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The Influence of Color on Impulsiveness and Arousal: Part 1 – Hue

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Abstract

Impulsiveness and arousal are two similar yet distinct emotional and behavioral states that have been shown to be influenced by color in many fields, such as clothing and environment design. This series of studies investigates the fundamental theory of how color impacts on people's impulsiveness and arousal states. To achieve this goal, psychophysical methods were used to examine the impact of color environment on impulsiveness and arousal. Two main factors were used to quantify them: response time and error rate in problem solving. The psychophysical experiment was designed to examine whether, in a particular color environment, the response time and error rate were different. Participants sat in front of a large TV screen showing different colored backgrounds against which a range of psychometric tests were completed. The color backgrounds varied in hue. During the experiment, participants were required to give their responses to each of the psychometric tests as quickly and accurately as possible. The results showed that different colors can significantly influence response time and error rate, which suggests that color has a distinct influence on impulsiveness and arousal. Gender difference has also been investigated. This paper mainly discusses hue influence on impulsiveness and arousal. The influence of chroma along with hue will be explored in the next paper.

Key words: impulsiveness; arousal; hue; Color psychology.

Introduction

Color can impact on not only aesthetics and meaning within design, but may also be used to support design with a scientific basis. Taking sportswear as an example, research has shown that the color of apparel can influence an athlete's performance.[1-3] Thus, in professional sports games, clothing color may be a deciding factor when competitors have similar abilities. Color's influence on behavior can also be found in environmental design. For example, vivid colors used in learning environments led to significantly higher reading scores.[4] The differentiation in wall color is related to higher levels of cooperative behavior among pre-school children.[5] Beyond these clear target application areas, research exploring the fundamental theory of how color influences behavior, especially impulsiveness and arousal, is limited.

Impulsiveness

Although there is evidence that color can influence emotional states,[6-8] research into how color influences mental state and bodily behavior is lacking. Impulsiveness is the behavioral ability to respond quickly and without mental reflection, which is highly related to the control of thoughts and behavior.[9-10] Impulsiveness can be classified into three types: *motor impulsiveness*, such as acting without thinking, taking evasive action while driving to avoid an animal; *cognitive impulsiveness*, such as making quick conscious decisions; and *non-planning impulsiveness*, such as a lack of concern for the future.[11]

Arousal

Arousal is the physiological and psychological state of being awoken, such as the sudden confrontation with danger.[12] Literally, arousal defines a situation regarded to vary in a continuum from a low point in sleep to a high point in

extreme effort or intense alertness.[13] From daily life, to be aroused means to be wide-awake, alert, vigorous, excited and full of pep; whereas to be less aroused means to be sleepy, sluggish, tired and relaxed.[14] In many situations, impulsiveness and arousal may conflate. For example, being suddenly confronted by a snake would result in significantly increased arousal and could also lead to impulsive action such as jumping to one side.

Measuring Impulsiveness and Arousal

Whether color can impact on people's impulsiveness and arousal is a relatively unexplored area of research. The measurements of impulsiveness and arousal are actually very similar. Four types of data are normally collected to assess a person's impulsiveness state and usually three types of data are collected to measure arousal. They have been classified by Barratt[10] and Andrea[13] as follows:-

Measuring Impulsiveness

1) Everyday life experiences, such as peer ratings, hobbies or family relationships;
2) Psychometric and psychiatric interviews, such as Barrat Impulsiveness Scale (BIS scale);
3) Laboratory behavioral measures, for example classical eye-blink conditioning and two-dimensional tracking;
4) Psychophysiological or neuro-physiological measures, such as heart rate, cortical evoked potentials, Galvanic Skin Response (GSR) and so forth.

Measuring Arousal

1) Self-reporting method, such as verbal scales, non-verbal scales;
2) Psychophysical measures, such as the paper-folding and cutting task;
3) Psychophysiological measures, such as EEG, heart rate, and EDA, or studies with brain-imaging technologies.

This study used the laboratory psychophysical behavioral measures as its main method as these are more quantifiable and practical. A more objective way of measuring impulsiveness and arousal can be applied to the later stages of research to support the findings from the behavioral measures.

Relationship between Impulsiveness and Arousal

According to the literature, typical laboratory-type tests designed for adults to measure impulsiveness are psychometric-related, such as the Porteus Maze Test, Matching Familiar Figures Test, Trail Making Test, Wisconsin Card Sorting Task, Circle Tracing, and Rorschach Test. In most of these tests, response time and error rate are the key data collected to judge impulsiveness.[15-17,8] In this study, there is a need to establish a reliable method for measuring both impulsiveness and arousal. Based on the literature, psychophysical measures are also suitable to measure arousal, for example the Paper-folding and Cutting Task.[13] The often-used indicators for measuring arousal are also response time and error rate. The theory of four quadrants of impulsiveness using response time and error rate as its coordinates is a suitable starting point to build on.[18-19] The four quadrants of impulsiveness defined by Kagan are:-

1) Quick response, many errors (High Impulsiveness).
2) Quick response, few errors (Medium Impulsiveness).
3) Slow response, many errors (Medium Impulsiveness).
4) Slow response, few errors (Low Impulsiveness).

The four quadrants of impulsiveness clearly describe the characteristics of high impulsiveness and low impulsiveness. However, there are two types of states grouped into medium impulsiveness which lead to very different results. When considering the definition, the two categories within medium impulsiveness were highly associated with arousal state: high arousal showing

a quick response with fewer errors in performance (awoken, excited); and low arousal showing a slow response and a higher error rate (sleepy, tired). Therefore, it is appropriate to improve Kagan's four impulsiveness quadrants theory to an error/speed theory which can clearly explain both impulsiveness and arousal. Figure 1 shows an example of the error-speed space designed for this study.

(Figure 1 is about here.)

This research intends to study the impact of color on impulsivity and arousal in a more fundamental method. The starting point for this research was using colors on a TV screen. In later research, the conditions can be extended to colored lighting in an actual working environment.

Methods

The overall goal of this study is to investigate the influence of color on impulsiveness and arousal. An initial psychophysical experiment was conducted to explore hue influence. Six types of psychometric tests were used in the hue experiment: logical rule, spatial structure, rotation, mathematics sequence, odd one out, and same detail. Table 1 describes the six types of tests. There were three repeats for each test type, therefore in total each participant needed to complete 126 (6 tests $\times$ 7 colors $\times$ 3 repeats) psychometric trials in one experiment. The influence of hue on impulsiveness and arousal has also been compared between the genders.

(Table 1 is about here.)

Color Samples

Six commonly-used colored backgrounds – red, orange, yellow, green, blue and purple – having a similar luminance and chroma and an equally-luminous

reference white color (used as a control) were studied in the experiment. The CIELAB values of the seven colors were measured using a CS-1000 spectroradiometer. The L* and C* values of all seven colored backgrounds were both fixed at around 66 (± 2). The detailed characteristics of these seven colors are given in Table 2.

(Table 2 is about here.)

Participants

A total of 27 participants (14 females and 13 males) took part in the experiment. As all subjects were Chinese, so cultural difference was a controlled factor. They were all university students, having various educational backgrounds, aged between 20 and 38. All participants had normal color vision according to the Ishihara Color Vision Test.[20] Based on the error rate and response time results of each participant, four impulsiveness/arousal states (High Impulsiveness: HI; High Arousal: HA; Low Impulsiveness: LI and Low Arousal: LA) have been classified.

Experimental Procedure

The psychophysical experiments were conducted in a dark room with individual participants. Upon entering the room for the first time, they were required to complete the Ishihara Color Vision Test. After passing this test, they were asked to read the instructions which explained the whole experimental procedure. Six examples, corresponding to each type of psychometric test, were then introduced to participants in order to familiarize them with the tests before beginning the main experiment. The main experiment began five minutes after they had entered the dark room in order to ensure that they had adapted to its conditions. Each participant was seated at a fixed distance (75 cm) from the display. The display used in the study was a 40” liquid crystal display having a resolution of 1920×1080 pixels and an aspect ratio of 16:9.

The settings used throughout were high contrast, medium brightness, medium color and cool color temperature.

During the experiment, participants were asked to focus on the reference white background for two minutes to adapt to the experiment environment before each test. For each test, they were required to speak out the answer with no opportunity to change their minds. After responding, participants then moved on to the next test. Participants solved tests with the reference white background first, followed by the other six colored backgrounds (with four reference white patches in the corners) in a random sequence. The whole experiment took approximately one hour for each observer. Every day after finishing all the experiments, the seven background colors were re-measured at the same distance from the display as participants (75 cm) to ensure the repeatability of the colored backgrounds. Figure 2 shows an example of seven colored screens from this experiment. Two weeks after the first experiment (which worked as a wash-out period to reduce carry-over effect from one experiment to the next), they were required to repeat the experiment once more to evaluate their repeatability.

(Figure 2 is about here.)

Results

The experimental data collected from the experiments were each participant’s response time and the number of errors. The combination of these two indicators can measure participants' performance. These two sets of data collected from the psychophysical experiments will be discussed by color and by gender respectively in the following sections.

Participant Performance

Participant repeatability indicates the agreement of a participant's

impulsiveness state between the first and repeat experiments. The participant's impulsiveness was determined as: LI, longer response time and smaller error rate; HI, shorter response time and higher error rate; HA, quicker and smaller error rate; and LA, slower and higher error rate (all compared with mean). Figure 3 depicts the four impulsiveness/arousal states in this experiment. Results showed that all participants did not have a big jump in impulsiveness states between the first and repeat experiments. (A big jump means from LI to HI or vice versa.) This indicates that participants do not need long-term training to complete the psychometric tests and their impulsiveness states were stable. Consequently, both data sets can be used in the study.

(Figure 3 is about here.)

The mean four-state categories are summarized in Table 3. HI was the biggest group among the four (16 participants). Participants who were high in impulsiveness normally spent around 20 seconds on each test, while their error rate was 26%. The second largest group was LI, which includes 14 participants. On average, participants in this group spent 11 more seconds for each test than those in the HI group; however, the error rate was nearly halved (14%). Participants with low arousal and high arousal states were fewer in number than those with high impulsiveness and low impulsiveness. The response and error rate for the LA group were 34 ± 2 seconds and 23% ± 1% respectively, which means participants in this group were the slowest to respond and their error rate was fairly high. The response time and error rate for the HA group were very similar to the HI group (21 seconds and 14% respectively).

(Table 3 is about here.)

General Trend

Hue influences on impulsiveness and arousal were judged by the response time and error rate of participants according to the different hue backgrounds used. While looking at these two factors together (Figure 4), participants were slower to respond, but their error rate was fairly high with yellow and blue backgrounds. The influences of these two colors were similar. This indicates that participants had a LA (low arousal) state when they performed on yellow and blue backgrounds. For purple, red and orange backgrounds, participants reacted significantly quicker than with yellow, blue and green. In addition, they made fewer mistakes for purple, red and orange backgrounds. The difference between yellow or blue backgrounds and purple, red or orange backgrounds is significant. This suggests that participants found them highly arousing, with HA (high arousal) state on purple and red backgrounds. Furthermore no significant difference between these two colors' influence on arousal was found. Orange is the only color that crossed the average line for both error rate and reaction time, which suggests that this is a relatively impulsive color that can influence participants to react moderately quickly but with more mistakes. However, the difference between the influence of purple, red, green and orange on error rate is not significant. This shows that error rates do not differ significantly across the four hues. For individual colors, the error bars for error rate are generally higher than those of the response time. This suggests that error rate is quite variable (noisy) but nonetheless is a better reflection of impulsiveness; and response time is more reliable but, on the other hand, it is a weaker reflection of impulsiveness.

(Figure 4 is about here.)

It is helpful to put the response time and error rate indicators in a single coordinate (error-speed) space in order to examine the relationship between these two indicators. The statistical method of dimensionality has been used to

calculate the dimensionless quantities. The method used to make the data dimensionless was the extremum method:

$$x_i' = \frac{x_i}{\max x_i}$$

where x_i' are the dimensionless data, $\max x_i$ is the maximum value of the whole data set of response time or error rate. The error-speed space of dimensionless values is shown in Figure 5.

(Figure 5 is about here.)

Figure 5 depicts the six colors' positions in error-speed space. The figure reveals that impulsiveness has an increasing trend from the bottom-left to top-right quadrant. Arousal has an increasing trend from the bottom-right to top-left quadrant. Most of the hues are located in HA and LA quadrants, which means that hue influences arousal more than impulsiveness. Orange is located on the boundary of the HI quadrant, whilst it is not the color having neither the quickest response time nor the highest error rate. Yellow is also on the boundary of the HI quadrant, however it produces the highest error rate. Therefore, orange and yellow can be considered as two relatively “impulsive colors” (that is leading to impulsiveness) within the six hues. Green is the least impulsive color according to its impulsiveness coordinates; it touches the boundary of the LI quadrant. Red and purple are located in the HA quadrant and can influence participants to perform quicker with fewer errors. Participants performed worse with blue and yellow backgrounds (they are located in the LA quadrant) as they required more time to think but still made more mistakes.

From the impulsiveness coordinates alone it is still difficult to determine the

order of these six colors according to their influence on impulsiveness state. This is because error rate has a positive correlation with impulsiveness, whilst response time has a negative correlation. The relationship between response time and error rate can be determined by the indicator: E/R (where E is error rate and R is response time). The impulsiveness state increased with the value of this indicator. Error rate and response time all have negative correlations with arousal, therefore the relationship between response time, error rate and arousal can be determined by the indicator: 1-ER (ER=E times R). The arousal state increases with the value of this indicator. The E/R value and 1-ER (ER=E times R) values for the six colors are summarized in **Error! Reference source not found.**4. From high impulsiveness to low impulsiveness, the six colors' impulsiveness and arousal order are summarized in Figure 6.

(Table 4 is about here.)

(Figure 6 is about here.)

From Figure 6 it can be seen that yellow can influence people to exhibit the highest impulsive state; red gives rise to the least impulsiveness among the six. On the other hand, red highly arouses performance while yellow gives rise to the least arousal. Orange can influence people in both a relatively high impulsive and aroused state; green results in both a relatively low impulsive and arousal state.

To investigate hue influence on impulsiveness and arousal, the six hues' impulsiveness and arousal values are plotted on the hue diagram shown in Figure 7. From this figure, it can be seen that colors having a hue around 100 degrees (yellowish colors) influence people to exhibit either the highest impulsiveness state or the lowest arousal state, meaning participants made quite a lot of errors with yellowish colors. The lowest impulsiveness state

occurred with colors having a hue between 210° to 240° (greenish blue colors) and 0° to 30° (reddish colors). Moreover , the highest arousal state was located at around 300° to 330° (reddish and reddish -purple colors). The reddish color can influence people to be more aroused but less impulsive. Greens at 180° have an equal influence on impulsiveness and arousal. Greenish blue and bluish colors between 210° to 240° can influence people to be both low in impulsive and aroused.

(Figure 7 is about here.)

Color Influence on Impulsiveness and Arousal by Gender

A tendency was found that females responded quicker yet made more mistakes throughout all colored backgrounds. This means female participants seemed to perform more impulsively than males in this experiment (as shown in Figure 8). Since most of the error bars overlap, this trend cannot be regarded as significant for all colors. Blue, however, may marginally increase the response time for males (30 seconds for males, 27 seconds for females) while decreasing their error rate (19% for males, 24% for females) since the error bars for response time and error rate do not overlap. This indicates that there is a gender-specific influence for blue which was not seen with the other colors. No gender difference can be seen for hue's influence on arousal.

(Figure 8 is about here.)

Figure 9 summarizes the impulsiveness and arousal values for male and female participants. From the figure it can be seen that gender difference has little influence on the order of impulsiveness and arousal. For impulsiveness, the only difference between males and females are the sequence of orange/blue and purple/green. The most impulsive color for both genders is yellow; the least impulsive for both genders is red. The only difference

between arousal order for males and females is that the highest arousal color for males is purple and the second red whereas the highest arousal color for females is red and the second is purple.

(Figure 9 is about here.)

Summary

This study has investigated the influence of hue on impulsiveness and arousal. Some novel findings from this experiment are summarized as follows:-

- Hue seems to have a greater influence on arousal than impulsiveness.
- Reddish colors, including yellowish red (orange) and bluish red (purple), can all influence people to exhibit a highly-aroused state.
- Yellow leads to the least aroused state. While it is also the color that influences people to be the most impulsive.
- Yellow, blue and green result in significantly slower response times compared with purple, red and orange.
- Yellow and blue induced participants to make the most errors. Red and purple backgrounds resulted in the fewest errors.
- Differential hue influence on gender was not significant, however females tended to respond more quickly with more mistakes (more impulsive) than males on all color backgrounds.

Hill and Barton reported that wearing red sports attire has a positive impact on athlete's scores in combat sports such as tae kwon do and wrestling.[2] Jacobs and Hustmyer also stated that red is the most arousing color followed by green, yellow and blue.[21] Physical strength may be increased in a red office compared with a blue one because strong colors such as red can put the brain into a more excited state.[8] From the experimental data collected in the hue experiment, it can be pointed out that red backgrounds can influence people to

be relatively more aroused in solving psychometric tests than most of other colors as it led to participants performing with the fewest errors and the second-shortest response time. This is in agreement with the present study and confirms that red can influence people to be more aroused and perform well (with a low error rate and short response time). This phenomenon was explained by Berlyne[22] as being because red and purple have the emotional meaning of danger, speed, blood, fire and so forth. These colors can lower people's blood pressure and heart rate, which also have the function of arousal. Blue and green are the colors prevalent in nature; they also have an association with calm, peace and so on, which can influence people to be less aroused. Moreover, this study finds that not only pure red, but also yellowish red (orange) and bluish red (purple) can also lead to a high aroused state.

This experiment has some limitations. Firstly, it is possible that participants may tire during the experimental period or even that their performance may improve as the task continued. For this reason, the order of the six colored backgrounds was varied randomly for each participant. This was to avoid bias. However, the reference white was always the first condition that participants encountered. It is therefore difficult to compare performance on a colored background with performance on a white background because there could have been some temporal bias. The white background was used first so that participants could adapt to the viewing conditions. Also, the ages of participants were between 20 and 38; thus, the findings might not be generalizable to children and the elderly. Finally, only six hues were used in this experiment. It is difficult to use these six colors to predict the whole trend of hue's influence on impulsiveness, so this should be further studied in the future.

Findings from this study could be used in various design areas such as in design marketing, using colors to promote impulse buying; in information

design, using colors to remind people and in functional design, using colors to enhance people's performance. The next stage of this study will move to the influence of chroma on impulsiveness and arousal.

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Biographies

Dr Yiting Duan is a textile design lecturer in Faculty of Material and Textile, Silk Institute, Zhejiang Sci-Tech University. Her research areas are related to color psychology, color design, textile and fashion product design. She was awarded a PhD from University of Leeds for her thesis "The Impact of Colour on Impulsivity, Arousal and Emotion", which proposed a possible beginning of research between color and two emotional and bodily response: impulsivity and arousal. She was awarded the Palmer Award from The Colour Group Great Britain (CGGB) in 2013 for her research in color and textile design.

Dr Peter A. Rhodes is a lecturer in color imaging at the School of Design, University of Leeds. He was awarded a PhD for his thesis “Computer Mediated Color Fidelity and Communication” from Loughborough University of Technology which led to the development of the first what-you-see-is-what-you-get system for color specification and communication within the textile industry. He has produced over 50 academic publications, including book chapters on color management and color notation systems, and contributed towards the development of the ISO 10617 standard for colorimetric communication. In addition to his role as Director of Student

Education, he is actively engaged in a number of commercially-oriented research and development projects.

Dr Vien Cheung currently holds an academic post as Associate Professor in Color and Imaging Science at the University of Leeds. Her research interests are color vision, spectral imaging, color reproduction and color, all as applied to the art and design disciplines. Dr Cheung is active in several professional bodies including The Colour Group Great Britain (CGGB), the International Colour Association (AIC), and the Society for Imaging Science and Technology (IS&T). She was awarded the Selwyn Award from The Royal Photographic Society in 2008 for her research in color imaging and imaging technology, a Silver Medal from the Society of Dyers and Colourists in 2011 in recognition of her contributions to education, the Society and in the interests of the allied industries, and the 2016 Service Award from the IS&T for her contributions in organizing IS&T color conferences.

Figures:

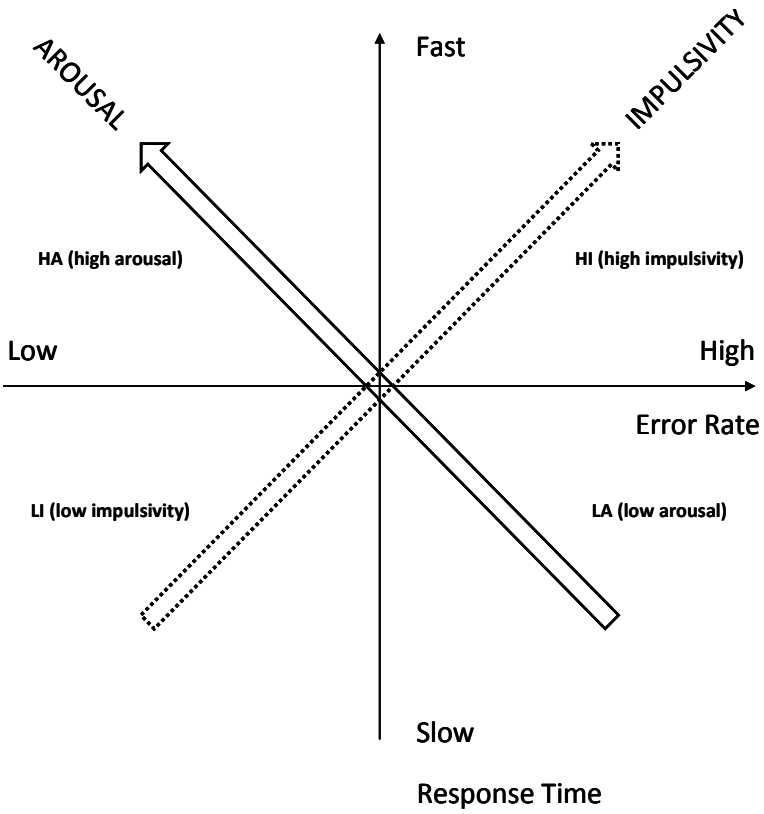


Figure 1 The error-speed space for predicting impulsiveness and arousal status.

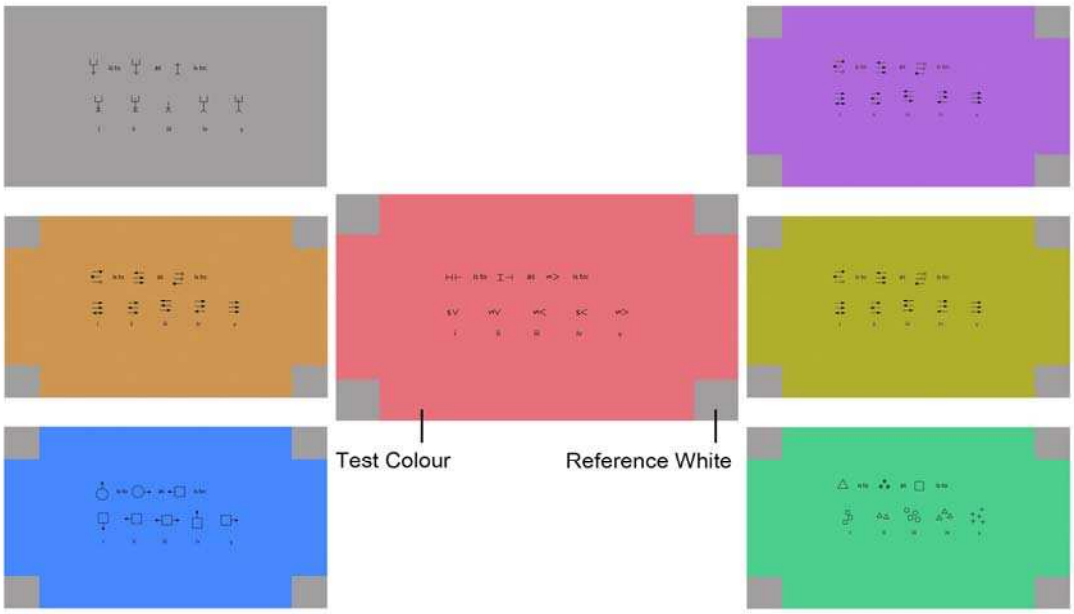


Figure 2 An example of 7 colored screens shown during the experiment.

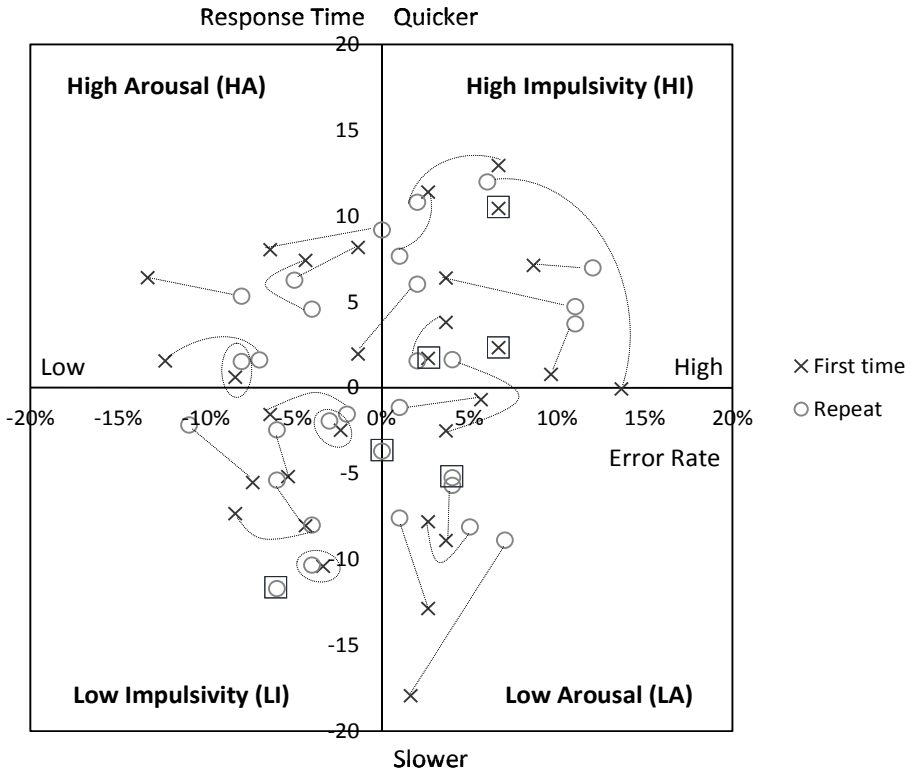


Figure 3 The Error-Speed space and participants' performance in the hue experiment.

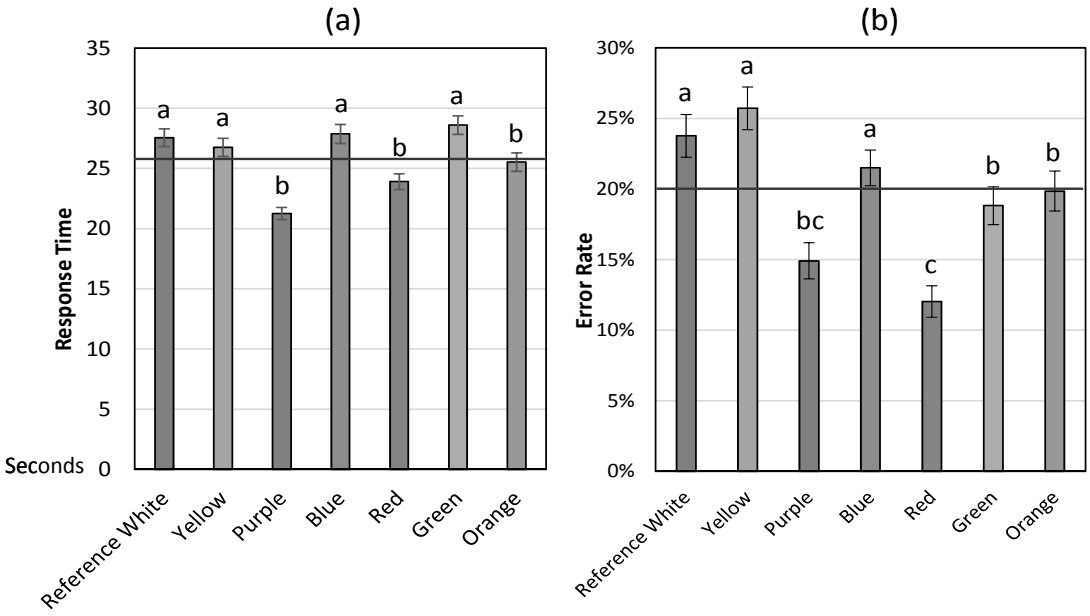


Figure 4 (a) Response time by background color; (b) Error rate by background color. The red lines in (a) and (b) represent the mean. The error bars are standard errors. Letters a-c refer to data sets shown to be significantly different to each other (at the P=0.05 level).

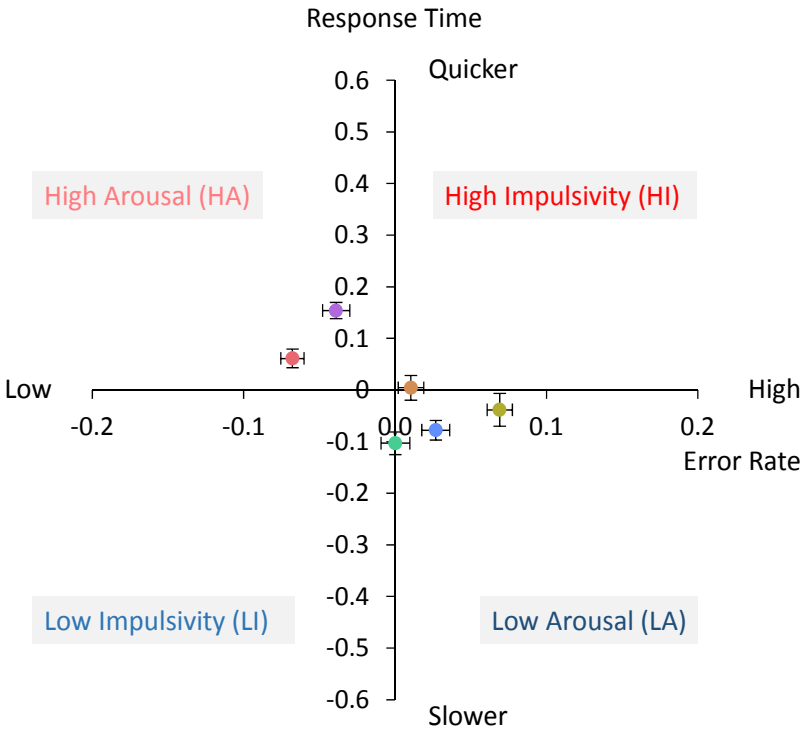


Figure 5 Six hues plotted in error-speed space.

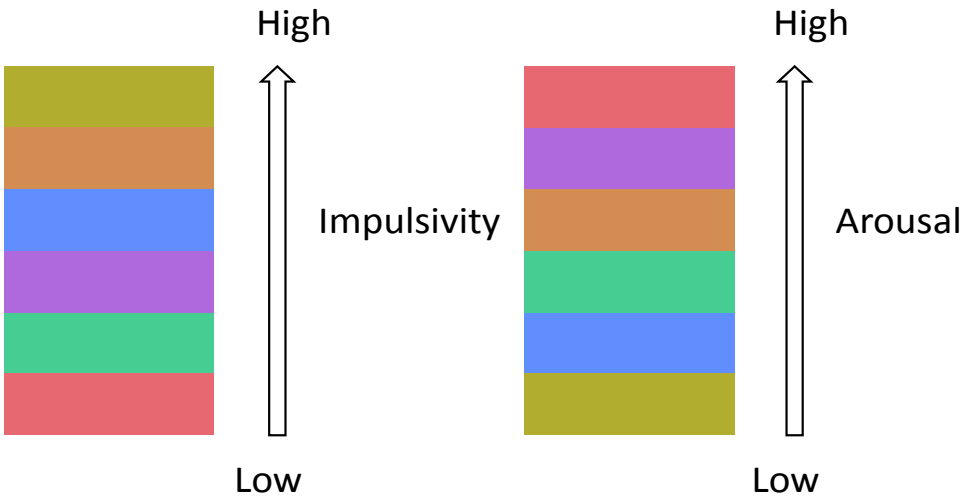


Figure 6 The six colors impulsiveness and arousal order.

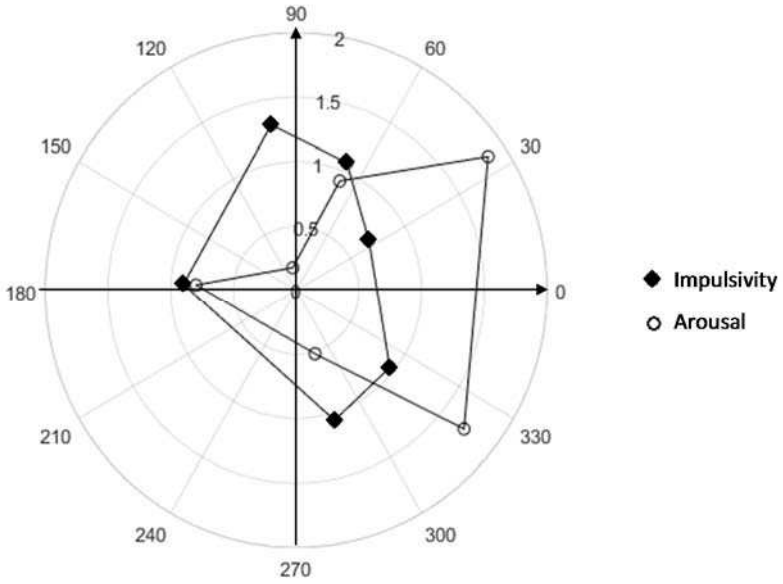


Figure 7 Color influence on impulsiveness and arousal according to hue.

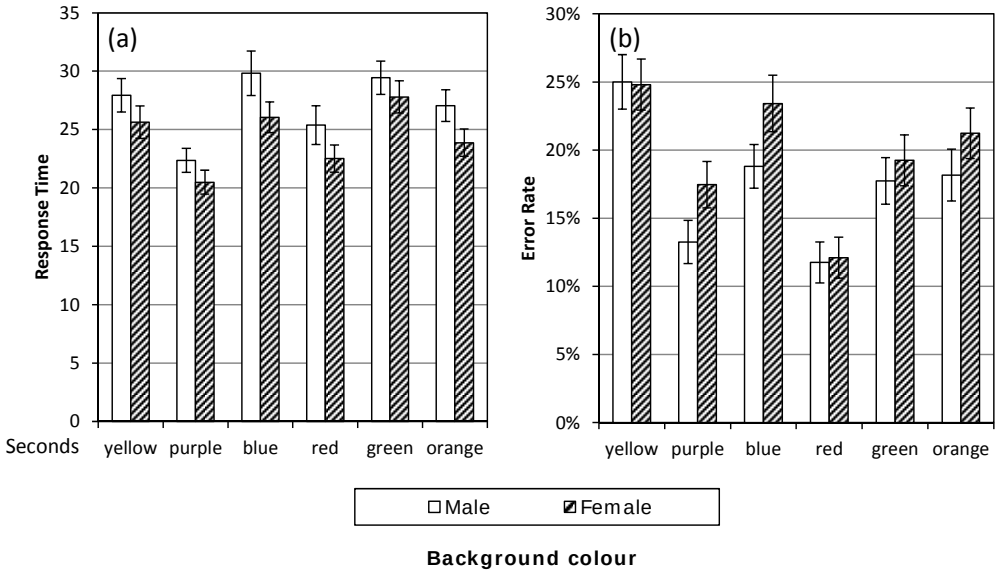


Figure 8 (a) Response time by gender; (b) Error rate by gender.

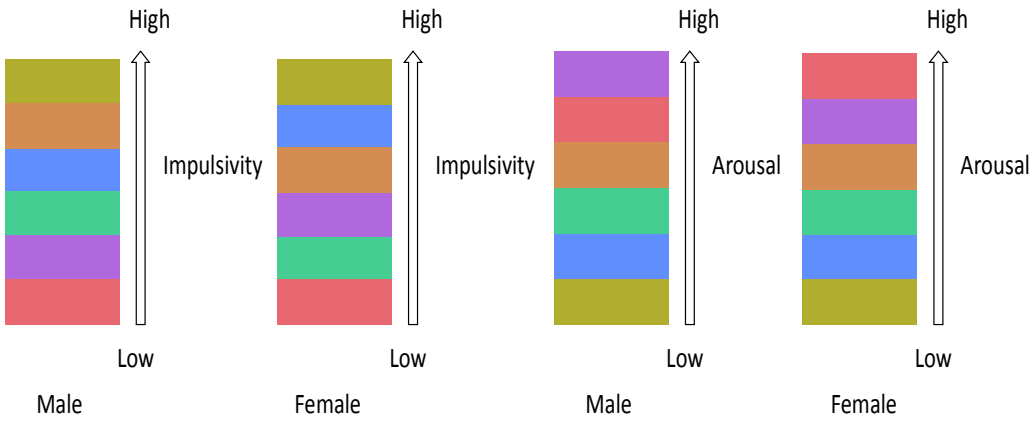
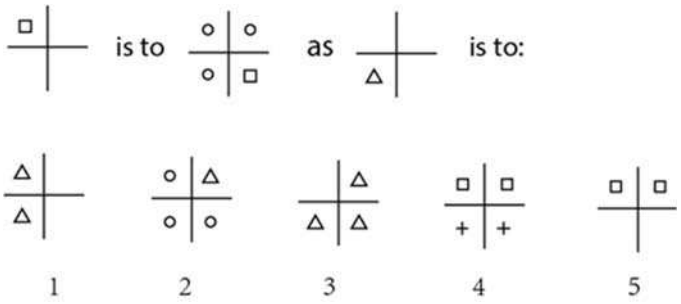
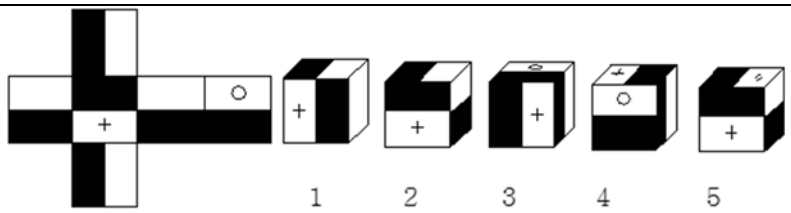
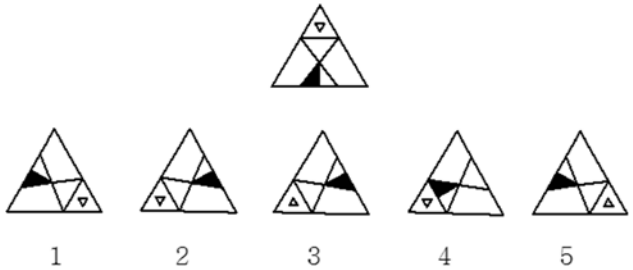


Figure 9 The order of hue impact on impulsiveness and arousal by gender.

Tables:

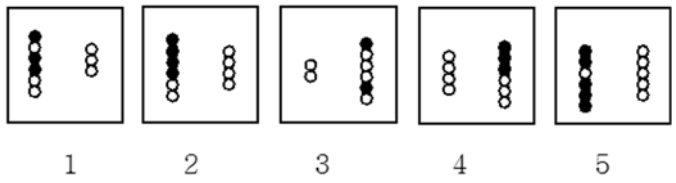
Table 1

(a) Logical Ability Test

Logical Rule: In this type of test, you are required to choose, from a set of alternatives, which diagram will complete a similar analogy to the first example.
9 16 25 36 ? 47 48 49 50 51 1 2 3 4 5
Mathematics Sequence: In this type of test, you are given a string of numbers. You have to work out the number that is missing from the string (marked ?).

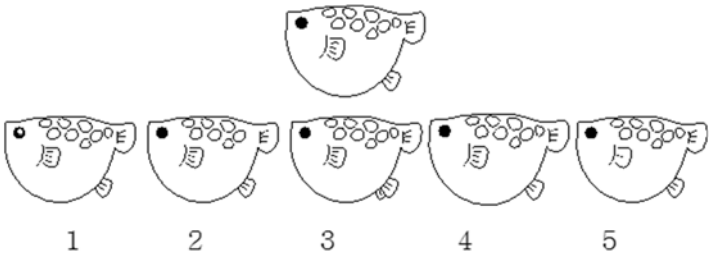
(b) Spatial Imagination Ability Tests

Spatial Structure: In this type of test, you need to look at the unfolded shape, and then choose which of the objects below would best represent the first object if it were folded.

Rotation: In this type of test, you are shown a shape in the middle of the page. Below they are five

other shapes. You have to decide which of the alternatives is identical to the original shape. It will still be identical to the original if it has been turned around. It will not be the same as the original if it has been turned over, or the proportions, parts have been changed.

(c) Detail Ability Tests



Odd One Out Test: In this type of test, you need to decide which of the objects is the "odd one out".



Same Detail Test: In this type of test, you are shown a pattern in the middle of the page. Below they are five other patterns. You have to decide which of the alternatives is exactly the same as the original pattern.

Table 2

colors	L*	h (°)	C*	a*	b*
Visual Reference White	69.71	29.10	0.48	0.42	0.23
Red	69.63	34.24	68.58	56.69	38.59
Yellow	70.71	98.78	70.97	-10.83	70.14
Blue	67.29	286.76	67.11	19.36	-64.25
Green	67.73	176.98	68.33	-68.24	3.60
Orange	71.17	67.83	67.07	25.31	62.11
Purple	67.96	321.03	68.17	53.00	-42.88

The white point in this experiment was customized. The CIE XYZ values for the white point are: X=109.9; Y=111.1; Z=182.3.

Table 3

Variables	Impulsiveness Status	Number	Mean± STD error
Response time (sec)	LI	14	31±1
	HA	13	21±1
	HI	16	20±1
	LA	11	34±2
Error rate (%)	LI	14	14±1
	HA	13	14±1
	HI	16	26±1
	LA	11	23±1

Abbreviations: LI, Low Impulsiveness; HI, High Impulsiveness; HA, high arousal; LA, low arousal.

Table 4

Indicators	red	purple	green	blue	orange	yellow
E/R	0.57	0.79	0.74	0.87	0.88	1.07
1-ER	0.60	0.56	0.26	0.17	0.30	0.06