ColorCode
Exploring Social and Psychological Dimensions of Color

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Abstract

Color representation have a great impact on the way we perceive information. The psychological influence of colors has been studied to improve the usage of color in the most various contexts, such as marketing and interface design. On the other hand, personality is a field of psychology which studies human character and behavior. The relation between personality and color preference has been theorized and studied. However, current research presents a lack of conclusive results. In this work, we cross personality data, not only with self-reported color preferences, but also with neurophysiological responses, overcoming the limitations of the current research. The results of this study suggested some trends on general preference and excitation levels, as well as on the influence of personality and color preference, and the influence of arousal on the preference between different Extraversion groups. These trends contribute for the improvement of color uses, in particular in the Human-Computer Interaction (HCI) field, based on personality.
Keywords: Color, Extraversion, Human-Computer Interaction, Neurophysiological data, Personality types

1. Introduction

Vision allows us to perceive the world around us and, for this reason, color has been extensively studied. Color is frequently used in various contexts, with different cultural meanings, being able to trigger on us different emotions. Therefore, it is of extreme importance to know how to take advantage of color in each specific context.

The connection between color and psychology, more specifically emotions, has been explored and applied to settings which can benefit from certain emotional states. In HCI, color can be an advantageous factor on affective priming. Personality is, as well as emotions, a field of psychology. Various theories on the relation of color with personality have been created, serving as basis to some personality tests based on color. Since these theories and tests have been used to define individual personality, some studies were performed to prove their validation. Using different personality tests, color tests and metrics, the results diverged. However, all of them had an aspect in common – subjects were asked about their preferences.

Color in different contexts may have different meanings and showing preference for a color may include an association to a concrete context. For instance, color in clothing may be strongly connected to culture and social image, not only with its effect on people's emotions.

We believe that, to study the influence of personality on color preference, we need to go beyond the rational self-report. Along this document, we will explore color and personality, as well as the studies performed to date. We propose a study that will try to clarify not only previous doubts but also answer to some questions formulated by us. Understanding the relation between color and personality may change the color usage in different contexts, in particular in HCI. Using the effects of color on different personality types may be the future of user-adapted interfaces.

Our goal with this work is to study the influence of personality in color preference. We focus on the relation between Introversion/Extraversion and color in terms of preference and emotional reaction. To this end, we needed to perform an extensive user study. This allowed us to collect personality and color preference data for a robust statistical analysis. With the results of our study, we were able to study the correlation between personality and color preferences, from which we intended to derive new guidelines for color uses, particularly in HCI.

The main contribution of our work consists in finding the following suggestions on the study results:

- General trends on the most and least liked colors, and more and less arousing colors, in general.
- Differences between self-reported and valence data.
- Influence of some Extraversion facets' scores in color preference and arousal level.
- Differences of most and least liked color between Extraversion groups.
- Influence of arousal in the color preference, per Extraversion group.
- Influence of Extraversion on the amount of colors liked and the preference intensity, by Extraversion group.

We believe these findings may be used to improve color usages, in particular in HCI, in general and based on personality.

2. Background and Related Work

In this section, we introduce the theoretical aspects of color and personality needed in the context of this work.

2.1. Color

Color is a sensation produced in the brain in response to the incidence of light on the retina of the eye [16]. In the retina, there are cones and rods: cones are active at normal light levels while rods are sensitive at low levels of light. Color vision in mainly based on cones' function. There are three types of cones, which are responsive to short, medium and long wavelengths [19]. The trichromacy theory states that the color vision depends on the activity of those three types of cones, each with different spectral sensitivities, and we need at least three different wavelengths (approximately represented by red, green and blue) to match any wavelength [20]. However, some people do not have all the cone types – that impairment is called color blindness.

Considering this, the RGB model was created and named after its primaries – the colors red, green and blue [19, 16]. CIE produced a set of recommendations on the use of three uniform color spaces - CIE L*a*b*, CIE L*C*h* and CIE L*u*v*. These three standards have some different properties that make them suitable for different tasks, so different industries can adopt the most appropriate standard [19]. In the CIE L*C*h* representation is represented by Lightness (L), Chroma (C) and the Hue angle (h). It is perceptually uniform, and based on how the human eye perceives color.

2.2. Personality

Personality has been studied for a long time: many models were created in order to explore this dimension of the human character. An extensive study of personality traits converged into the most widely accepted model these days – the Five-Factor model [9]. This personality model is based on five factors – Extraversion (E), Agreeableness (A), Conscientiousness (C), Neuroticism (N) and Openness (O) –, and defends that all personality types may be defined as the vector resulting of the combination of these five dimensions.

Extraversion is present in most personality classification systems, being considered as a continuum [13]. People with high Extraversion scores (Extraverts) tend to enjoy interacting with people and the exterior, since they seek energy in the outer world. On the other hand, recharging in their own world, people with low Extraversion scores (Introverts) have tendency to be more reserved. Therefore, as Introverts get easily tired from socializing, spending time alone drains Extraverts' energy. This can be explained by a difference of sensitivity between individuals. Introverts are more sensitive than Extraverts to sensory stimulation, getting overstimulated in social environments, while Extraverts need those environments to feel stimulated. However, it is unfair to label individuals only as extremes of the continuum that Extraversion is. Not everyone is a natural partygoer, nor a completely closed person. Some people have their own characteristics of Introvert and Extravert, laying in the middle of the Extraversion dimension – these individuals are called Ambiverts [6].

2.3. Preference and Arousal

When studying emotions through the dimensional perspective, one of the most common model used is the Circumplex Model of Affect [17]. Neurophysiological signals are commonly used in emotion related research, being Electroencephalography (EEG), Electrodermal Activity (EDA) and Heart Rate (HR) three of the most used signals to measure emotions.

Previous research has proved that valence may be measured through alpha wave asymmetry (using EEG) [5]. On the other hand, EDA and HR are widely used to measure arousal. In light of this, we will use these neurophysiological responses to measure preference and arousal.

2.4. Related Work

In some of his publications [2, 3, 4], Birren explores the relation of color preference with mental illness and personality. The most well-known theory correlates color temperature preferences with Introversion and Extraversion, defending that warm colors are usually preferred by Extraverts while Introverts prefer cool colors. The author explored these relations based on the effect that color stimulation has on humans and the way we interact with the world.

Several studies show that the association between color preference and personality, specifically Introversion and Extraversion, may be through color temperature. Some authors suggest repeating the tests with different conditions, due to the lack of rigor in some aspects, like the environment or the colors used for the tests.

We believe that the most important factor of all the studies explored in this document is the way the subjects expressed their preference for the colors. With or without a context, the individuals were led to choose the colors rationally. The rational factor does not include only the preference, but also the cultural and social context, as well as the emotional state. To focus on the preference only, the study would have to include detection and analysis of the effect of specific stimuli on the subjects. The detection could have been made by measuring neurophysiological signals as responses to the color stimuli.

3. Approach

In order to find an existing relation between personality – more precisely Extraversion – and color preferences, we needed to collect data related to both topics, following the procedure we describe next.

3.1. Required Data

For our study, we decided to collect the following data:

Profiling data Besides common demographic questions, such as Gender and Nationality, we also gathered data about each participant's self-reported Extraversion group, and their perception of color. To achieve the latter, we chose to perform a reduced version of the Ishihara color blindness test [12]. In case of color blind users, the data should be discarded or used as case studies.

Extraversion score data: Since it was essential to use a validated personality test, based on a widely accepted personality model, we chose the Portuguese version of NEO-PI-R[7], which is based on the Five-Factor model [9]. This inventory is composed by 240 questions

– 48 per personality dimension –, and it divides each dimension in six different facets. Extraversion, which is the only dimension we intend to study, is divided in the following facets: Warmth, Gregariousness, Assertiveness, Activity, Excitement Seeking, and Positive Emotion.

The length of the NEO-PI-R inventory is a major benefit of this test, since while performing longer tests the subjects tend to describe their actions and feelings more accurately, not being biased by what they think they are expected to answer. Moreover, it allows us to go deeper on the analysis of Extraversion, trying to find the influence of specific facets on color preferences.

Self-reported color preference data: Although we used neurophysiological data to indicate users' color preference, we considered important for this study to collect self-reported color preference data to explore the relation between rational and emotional responses to a set of colors. Collecting the self-reported preference allows us to draw a parallel with the previous works.

Neurophysicological color preference data: To collect the color preference through neurophysiological data, we needed to record the participants' responses to a set of colors. We decided to gather both the neurophysiological data and self-reported data at the same time, as response to each color of the set.

Since our goal is to know the subjects' preference for each color, our main focus for this work was the valence of the emotion felt when presented to each stimulus, which can be measured using alpha wave asymmetry on frontal channels of the brain, measured through EEG [1].

Previous research has supported valence theories that an increase in alpha wave activity is inversely related to cerebral activation, and higher activation of the right hemisphere is associated to withdrawal reactions [8, 5]. Therefore, greater alpha wave activity in the left hemisphere means a shift in cerebral activation to the right hemisphere and, consequently, a withdrawal reaction.

Since we would also like to discuss the excitation levels based on personality, we decided to collect information about the arousal induced by the color stimuli. We chose to record the participants' HR, which is a well known indicator of the emotional arousal.

3.2. Interface

In order to collect the data needed to explore the influence of personality in color preferences, we developed a web interface to be used during the user testing phase.

With the intention of collecting the users' profiling, personality and color preference data, we divided this test into 5 phases, being three of them questionnaires, one of them dedicated to the BITalino installation, and one merely informative. Each phase included an introduction screen explaining the task. When reaching these pages, the user was asked to warn the researcher, who would then explain the next task. We chose to to this predominantly through conversation, to bring the researcher and each user closer and more comfortable.

Since the personality questionnaire used was the Portuguese version of NEO-PI-R, the full test was developed in Portuguese. All the questions present in all questionnaires are mandatory.

The first phase of the test consisted in a profiling questionnaire. In the first half of the profiling questionnaire, we included basic profiling questions. This questionnaire included the fields: “Age”; “Gender”; “Nationality”; “Education”; “How do you rank your personality in term of Extraversion?”; and “Have you ever had your neurophysiological responses collected?”

The second part of the profiling questionnaire consisted in a six plate version of Ishihara's color blindness test [12]. Following the author's instructions, the six plates chosen for the simplified version of the test were: 1, 2, 7, 8, 10, and 15. Each of these plates is a question which can be answered by typing the number seen on the plate or selecting the button “It is not a number”.

After submitting the answers to the profiling questionnaire, the subjects were directed to the personality introduction page, which leaded them to the personality questionnaire (NEO-PI-R).

We selected the 48 questions relative to the Extraversion dimension. We presented those question to the subjects, to which they could answer in a five point Likert scale [11], from “Strongly Disagree” to “Strongly Agree”. Since this test could not be changed due to copyright, this Likert scale served as basis for the Color Preference Test (CPT), in order to maintain the study coherence.

Each question was implemented as a multiple choice question, in which the users clicked the most adequate button to choose the most reliable answer. The questions were also numbered in ascending order, so we could easily identify missing answers and alert the users.

The next phase was BITalino installation and calibration. The user was introduced to the neurophysiological signal recorder for the first time in the test.

The calibration phase had extreme importance in terms of data gathering, since it served as baseline for the extraction of arousal for this study, which is fundamental to calculate the HR change for each color, per user. Our main goal was to induce a relaxed emotion, having in mind not only their previous emotional state but also the study conditions. We chose to include in our calibration phase images from the International Affective Picture System (IAPS), a research image dataset developed to provide a set of normative emotional stimuli for experimental investigations of emotion and attention[1]. The pictures used for this study are all of them representative of flowers and landscapes, since they are considered pleasant and relaxing, in terms of valence and arousal respectively [15, 14]. During this calibration phase, each image of this set was shown for 20 seconds, and the set was displayed twice in loop, having this phase the total duration of 4 minutes. This way, each visual stimulus is long enough for the user to get used to the image while being induced to the relaxation state.

For the fourth phase, the CPT, we decided to use a set of colors defined to be used in Information Visualization, which includes the colors: red, orange, brown, yellow, green, cyan, blue, purple, pink, white, gray, and black [19].

For this test, we considered the stimulus period of 5 seconds per color, during which the color occupied the

[1]http://csea.phhp.ufl.edu/

full screen, with nothing beside a white circle in the middle of the screen. This circle was added to the interface in order to avoid ocular movements and artifacts on the EEG recordings, which could affect the resulting data.

After these 5 seconds of stimulus, a preference scale appears on the lower half of the screen. In this scale, the user should rate the presented color from "Strongly Dislike" to "Strongly Like", similarly to the scale used for the personality questionnaire. Ten seconds is the duration that the user has to rate each stimulus, which is enough time to click in the felt preference, without thinking too much about the emotion felt.

A black screen is presented between colors, to separate the stimuli. This screen is shown for a period of 5 seconds and, as well as each self-report screen, included a countdown of the remaining time until the next stimulus.

This black screen was added after performing the pilot tests, since the afterimage effect was detected between some colors. Since we are using the RGB color model – an additive model –, black represents the absence of color, being the best color to minimize the visual artifacts between stimuli.

The final version of this test on the interface consisted in 12 colors shown for 15 seconds each, separated by a black screen for 5 seconds, resulting on a fixed duration of 4 minutes. The order of the stimuli inducted is random, to avoid emotional responses influenced by the previous stimulus. This is true for all the colors except black, which is always shown as the first color. We were looking forward to avoid the user's misconceptions possibly caused by the separation black screen.

When the user reached the appreciation page, their test was considered as complete. Then, we thank the subject for participating in the study, giving them the option of reviewing their personality test result.

This review presents to the users their Extraversion scores – dimension and its facets –, using percentage bars. We also included the descriptions of the Extraversion values, based on the NEO-PI-R Manual [7].

3.3. Apparatus

As this work consists on studying social and psychological dimensions of color to derive new guidelines for color uses, particularly in HCI, the development of the interface, the execution of the user tests and the data processing required specialized apparatus.

During the tests, we used used the toolkit BITalino[2], connected to a personal laptop, to collect the neurophysiological recordings, while the user performed the test using an auxiliary computer.

The BITalino (r)evolution Plugged Kit BT, used in our work, includes Electromyography (EMG), Electrocardiography (ECG), Electrodermal Activity (EDA), Electroencephalography (EEG) and pulse sensors among other components. In this research, we focused on collecting neurophysiological responses which could be used to compute emotional valence and arousal. To this end, we used the pulse sensor to collect Blood Volume Pulse (BVP) – later converted to HR, which is a well known indicator of arousal –, and EEG, from which emotional valence may be extracted.

[2]http://bitalino.com/en/

This setup was used for all the participants to maintain the coherence of the study. For HR, we used the pulse sensor (composed by an ear clip and a sensor connection cable) clipped to the user's right earlobe. For EEG, we connected three gelled self-adhesive disposable Ag/AgCl electrodes to a 3-lead accessory, linked to an electroencephalography sensor, which is plugged to the BITalino board using a sensor cable.

The 3-lead accessory identifies the EEG electrodes with the colors black (negative), red (positive), and white (reference). This also allows us to work with a bipolar configuration, in which the red and black electrodes detect the electrical potentials in the specific scalp region with respect to the white electrode, which is placed in a region of low muscular activity. The resulting signal is the amplified difference between these two signals ($red - black$), eliminating the noise detected by the third electrode.

The black and red electrodes were applied on the left and right sides of the user's forehead, respectively, and the reference one behind the ear, a zone of neutral brain activity. Since BITalino measures EEG using differential amplification, it is important that both black and red electrodes are placed in the same place of the user's head, but in opposite brain hemispheres, to measure the brain activity difference between hemispheres. Thus, we used the nose and the eyebrows as reference points, applying each electrode one finger above the side eyebrow and one finger from the nose line.

3.4. Software

For the neurophysiological recordings, we used the OpenSignals (r)evolution[3], developed to visualize and record signals from BITalino. We used the Public Build 2017-08-28 version of this software.

After gathering all the recordings, we used the BioSPPy toolbox, (version 0.4.0). This toolbox was developed to process biosignals such as BVP, ECG, EDA, EEG, EMG and Respiration, allowing feature extraction from these signals. For this work, we used it to extract the alpha waves from EEG and HR from BVP.

Lastly, for data organization and statistical analysis, we used Microsoft Excel 2013[4] and IBM SPSS Statistics 25[5]. Since our work leads to the derivation of new guidelines for HCI uses, a detailed statistical analysis was required. These software programs were used to normalize and organize the data, apply specialized statistical tests, and drawing charts representative of our results.

4. Data Collection

In this section, we describe how we gather, organize, process and interpret the data.

4.1. Data Gathering

When developing a coherent study, it is essential to guarantee that the conditions are the same between users. To achieve this, a Study Protocol was created, describing all the steps each user test should follow. Before proceeding

[3]http://bitalino.com/datasheets/OpenSignals_Datasheet.pdf
[4]https://products.office.com/en-us/microsoft-excel-2013
[5]http://www-01.ibm.com/support/docview.wss?uid=swg24043678

with data gathering, the planned procedures were tested through pilot tests, which led to an improvement of the study protocol before its final form.

The user testing phase occurred between November 26th 2017 and January 26th 2018, in room 1-23 in Instituto Superior Técnico (IST), Taguspark campus. Belonging to the Visualization and Intelligent Multimodal Interfaces (VIMMI) research group, the room where the user tests took place was already prepared for a controlled laboratory environment, having controlled temperature and lighting conditions. These were crucial points of the protocol, since the test included recordings of reactions to visual stimuli and personal information sharing. It was also important to prevent the presence of others during the tests, which was also successfully achieved.

Since this work is a study whose results are of extreme importance for HCI and interface design, it was crucial to collect a considerable amount of data to make the statistical treatment as robust as possible. Therefore, the testing phase counted with 50 users – equal amount of women and men.

The user tests were directly related with the interface developed, using specialized apparatus and software, all explained in detail in Section 3. Each test was divided in the five phases. Each phase included an introduction speech, during which the user was clarified about the task. The tasks were followed as previously shown. At the end of the test, the researcher thanked the user's participation in the study, giving them a symbolic reward.

The majority of the data was directly collected through the interface, while the subjects answered the questionnaires during the user tests. To this end, and in order to create the best data organization, we created a MySQL database, dividing the data in several tables. During the data processing phase, other tables were created in order to organize the neurophysiological data, for further use in statistical analysis. Lastly, new tables for each neurophysiological response type were created, containing the normalized neurophysiological data.

4.2. Data Processing

After collecting the responses saved from the user tests through the interface and the subjects' neurophysiological responses, we proceeded to processing the latter in order to extract the data needed in their final form.

Collecting the neurophysiological responses using Opensignals, the data is saved in a plain text file, containing an information header and a set of columns below, representing the sample sequence number generated on the device, state of the digital input, state of digital output and raw data sampled by the device through the chosen channels.

The values sampled from each channel are the result of the conversion of the analog signal to the digital form. To process the data in its Analog-to-Digital Converter (ADC) form, the first step is to divide the raw data files into a file for each channel, to convert the ADC values to EEG values (in microvolt). On the other hand, the ADC values of BVP are already ready to be converted to HR. To get a baseline for arousal, these BVP values were also recorded while inducing a neutral emotional state in the user. Then, a selection was performed from the resulting data, being saved 60 seconds of the BVP neutral data, and 4 seconds per color stimulus, per user. We needed the baseline to be as solid as possible for each user. Since the neurophysiological responses were recorded and sampled while the user was relaxing observing a set of neutral images, some emotions could be induced in some user by specific images. In order to avoid this, in that 60 second period, three to four different images were shown to the user, giving us a stronger baseline for HR.

On the other hand, we needed to divide each CPT recording by color, saving then 4 seconds of each color stimulus, corresponding to the period when the user focused on the white circle on the screen, to avoid ocular movements and blinks.

During the data selection we faced some challenges, such as in the synchronization phase between the time the user started the tasks and the time saved by OpenSignals when recording the neurophysiological responses. Both times were saved previously, to ease this synchronization. However, an issue was detected when we realized that, for some cases, the difference between starting times was longer than ten minutes, when the recording was shorter than five minutes. In other cases, this difference was negative, pointing that the users started the test before the researcher started recording the neurophysiological data through OpenSignals. It should be noted that the User Test Protocol was followed equally for all the tests, meaning that this difference could never be negative. The solution found for this challenge consisted in using OpenSignals to find the stimuli starting time manually, by detecting eye movement trends in the signal visualization.

To extract the intended features from the neurophysiological data collected, we used the BioSPPy toolbox[6]. We obtained HR from BVP, and the theta, alpha high, alpha low, beta and gamma brain waves from EEG.

For arousal, we have chosen to compute the HR change from a baseline value. We extracted this feature from each user's BVP files – resulting from the neutral and color selection –, using BioSPPy. Then, we calculated the median value from the values resulting from the output files. The last step was to find the difference between the baseline value and each color value. For valence, we performed slight changes to the BioSPPy script. Since our intention was to extract the alpha waves, we added a new range of frequencies. Since the alpha low waves have average power in the 8 to 10Hz frequency band, and alpha high waves in the 10 to 13Hz frequency band, we added the extraction of alpha brain waves with average power in the 8 to 13Hz frequency band.

Using this modified version of BioSPPy, we were able to obtain an output corresponding to the whole range of frequencies of the alpha brain waves. Following what we previously did for the HR values, we calculated the median value for each color, considering it as the value of the alpha right-left asymmetry, representative of approach/withdrawal responses [5]. The choice of using a median value for these final values was made having

[6]https://github.com/PIA-Group/BioSPPy

in mind that median is the measure of central location which is less affected by outliers [10].

4.3. Data Interpretation

The next step was to interpret the data. The responses collected through the questionnaires that need further interpretation are the answers to the Ishihara color blindness test and the personality questionnaire. Both of them were interpreted following the instructions given on their manuals.

In terms of the neurophysiological data, we mapped it into valence and arousal scales. Since we are using a standard scale along the development of this work, in which the Extraversion score and the self-reported color preference are already mapped, we chose to use this scale for the data normalization – from 0 (minimum value) to 4 (maximum value).

Since we are dealing with neurophysiological responses, which may vary from subject to subject, we chose to normalize the data per user, having into account their individual responses. To this end, and having the final values of the Alpha waves values extracted from EEG and the HR difference for each color, we started by identifying each user's minimum and maximum values for both these features. We then proceeded to normalize the values applying the following function:

$$normalizedValue = \frac{(value - userMin) \times 4}{userMax - userMin}. \quad (1)$$

Although we are aware that some data may be affected by the use of this normalization, since the user may have no color which they strongly like or strongly dislike, we believe this is the best approach because it depends on each user values only, preventing the data impairment caused by other users' neurophysiological responses. Also, normalizing the values on this stage of the data interpretation, before the statistical analysis, allows us to have more reliable values to compute valence and arousal median values per color.

5. Results

In this step of our work, we studied the data by observing trends and applying widely used statistical tests, to explore the influence of personality on color preferences.

5.1. User Profiling

Although 50 people participated in the user testing phase of this work, we faced some issues with the neurophysiological data collected for one participant. When processing their BVP recordings, it was not possible to compute HR due to lack of heart beats detected in the signal. Therefore, we did not use this user's data for our study, making the decision of slightly compromising the even balance we had when gathering the data to get more reliable conclusions from our study. Nevertheless, we succeeded in guaranteeing a significant number of subjects participating in our user tests. The study counted with the participation of 49 subjects, 49% females and 51% males, with ages between 18 and 45 years old (only two participants were older than 35 years old). All the participants had Portuguese as their mother language, having the great majority of the users Portuguese nationality (around 90%), while the remaining subjects were Brazilian. In terms of education, around 78% of the subjects had an academic degree (Licentiate or Master), while 20% had a high-school degree, and only one participant had upper secondary education level. For the majority of the users (80%) it was the first participation in tests with neurophysiological recordings.

Regarding Ishihara's color blindness test [12], five subjects failed to answer the six plates correctly. However, a pattern was found among these subjects – all of them failed only one of the plates, considering the forth plate as not being a number instead of being the number 6, or finding the number 4 in the last plate, where no number should be found. Following the guide instructions to detect color blindness, these mistakes could suggest these subjects had red-green deficiencies. The author states that for the forth plate, the subjects with these deficiencies find no number, while for the last plate, they find the number 45. However, these types of deficiency would affect the users' capability of recognizing the numbers on the remaining plates correctly. Since this was not true for the participants who failed the six-plate color blindness test, we did not consider these subjects as color blind, thus including their results in this study.

5.2. Extraversion

Extraversion, was collected in two forms: self-reported data, through the profiling questionnaire, and personality data, through answering the NEO-PI-R reduced to Extraversion.

When asked to which Extraversion group they belonged, 29% of the subjects considered themselves as Introverts, 37% saw themselves as Ambiverts, 33% said they belonged to the Extraverts' group, and one participant did not know which group they belonged to. However, these results proved to be different from the personality questionnaire results. After performing the division of the users by Extraversion groups, the personality questionnaire shown that: 18% of the users were Introverts, 65% were Ambiverts, and 16% Extraverts.

Comparing the self-reported and the personality data, we observed that 63% of the users got their Extraversion group right, while 14% reported themselves to belong to a lower Extraversion group, and 20% thought they belonged to a higher Extraversion group than the actual one. Among the Ambiverts, around 19% wrongly classified themselves as Introverts and 28% as Extraverts. These results suggest that:

- The facets of Extraversion with higher scores are Warmth (Mdn = 2.75) and Positive Emotion (Mdn = 3.00).
- The facets of Extraversion with lower scores are Gregariousness (Mdn = 1.88) and Assertiveness(Mdn = 1.75).

Shapiro-Wilk normality test was then applied to Extraversion dimension and its facets, having shown that the Positive Emotion score is the only data which does not follow a normal distribution (p = .001). Therefore, to maintain the study coherence, nonparametric tests will be used for further analysis of the relation between Extraversion and Color.

5.3. Color

We collected data referring to self-reported score, valence score through alpha wave asymmetry, and arousal score through HR.

The descriptive statistics for the color preference self-reported scores suggest that:

- White (Mdn = 3.00), gray (Mdn = 3.00) and black (Mdn = 3.00), colors with no saturation, are three of the most preferred colors.
- Among the remaining colors, orange (Mdn = 3.00), cyan (Mdn = 3.00), and purple (Mdn = 3.00) have the highest scores.
- The colors with lower scores are yellow (Mdn = 1.00) and green (Mdn = 1.00).

Since the Shapiro-Wilk test showed an evidence against normality for all the colors in all samples – except for arousal scores of orange (p = .067) and brown (p = .071) –, a Friedman test was used, showing that, for self-reported color preference, there is a significant difference between the color scores ($\chi^2(11)$ = 69.292, p = .000).

In terms of the valence scores, resulting from the alpha wave asymmetry, the descriptive statistics suggest that:

- Black (Mdn = 2.14) is the most liked color.
- Blue (Mdn = 1.57) and white (Mdn = 1.48), are the most preferred colors after black.
- The least liked colors are orange (Mdn = 1.15), and cyan (Mdn = 1.17).
- Cyan is the only color which was not considered a favorite color.

Performing the Friedman test we found that there is no statistically significant difference between the scores for valence, gathered through alpha wave asymmetry (p >.05).

Both self-reported data and neurophysiological data were collected with the intention of comparing the color preference stated by the users and their neurophysilogical responses. Since the self-reported preference was ranked in a Likert scale, and valence was measured in a continuous scale, we rounded the valence scores. The comparison of the self-reported scores and the valence round suggests that:

- Yellow, green and blue have equal median scores of self-report and valence, suggesting that the self-reported preference for yellow, green and blue is the most legitimate.
- Orange, cyan, purple, white and gray are the colors for which the self-reported preference is further from the neurophysiological preference, since they show the biggest difference between median scores.

Since the distributions present evidence against normality, a Wilcoxon signed ranks test was applied between the self-reported score and the valence score, per color. This test showed that there is not a statistically significant difference between the self-reported and valence scores for the colors yellow, green , pink, and black. From the results with a statistically significant difference, blue is the color with closest scores of self-reported preference and valence (Z = -2.010, p = .044, r = -.287). On the other hand, cyan is the color with biggest difference between scores (Z = -4.246, p = .000, r = -.607). The test shows that, for all the colors proved to have a statistically significant difference, the users tended to self-report their preference higher comparing to their feelings.

Lastly, the descriptive statistics resulting from the color arousal scores, through HR, suggest that:

- Red (Mdn = 2.26) is the color which induces most arousal.
- After red, orange (Mdn = 2.00) and black (Mdn = 2.07), are the most exciting colors.
- The color with lowest arousing properties is white (Mdn = 1.59).
- Blue (Mdn = 1.59), and purple (Mdn = 1.14) are the most calming colors after white.

5.4. Color and Extraversion

Our main goal with this work was to study the influence of personality on color preference. The first step was trying to find a correlation between Extraversion and color scores. Since the Shapiro-Wilk tests performed showed an evidence against normality in the majority of our data, we applied Spearman's correlation test.

Some correlations were found between self-reported and arousal scores and Extraversion (dimension and its facets), but focused mainly on valence correlations. The Spearman's tests found only two correlations between valence and Extraversion: medium, positive correlation between Assertiveness score and the preference for color white (r = .354, p = .013), and a medium, negative correlation between Activity and black (r = -.288, p = .045). All the other tests proved no statistical significance on the correlations.

The nonparametric Kruskal-Wallis H rank-based test was then used to find differences of self-reported, valence and arousal scores between Extraversion groups, per color. No statistically significant differences were found, except for the color pink, when comparing valence scores between Introverts, Ambiverts and Extraverts. The mean ranks for this color were, respectively, 13.39, 29.20, and 21.25.

Since we cannot draw conclusions on these results, we tried to find tendencies in the data through descriptive statistics separated per Extraversion group. The results suggest that:

- Introverts' most liked color was cyan (Mdn = 2.16), followed by brown (Mdn = 1.53), while their least favorites were pink (Mdn = 0.86), gray (Mdn = 0.89), and orange (Mdn = 0.93).
- Ambiverts' preferred colors were black (Mdn = 2.40), pink (Mdn = 1.78), and blue (Mdn = 1.76), being cyan (Mdn = 0.96) and orange (Mdn = 1.10) the least liked colors.
- Extraverts preferred orange (Mdn = 2.43), black (Mdn = 2.35) and gray (Mdn = 1.47), disliking brown (Mdn = 0.89), pink (Mdn = 0.83), and white (Mdn = 0.89).

- The highest score median values belong to orange, rated by Extraverts, and black, rated by Ambiverts.
- The lowest median scores was given by Introverts and Extraverts to the color pink.
- Roughly comparing to the score value 1.50 – score that, when rounded to the Likert scale used for the self-reported preference, corresponds to neutral preference:
  - Introverts scored one color with a higher score, eight colors with a lower score, and three matches.
  - For Ambiverts, four colors were scored higher than that value, six were scored lower, and two matched that value.
  - Extraverts liked five colors more, six colors less, and one the same.

When observing trends in the descriptive statistics of the arousal scores between Extraversion groups, we saw that:

- Introverts showed to be easily aroused by black and red, contrarily to white and blue.
- Roughly, the Ambivert group had Neutral median scores for all colors.
- Red, orange and purple are the most arousing colors for Extraverts, while white and brown are the least.

5.5. Discussion

Although some results were not statistically significant, we worked on finding tendencies in the data. Having said this, it would be interesting to perform a study with a bigger, more diverse sample. Our sample had some limitations in terms of diversity, particularly in terms of age, nationality and Extraversion group. Since this study was performed in a university, the majority of our users were students, being that the reason why the majority are aged between 18 and 35 years old. In terms of nationality, the sample was restricted to Portuguese speakers, due to the personality questionnaire used being written in this language. The last limitation is the hardest to overcome, since the Extraversion group is assigned after completing a personality questionnaire, during the user tests. However, the more subjects participate in a study of this kind, the greater are the chances of getting a more balanced sample.

Regarding the distribution of our sample by Extraversion groups, the majority of the subjects were Ambiverts. This was expected, since Extraversion facets are very diverse and to get a higher score of Extraversion implies having a higher score in all of the facets, and the opposite for lower scores.

From this Ambivert group, almost half of the subjects classified themselves as Introverts or Extraverts. One of the reasons why this happens is because people are used to see Extraversion as a scale divided in two halves – Introverts and Extraverts. This was also noticed by the researcher, since during the user tests a large amount of subjects asked the meaning of “Ambivert”. Another cause is that rating personality on a scale is not an easy task, even more when people tend to associate Extraversion with social behaviors, underestimating facets like Activity and Positive Emotions. Lastly, the division thought of when self-reporting their Extraversion group may differ between users, since there is no validated division between the three groups.

In this work, RGB was the model used to develop the interface, including the CPT. However, we will base our discussion mainly using the CIEL*C*h* color representation, since it is perceptually uniform and based on how the human eye perceives color [19]. It also has a main advantage: it allows us to isolate the Hue channel, which we proposed to study in this work.

When focusing on color preference – self-reported and obtained from neurophysiological recordings –, the data suggested that both results varied depending on the color. For instance, in general, white and black were considered two of the most liked colors through both self-report and valence scores. They are neutral colors, with both hue and chroma values 0, but opposite Lightness values. These results suggest that the general color preference is not based on the Lightness channel.

On the other hand, we can see that the most liked color – blue –, and some of the colors self-reported as most liked – gray and purple – have medium-low Lightness (30-50), while all the least liked colors – yellow and green through self-reported, orange and cyan through valence scores – have high Lightness levels (>70). We also found that orange and cyan, considered two of the most liked colors through self-report, were, in fact, the least liked colors, and nothing besides the Lightness level differs from the most liked colors.

Overall, the results suggest that Extraverts and Ambiverts like a larger amount of colors than Introverts, supporting Birren’s theory [2, 3, 4]. It is also suggested that Extraverts’ scores tend to be higher than Introverts’.

In terms of arousal, derived from HR, the results suggested that the most arousing colors are red, orange and black, while the least arousing colors are white, purple and blue. In terms of color preference, white and blue – and purple, though self-report – are least arousing and have higher scores in terms of preference, while orange is one of the most arousing and least liked colors. Although red was not considered one of the most liked, neither one of the least liked colors, the results suggest that people, in general, tend to prefer least arousing colors.

In Fig. 1, each color with Chroma different from 0 is represented in terms of median score of arousal and Hue. Observing the chart, we can notice that, following the Hue degree, the arousal level starts high (red) and decreases until its lower level (blue and purple) and then starts increasing again. Since Hue is represented as a circumference, where 360º is equivalent to 0º, the color pink is closer to red. These results also suggest that cold colors are least arousing than warm colors.

The only color whose result stands out while observing Fig. 1 is brown, being a warm color and one of the least arousing colors. Besides the Hue tendency found, this color has something in common with the other two least arousing colors (blue and purple) – the Lightness. Except for black, these are the three colors with the lowest levels of Lightness (brown = 34.51, blue = 32.30, and

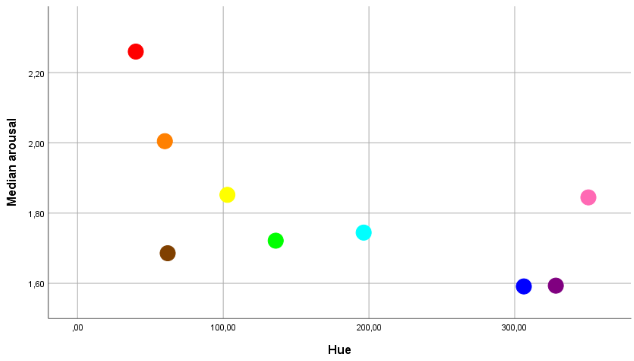

Figure 1: Median arousal levels of the colors by hue.

purple = 29.78), suggesting that colors with lower lightness are less arousing colors.

On the other hand, black (Lightness = 0) was considered the second more arousing color, following red. It is possible that this value is influenced by the fact that black was the first color shown to all the users. Since the first color is the first time the user deals with the test, understanding visually the explanation given by the researcher before, this can generate a higher level of anxiety. However, this result coincides with previous research, where black was proved to have the greatest arousal level, when comparing achromatic colors through self-reported ratings [18].

With respect to the correlations studied between Extraversion scores and color preference, the statistical tests revealed that the more assertive a person is, the more they like white, and the more active a person is, the less they like black. Since both are achromatic colors, the only difference between these two colors is Lightness. Having in mind that excitement seekers seek higher arousal levels, we expected to find a positive correlation in terms of preference between Excitement Seeking scores and colors with higher arousal level, which was not found.

Since the majority of the statistical tests results were not statistically significant, we observed trends in data. Orange and gray showed to be two of the most liked colors for Extraverts, while being two of the least liked colors for Introverts, and the opposite happens for brown. On the other hand, the most liked color by Introverts (cyan) is not disliked by Extraverts, and the second preferred color for Extraverts (black) is not disliked by Introverts. Having said this, we can not claim that Introverts and Extraverts hate each others' most liked colors. However, the results suggest that Introverts and Extraverts do not share the same favorite colors, and their most liked colors – cyan for Introverts and orange for Extraverts – are opposite in the color wheel.

Comparing color preference between Extraversion groups, Introverts and Extraverts show opposite preference for some colors. For orange, brown and purple, the preferences show an increasing or decreasing tendency. However, the Ambiverts' preference for those colors is not always between the two extreme groups. The statistical analysis showed that the Ambivert group appreciate pink more than Introverts and Extraverts. Having this in mind, it would be interesting to go further on studying Ambiverts' preference.

Speaking in terms of color temperature, we can see that Extraverts' favorite color (orange) is a warm color, while Introverts' favorite color (cyan) is a cool color, which is consistent with Birren's theory that warm colors are usually preferred by Extraverts while Introverts prefer cool colors [2, 3, 4]. However, this is not true, for instance, for brown (warm color), which is one of both Introverts' most liked and Extraverts' least liked color.

In terms of arousal, the comparison between Extraversion groups revealed that all the groups considered red one of the most arousing colors, and white one of the least arousing colors. As well as preference, some colors have opposite arousing effects in Introverts and Extraverts, but there is not always an increasing or decreasing trend.

However, the results suggest some trends between the arousal levels and preferences by Extraversion groups. For instance, none of the colors that caused more arousal on Introverts is one of their favorites. Supporting this, there is a color (gray) which is one of the most arousing and least liked by Introverts. The opposite happens for Extraverts – their most liked color is one of the most arousing colors for the group, while white is considered a relaxing color and one of their least liked. Since Extraverts tend to seek for outside stimulation, while Introverts tend to protect themselves from that stimulation, this finding matches the characteristics of Extraversion.

6. Conclusions and Future Work

Color and personality have been widely studied, being of extreme importance in human life. While personality studies try to define a representation of human character and behavior, the research on color tries to understand visual perception and how color influences our lives.

Nowadays, graphic displays are widely used to accomplish the most varied tasks. Therefore, it is crucial to understand color and study the most appropriate ways of representing color in these devices, in order to represent information clearly.

This work has allowed us to study valence and arousal of color stimuli, not only in a general way but also in terms of the personality dimension Extraversion. We found that users with different Extraversion levels have distinct emotional reactions to color stimuli. We also found that, depending on the personality traits, the approach/withdrawal reaction to the stimuli is related to the arousal level felt. In this case, we found that Extraverts' favorite colors cause them higher arousal, while Introverts tend to prefer more relaxing colors. Correlations between Extraversion facets and the preference for some colors were also found.

We could also verify that Introverts' most liked color is on the opposite side from Extraverts' on the color wheel. Arousal showed to be related to the Hue angle and, consequently, the color temperature – warm colors showed to be more arousing than cool colors. On the other hand, colors with lower Lightness level showed to be more relaxing (except for the color black).

In terms of the self-reported preference, the study showed that the responses were very different from the preference collected through neurophysiological responses. This reinforces that self-reports include not only the preference but also the cultural and context.

Although the results suggest some tendencies, we could not draw conclusions based on the statistical analysis. It would be interesting to continue the studies on the influence of personality in color preferences. Future works on this field of study should be based on a larger, more diverse sample.

It would be interesting to design the study with more options in terms of languages, to allow a wider cultural diversity. It is very important to have in mind that, to gather data in terms of Extraversion, a personality test shall be answered honestly, through the most accurate options. Therefore, a test performed in the subjects' native language may lead the researchers to getting more reliable results. In order to maintain the study coherence, the entire test should be performed in the users' native language, meaning that further studies should include several languages to cover more cultures.

Further studies should also include a wider diversity in terms of the other demographic information, such as age and education. Since self-reported color preference may be influenced by social and cultural factors, it would be interesting to underlie the studies on samples with more diverse information.

It would also be crucial to have a more balanced sample in terms of Introverts, Ambiverts and Extraverts. Since this is not easy to guarantee in advance, the wider the sample, the greater chances of getting the desired results. Regarding personality, it would also be interesting to focus on Ambiversion differences. For instance, dividing the Ambivert group into subgroups would allow the analysis between Ambiverts with higher and lower scores, as well as with Introverts and Extraverts, to study any preference and arousal similarities between the closest groups. The study of the influence of personality in color preference can even be extended beyond Extraversion.

Our results suggested some trends in terms of preference and arousal when comparing single channels of the CIEL*C*h* color representation. To go further studying the influence of color properties, it would be interesting to compare reactions between colors changing one channel at a time and maintaining the two remaining channels with the same value. This way the researchers could explore, for instance, the influence of Hue itself, not depending on the other properties of the colors.

With the results obtained from further studies, new guidelines may be derived for varied HCI applications. Regardless of the application chosen, the adaptation to each user's personality should be made through a validated personality questionnaire. In contrast with emotion – a psychological topic widely researched for HCI uses –, personality is lifelong tailored. This means that the questionnaire should be answered from time to time, but sudden changes are not expected.

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