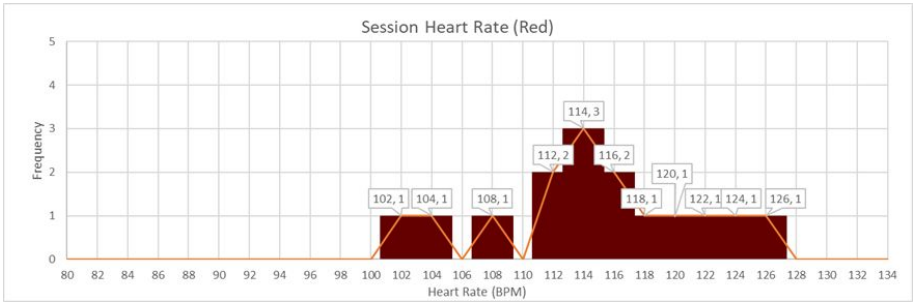

Figure 12. Session Heart Rate in Red skybox

Idle heart rate of both Blue and Red show no significant differences however session heart rate in Red skybox has a slightly larger gap between idle measurements. In conjunction with accuracy results, higher BPM correlates to lower overall accuracy due to the color associations of red. As stated above, the color red is warm and bright color that evokes emotion,

stimulating the physical body raising heart rate and respiration. Increased respiration is a likely cause that limits the user's ability to aim accurately. On the contrary, blue is a calming color and based on data observations the average heart rate much lower than red, which translates to slightly increased overall accuracy. However, since tests were not done consecutively, heart rate could be affected by general fatigue due to recordings at different times of the day. To avoid interfering with the distribution trends, sample size has to be increased significantly over a longer course of testing.

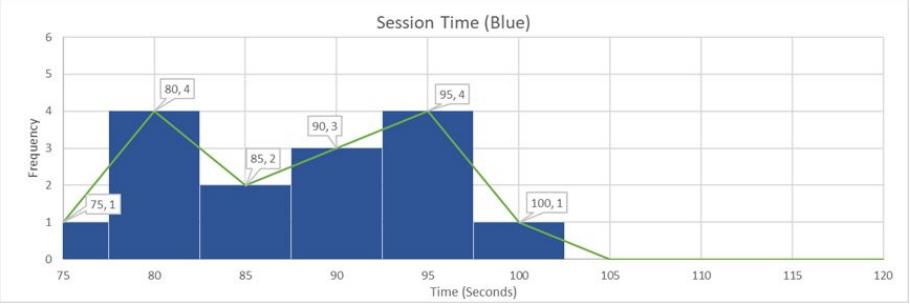

Figure 13. Session Time in Blue skybox

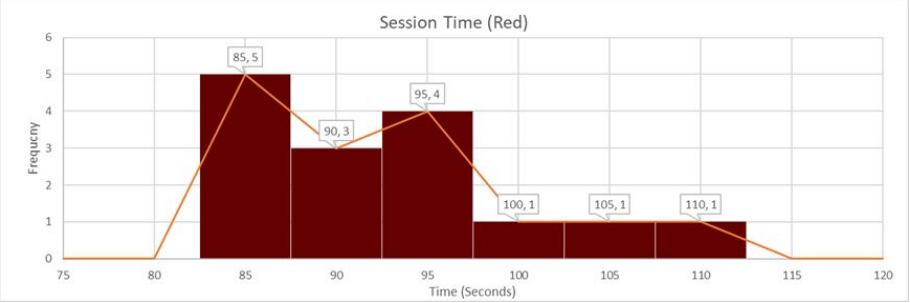

Figure 14. Session Time in Red skybox

The majority of results of both colors are mostly in the range of 80 to 100 with lower minimums in Blue skybox and higher maximums in Red skybox. This correlates with overall accuracy with the amount of time taken to destroy a target. Faster session times could be caused by accurate aiming as time to target destruction is lower and vice versa. However since there is no time limit in the game, the user could possibly take extended periods of time to aim slowly, increasing accuracy but increasing session time as well. In depth analysis of individual session results could be done to draw a stronger conclusion.

In conclusion, there are significant differences in performance between results in Blue skybox and Red skybox as demonstrated by frequency trends. The color red was proven to be more stimulating than blue, as evident in higher heart rates. Blue on the other hand was proven to be calming, with higher accuracy than results in Red skybox. In the case of the individual test subject, a safe assumption can be made that the person prefers the color blue over red as overall performance in a blue colored environment is slightly higher than red. However, with the low amount of test entries and rounded numbers in a frequency chart, the significance of differences could be less apparent when compared with raw data. In addition, a total of 4 entries were removed for hardware failures and 3 were removed for a mix of hardware and software related issue. The Pulse Sensor Amped showed readings for up to 240 BPM due to incorrect positioning on the finger and the VR application showed signs of framerate drops during testing. This is however difficult to identify the cause as it could be caused by numerous hardware and software instabilities. While 240 BPM is not an impossible heart rate for humans, the activities that causes such high heart rate to be reasonable are usually extreme sports or heart related health conditions. The VR experience in this case is a standing or sitting experience where scoring is lenient and therefore should not pose a huge amount of physical stress to the user.

7. Significance of Research

The world of Virtual Reality is still in early stages despite the rapid advancement of hardware in recent years. As such, the catalogue of VR applications are rather limited, even more so when searching for VR applications that incorporate biometric sensors into the experience. However, there is one case study that draws multiple similarities with this research. STRATA, the world's first VR experience driven by biometrics, created by a US and UK based studio The Mill (The Mill 2017). The company claims that the application uses "information-coded biofeedback" to teach individuals on changing physiological activities for the purposes of improving health and performance. Sensor technology implemented are electroencephalography headsets, or EEG for short, galvanic skin response sensors, heart rate monitor and a breathing measurement band custom created by the company. The basic gameplay or experience is a meditation and relaxation experience where the user immerses themselves into a VR world where geometry, color and sound morph depending on their biometric readings. This application has much higher user interactivity in terms of controls compared to other offers on the market. The method of success compared to this research is

slightly similar as biometrics are used to better understand the user and provide improvements.

8. Evaluation of research project

Despite the extremely early stages of the VR target shooting game, it has proven to be able to measure player performance differences across multiple tests in different colored environments. Multiple improvements can be made to further increase the accuracy of measurements for more reliable data. The shooting mechanic can be improved with better targeting indicators, to decrease the risk of the user missing shots due to misleading visuals. Overall optimization of the game can be improved for increased performance as frame rate is critical for VR experiences in general, low or inconsistent frame rate is a leading cause for motion sickness and breaking immersion. Biometric sensors can also be upgraded to more sophisticated data for more accurate results, hobbyist hardware such as the Arduino sensors are only capable of demonstrating a general range. Heart rate fluctuations varies on an individual level and more accurate results allow for precise comparisons even if the user shows no significant increase during a session.

8.1 LIMITATIONS IN DATA GATHERING

As mentioned above, the data gathering is only performed on one individual. While it is sufficient if the purpose in question is to design for one client only, an increased test pool is necessary if the target client is a mass demographic. By increasing the test pool, interferences such as cultural background, age and gender are reduced exponentially, producing a more convincing analysis. Furthermore, the assumptions on preference made above could be inaccurate as performance alone is not fully sufficient in drawing a strong conclusion. The color red as mentioned above could be both mentally empowering or causing anger and frustration. A post testing survey can be given to the user with questions such as, picking keywords from a list based on their mood during testing to further provide an understanding of user responses by matching the correct color association.

8.2 FUTURE IMPLICATIONS

Color compliments geometry in architecture, and could potentially present color with a different association based on geometry shape and sizes. Future additions to the VR experience can incorporate geometry as part of the testing process. Understanding how individuals respond to certain forms of

geometry is beneficial to a design process, saving time and resources in designing iterations by improved decision making.

9. Conclusion

In conclusion, the research questions listed above are answered in a satisfying manner. This research has demonstrated understanding of color psychology in general and identified the issues with generalization in popular culture. Through a Virtual Reality target shooting video game, the data gathered presents a strong demonstration of its ability to measure user color preferences through matching color associations and physiological changes through biometric readings. Data such as accuracy, session time and heart rate were gathered and averages were taken to demonstrate frequency trends. Through analysis a conclusion was drawn to safely assume a user's preference in color by their performance in testing. This method of data gathering provides a deeper understanding of preference and when applied to an architectural design process, it can potentially increase the efficiency in iteration design, saving time and resources through improved interaction between client and architect.

Acknowledgements

I would like to thank Ben and Nicole for directing me into a more worth topic of discussion, and also Hank and Alessandra for guiding me into creating a full VR application within the given timeframe.

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