Measuring the Emotional and Physiological Effects of Light and Colour on Space Users

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Abstract. Colour and light are known to have an impact on our health and wellbeing. While large resources are allocated for well designed buildings with the right choice of colours and lighting conditions, there is little scientific evidence that supports these choices. The aim of this research was to determine the impact of different colours and lighting conditions on people, using non-invasive means. Close correlations between skin conductance (SC), our emotions and health are well reported in literature and hence these are expected to be good measures of the environmental conditions on people.

1 Introduction

There are numbers of factors in a constructed environment that influences the psychological and emotional state of the users in that space. Light intensity and colour are two important factors with impact on users' performance in the space. While people are known to adapt to different environments, the different conditions have an impact on their productivity and general wellbeing. For effective usage of our buildings, it is important to have an objective measure of these factors on the health and wellbeing of human.

The literature on light and colour is extensive, however a uniform set of findings is lacking for a consistent perspective on the influence of colour and light. There are numbers of publications that report the research conducted to determine the effect of various lighting and colour conditions on peoples' emotions. Most of these are based on subjective measures [1], [2], [3], [4]. The subjects complete questionnaires to describe their feelings after being exposed to different colour and lighting conditions. Research conducted by Karrie on interior design for ambulatory care facilities reports some important design factors. The research reports that colour and lighting have profound influence on patients and consumers satisfaction, stress level, health and wellbeing. The paper also reports that the effects of colour and lighting are inseparable and lighting intensity affects the perception of colour [5].

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The research by Igor Kenz reports subjective tests to study the effects of the recommended office lighting on mood and cognitive performance. The work demonstrates that the physical setting of an office and the use of artificial light can have a significant impact on the mood of the inhabitants [1]. Another research conducted by Warren E. Hathaway has found that students who study under daylight like light were less absent and achieved higher scores than those working under yellowish-orange sodium vapour bulbs [4].

However the outcome of subjective tests is uncertain. It has been reported that subjective tests such as questionnaires are insufficient and may be misleading especially when conducted at the end of the experiment [6], [7]. Often, participants may mix their emotions between the start and the end of experiments, and the recollection of a series of emotions that occurred earlier may lack accuracy.

Peter J. Lang said that emotion manifests itself in three separate aspects of people; (i) physiological, (ii) psychological (i.e. subjective experience) and (iii) behavioural. The physiological is the change in the physical properties of the person, psychological being the subjective experience while the behavioural is manifest by the physical actions such as approach and avoidance, and each of these associated with specific measures [6], [7]. The paper also suggests that it is necessary not to limit the studies to the assessment of a single response but include sample measures from each of the three manifestations.

Research was conducted by Binjamin to identify the impact of short film clips (6s) on people, where some of these clips were coloured and some were black and white. Skin conductance, heart rate and facial movement were used in the research as physiological measures in addition to subjective tests to study the short term effect of colours on people. The results indicated that colour has a small effect on the subjective experience but did not exert a main effect on the skin conductance response. The paper recommended further studies to explore the impact of colour and light on physiological measures using stimuli of longer time durations [8].

The authors are unable to find any research that has measured the physiological changes in people due to light and colour stimuli of long duration. To identify the best choice of interior conditions for buildings there is a need to determine the physiological changes in people under these conditions. The reasonably long exposure is to allow the participants of the study to adapt to the conditions.

1.1 Skin Conductance and Emotions

Skin conductance (SC) is one of the fastest responding non-invasive measures of autonomic nervous system activity. It is a method of capturing the autonomic nerve response as a parameter of the sweat gland. Physically SC is a change in the electrical properties of the skin in response to different kinds of stimuli. The response is measured by the change in voltage from the surface of the skin [9].

The close correlation between SC and emotions is well documented in the literature. Lane reported that SC shows different values for different emotions when studying the effects of emotional valence, arousal and attention on neural activation during visual processing of pictures [10]. Storm also reported that SC fluctuations are a measure of preoperative stress [11]. Healy used SC as a measure of the emotional stress developed during driving [12]. Heo used SC as a measure of emotional response to web advertising [13].

The aim of this research was to provide a definitive answer for the choice of light and colour conditions in a constructed environment for the betterment of health and well being of the occupants. This paper reports experimental research conducted to identify the physiological changes when exposed to different light and colour conditions. For this aim, the paper reports changes in the SC of people when exposed to different colour and intensity lights for periods of time that allowed the participants to adapt to the conditions.

The research has been built on the current body of knowledge that physiological measures are necessary to measure the effects of light intensity and colour on people to ensure objectivity and reproducibility of the experiments. This would remove the shortcomings of earlier research where questionnaire-based and other subjective experiments were used for identifying the effect of colour and light conditions. The aim is to help provide an objective rational for the choice for light intensity and colour by architects for different buildings.

2 Methodology

To determine the physiological changes due to the exposure of people to different light and colour conditions, it was important to conduct controlled experiments where all other conditions were kept constant. This was necessary to ensure that the changes recorded were due to the effect of light and colour conditions only. To measure the physiological changes, experiments were conducted where measurable changes in SC were recorded in response to change in colour and intensity of light.

2.1 Subjects

The experiments were conducted on 15 healthy subjects comprising 3 males and 12 females. They were not under any medication that may affect their mental and neural activities. The participants were recruited with the help of posters and most were university students. Their participation was voluntary. Ethics approval for the experiments was obtained and subjects completed consent forms before the experiment. Subjects were made aware of the details of the experiments and were also informed that they could stop the experiment if they chose to.

2.2 Experimental set up

The experiments were conducted in a neutrally coloured and furnished multi-user laboratory approximately 10m x 4m in size. Subjects were seated comfortably facing a 1.5m x 2m white non-reflecting screen approximately 1.5m away from the chair. Environmental conditions such as air temperature and humidity, furniture and layout setting were kept constant. All experiments were conducted in a quiet laboratory early in the morning to exclude noise disturbance and circadian rhythms as potential confounds. The order and interval of exposure to lights were kept constant for all subjects. The participants were exposed to the different light and colour conditions by illuminating the screen with floodlights that had globes of green, red and blue colours. The light conditions were recorded using LUX and FC light meter. During the experiments, the participants were exposed to eight different colour and light intensities which are described in table 1. The duration of the complete experiment was approximately 110 minutes. In preliminary experiments it was observed that eight minutes were sufficient to ensure that the participants adapted to the light and colour. Skin conductance was recorded for two minutes after the eight minutes had elapsed.

Table 1. Intensities of coloured lights used.

Colour of lights	Intensity of light/ lux
White	207
Blue low	28
Blue high	48
Green low	90
Green high	169
Red low	92
Red high	157
Natural	20 - 105

At the start of the experiment, the fingers were prepared for recording SC using wipes. Two electrodes were wrapped around two fingers in the right hand for the duration of the complete experiment. The subjects' SC was recorded in the last 2 minutes of each coloured light. The signals were recorded using Amlab biosignal recording equipment with sampling rate of 200 samples/second. The quality of signals was visually monitored at the start and during the experiment. The data was saved as text files and analysed using Matlab. A three minutes break was given to the subjects after each light condition where they were allowed to relax and move. During the experiment, the participants were engaged in continuous and pre-prepared non-controversial discussions on the history of architecture so as to reduce stress due to boredom. The style of speaking was maintained constant to avoid the sound and conversation related variations during the experiments.

3 Results and Discussion

In this section the results of the experimental data have been analysed. Skin conductance of the human body has continuos variation over time even when there are no external stimuli. The aim of this research was to identify the changes in SC due to the lighting and colour conditions. For this aim the values of SC were recorded for 2 minutes under each colour and intensity light for all the subjects. These recordings were graphed for each subject; the graph for subject 10 is shown as an example in fig 1.

The values of SC were then averaged over the two minutes for each colour and lighting condition. The mean and the standard deviation of SC values for the two minute

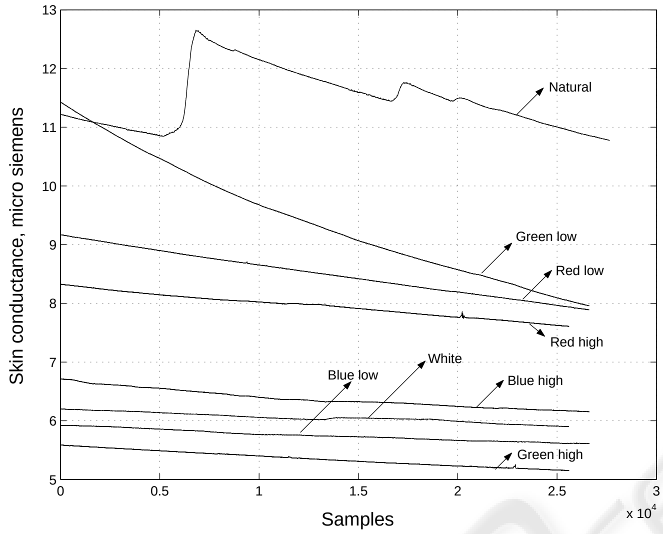

Fig. 1. Skin conductance for subject 10 under different colour lights

recording were tabulated and are shown in table 2. The SC under white light was then taken as a base level for each subject and SC readings under all other colour lights were compared to it. Subtracting the mean SC under white light from each coloured light provided these figures; the results were tabulated and are shown in table 3. The results were also normalised for each subject by taking the mean SC under white light as a reference, the results were tabulated and are shown in table 4.

The difference in mean SC, obtained from table 3, was then put into bar charts for comparison. An example for subject 10 is shown in fig 2.

As can be seen from table 2, there are changes in SC under different colour and intensity lights. From tables 3 and 4, it has been observed that 60-73% of the non-white conditions caused higher skin conductance than white conditions. It is also noted that some colours caused greater change in SC than other colours. Natural light caused the largest increase in SC for 20% of the subjects and the largest decrease in SC for 20% of subjects. Green high light caused the largest increase in SC for 13% of the subjects and the largest decrease in SC for 13% of the subjects. Red high light caused the largest increase in SC for 20% of the subjects and blue low light caused the largest decrease in SC for 20% of the subjects.

It has also been observed that the direction of change in SC (increase or decrease) is subject dependent, where the same colour and intensity light can cause an increase in SC for some subjects and a decrease in SC for others. However it is also noted from the results that the inter subject variation is large. That can be seen clearly from the last rows in tables 3 and 4 where the variation in SC between different colour and intensity lights is relatively small compared to the inter subject variation.

T-test was conducted to determine if the change in mean SC due to different colour and intensity lights is significant. The results are shown in table 5.

Table 2. Mean Skin Conductance values.

Subj	W light	BL light	BH light	GL light	GH light	RL light	RH light	N light	Mean	SD
1	20.38	13.65	16.18	19.95	13.59	19.61	20.38	21.34	18.14	3.17
2	7.9	9.31	7.64	6.8	6.22	6.13	5.22	6.09	6.91	1.30
3	16.5	27.12	26.54	99.91	99.92	64.62	17.36	41.39	49.17	34.90
4	60.7	61.22	59.12	56.72	54.61	53.1	51.89	51.05	56.05	3.99
5	9.14	12.71	11.09	10.49	11.37	8.58	10.07	7.45	10.11	1.68
6	13.99	15.55	23.77	31.24	16.85	18.5	21.81	25.25	20.87	5.77
7	27.13	50.31	49.95	39.22	43.57	55.28	53.89	69.56	48.61	12.48
8	55.74	25.6	65.09	47.32	90.25	99.92	99.92	99.92	72.97	28.63
9	30.44	15.06	13.88	43.02	38.7	33.98	45.66	37.46	32.28	11.97
10	6.05	5.75	6.38	9.41	5.36	8.51	7.96	11.47	7.61	2.12
11	40.04	55.35	50.35	51.93	57.88	59.87	63.02	47.25	53.21	7.42
12	25.04	28.55	30.77	35.59	37.57	35.05	42.08	35.96	33.83	5.42
13	38.2	74.78	64.01	23.62	28.94	29.13	24.36	40.91	40.49	19.05
14	7.46	7.07	6.84	6.63	7.61	7.78	6.72	5.68	6.97	0.67
15	8.1	9.6	9.42	10.07	11.57	11.33	11.14	10.52	10.22	1.17
Mean	24.45	27.44	29.40	32.79	34.93	34.09	32.10	34.09	-	-
SD	17.65	22.24	22.23	25.33	30.07	27.41	26.86	26.42	-	-

Table 3. Difference in mean skin conductance.

Subj	W light	BL light	BH light	GL light	GH light	RL light	RH light	N light	Mean	SD
1	0	-6.73	-4.2	-0.43	-6.78	-0.77	0.01	0.97	- 2.56	3.17
2	0	1.4	-0.26	-1.11	-1.69	-1.77	-2.68	-1.81	- 1.13	1.30
3	0	10.62	10.04	83.42	83.42	48.13	0.86	24.89	37.34	34.90
4	0	0.52	-1.58	-3.98	-6.09	-7.6	-8.81	-9.65	- 5.31	3.99
5	0	3.57	1.95	1.35	2.22	-0.57	0.93	-1.69	1.11	1.68
6	0	1.56	9.78	17.25	2.86	4.51	7.83	11.26	7.86	5.77
7	0	23.18	22.82	12.09	16.44	28.15	26.76	42.43	24.55	12.48
8	0	-30.14	9.36	-8.41	34.51	44.18	44.18	44.18	19.69	28.63
9	0	-15.38	-16.56	12.58	8.25	3.54	15.21	7.02	2.09	11.97
10	0	-0.3	0.32	3.36	-0.7	2.45	1.9	5.42	1.78	2.12
11	0	15.31	10.3	11.89	17.84	19.83	22.97	7.21	15.05	7.42
12	0	3.51	5.73	10.55	12.53	10.01	17.05	10.92	10.04	5.42
13	0	36.58	25.81	-14.58	-9.27	-9.07	-13.84	2.7	2.62	19.06
14	0	-0.39	-0.62	-0.83	0.16	0.32	-0.74	-1.78	- 0.55	0.67
15	0	1.49	1.32	1.97	3.47	3.23	3.04	2.42	2.42	1.17
Mean	-	2.99	4.95	8.34	10.48	9.64	7.64	9.63	-	-
SD	-	15.38	10.50	22.50	23.17	17.64	15.10	15.75	-	-

Table 4. Normalised values of mean skin conductance (white light as reference).

Subj	W light	BL light	BH light	GL light	GH light	RL light	RH light	N light	Mean	SD
1	1	0.67	0.79	0.98	0.67	0.96	1.00	1.05	0.87	0.16
2	1	1.18	0.97	0.86	0.79	0.78	0.66	0.77	0.86	0.17
3	1	1.64	1.61	6.06	6.06	3.92	1.05	2.51	3.26	2.12
4	1	1.01	0.97	0.93	0.90	0.87	0.85	0.84	0.91	0.06
5	1	1.39	1.21	1.15	1.24	0.94	1.10	0.82	1.12	0.19
6	1	1.11	1.70	2.23	1.20	1.32	1.56	1.80	1.56	0.39
7	1	1.85	1.84	1.45	1.61	2.04	1.99	2.56	1.91	0.36
8	1	0.46	1.17	0.85	1.62	1.79	1.79	1.79	1.35	0.54
9	1	0.49	0.46	1.41	1.27	1.12	1.50	1.23	1.07	0.42
10	1	0.95	1.05	1.56	0.89	1.41	1.32	1.90	1.29	0.36
11	1	1.38	1.26	1.30	1.45	1.50	1.57	1.18	1.38	0.14
12	1	1.14	1.23	1.42	1.50	1.40	1.68	1.44	1.40	0.18
13	1	1.96	1.68	0.62	0.76	0.76	0.64	1.07	1.07	0.54
14	1	0.95	0.92	0.89	1.02	1.04	0.90	0.76	0.93	0.09
15	1	1.19	1.16	1.24	1.43	1.40	1.38	1.30	1.30	0.11
Mean	-	1.16	1.20	1.53	1.49	1.42	1.27	1.40	-	-
SD	-	0.44	0.38	1.31	1.30	0.78	0.42	0.59	-	-

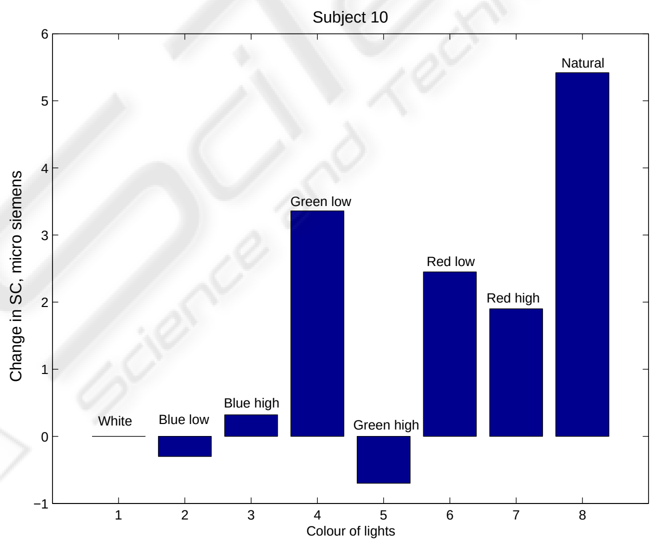

Fig. 2. Difference in mean skin conductance compared to white light for subject 10

Table 5. T-test for change in mean skin conductance.

colour of light	t-value	p-value
Blue low	-0.408	0.6904
Blue high	-0.675	0.5107
Green low	-1.046	0.3054
Green high	-1.164	0.2634
Red low	-1.145	0.2626
Red high	-0.921	0.368
Natural	-1.174	0.2559

The t-test shows a high p-value under all colour lights ($p > 0.05$) which means that the variation of SC in response to colour and lighting conditions is not significant.

The results show that there is a change in SC under different colour and intensity lights. Results also show that some colours and intensities caused greater impact on the SC of participants than others. Since SC is associated with arousal of the participants, from the experiments we can see that white light caused the most relaxed state (lowest SC) in 2/3 of the experiments. However it is also observed that the inter subject variation in SC is relatively high in the 15 participants. That is also confirmed in the t-test which shows that the change in SC in response to different colour and intensity lights is not significant. From the above it is not possible to co-relate the changes in SC to the specific colour and intensity lighting conditions.

Previous research reported by Binjamin [8] reported that short term colour exposure (6 seconds) did not exert a main effect on the skin conductance response. This research demonstrates that there is a change in SC when people are exposed to different colour and lighting conditions for longer periods of time (10minutes). However the inter subject variation is very large which makes it hard to co-relate the changes in SC to the specific colour and lighting conditions.

4 Conclusion

This research investigates the emotional and psychological effects of different colour and lighting conditions on people. It reports changes in the SC of 15 subjects when exposed to different colour and intensity lights. The research demonstrates that the change in colour and intensity of light caused a change in SC. It also shows that some colours have greater impact on SC than others. In most experiments (2/3 of the experiments) white light caused the lowest SC, which means that it provided the most relaxing condition. However the hypothesis t-test analysis for change in mean SC due to different colour and intensity lights indicated that the changes in SC are not significant, that is due to the large inter subject variation. The research has not studied the difference between the response to different colour and intensity lights based on gender and age [14], the authors would recommend that further experiments would take that into account.

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