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Study of the effects of varying colours on industrial illumination, human working and production model

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Abstract

In this paper, an attempt has been made to investigate the reflectance of various colours and effects of varying colours on human working and production. Different colours have different reflectance and energy associated with it. Colours play a significant role in the colour scheme of the houses, offices, factories etc. The colours may be seen on walls, tabletops, equipment, machines etc. In the experiment, assembly shops of electric meter and plastic toys were selected for study. Four experiments were conducted with different colours and observations taken for eyestrain and production. The significant effects were noticed on the effects of colours. Colours not only improve the aesthetic value of the product or the facility, but also affect human working and hence, productivity.

Keywords: Ergonomics; Colour; Reflectance; Illumination; Contrast; Eyestrain; Human working

1. Introduction

Colours are the light rays, emitted by a light source or reflected from an object. When light passes over a body, all the light waves are absorbed except the light, which is reflected back and one can see in the form of the colour. Every colour has its wavelength and energy associated with it. In designing of work system and everyday life situations, the focus of designer is man. Unsafe, unhealthy, uncomfortable or inefficient situations are avoided by taking into account the physical and psychological capabilities and limitations of humans. Number of factors plays an important role in designing of industry or work system for worker. These include body posture and movement (i.e. sitting, standing, lifting, pulling and pushing), environmental factors (i.e. noise, vibration, illumination, climate, chemical substances), information and operations (i.e. information gained visually or through other senses, controls, relationships between display and control), as well as tasks and jobs (i.e. appropriate tasks, interesting jobs) etc. These factors to a large extent determine safety, health, comfort and efficient performance at work and in everyday life.

2. Literature review

Light are the electromagnetic waves. When light falls on human eyes, in the retina, they are converted into electrical impulses that pass to the hypothalamus, the part of the brain governing our hormones and our endocrine system. Although we are unaware of it, our eyes and our bodies are constantly adapting to these wavelengths of light [19]. Colours are classified as primary, secondary and tertiary colours. These may be classified as hot colours, which have high energy (e.g., red, yellow) and cool colours, which have low energy (e.g., green, blue).

2.1. Lighting

Proper lighting system for a workstation takes into account the visual demands of the task(s) and balances general or ambient lighting with task specific lighting to achieve comfort, efficiency and accuracy [7]. The proper lighting can contribute to the following functions: Illuminates specific tasks

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so that they can be completed accurately and efficiently; plays an important role in accident prevention and contributes to security in and around the workplace [1]. The colour affects the brightness of light [18].

Improper lighting causes excessive eyestrain and can result in tiredness or fatigue of the eyes. It can also contribute to generalized fatigue and stress. Poor lighting is also a workplace security hazard, especially for shift workers who may not have co-workers nearby or must walk to a bus or parking lot after dark [8].

2.2. Direct or indirect light sources

The source of the light can be either direct or indirect. Indirect light (reflected from a ceiling or wall) from several sources is better than direct light from a single source, because the light is more spread out and does not create shadows [13]. Direct light sources, such as overhead fluorescent lights, should be covered with diffusers or baffles to reduce shadows and spread out the light. For a specialized task such as parts inspection, lighting may be designed to form shadows.

Contrast is the dissimilarity or difference between things. Another meaning for contrast is in the context of colour. This can be the opposition of items that are compared or the act of distinguishing via differences comparison.

When determining proper lighting for a workstation, it is important to determine the visual requirements of the task, first. Electronics assembly, engine repair, and data entry on video display terminals all require different lighting. Size of the objects being viewed, amount of contrast between the object and the background and the allotted viewing time all help to determine both quality and quantity of light required for any given task.

The quantity of light falling on a surface is called illuminance [3]. More light is needed for fast paced fine detailed work with low contrast, such as rapid reading of small letters in pencil than for rough assembly work. The Illuminating Engineering Society of North America (IESNA) has developed recommended illuminance levels that account for the task, the age of the worker, and the speed and accuracy required.

There are several elements of light quality that must also be accounted for when determining the proper lighting for a workstation or work environment. These include luminance, reflectance, contrast, glare, and colour. Text colour did not significantly affect visual performance if an acceptable level of contrast ratio was present [16]. Luminance combination did significantly affect character identification performance, the effect of screen luminance combination may be disregarded as the luminance combination of screen is adequate and the contrast ratio is high enough. In general, character identification performance increased with increasing background screen luminance [17].

Each organ of our body is associated with a specific colour. Heart, bones, flesh and nerves have its own special colour. Even the microscopic cells also posses colour. Whenever the equilibrium of colour in an organ is weakened, one becomes ill. By colour therapy, the balance is restored; it can be used to cure psychosomatic illness and mental imbalance. One can get rid of both mental and physical weakness by continuously meditating on colours. Hence, there is a deep impact of colour on the human and its working. Coloured light has a particular ability to balance the autonomic nervous system, which is crucial in most chronic and functional disorders as it regulates all of the automatic processes of the human body: breathing, the beating of the heart, the functioning of the digestive tract, the stress response.

Now, a question arises, is there any effect of colour of walls, tables, machines etc. on human working, which affect the productivity in the industry or factory? By extensive literature survey it was found that colours affect a person's psychology, physiology, personality, mood etc.

Till now, the colour scheme has been used in offices, in factories, in machineries etc. to improve the aesthetic values of it. Colours have also been used in colour signals, in display devices etc. But the impact of colours on the production and eyestrain require exhaustive study. Now which colour has more reflectance, has positive effect on the person working in the environment and has effect on the productivity? To strengthen the idea, first of all an experiment was performed in laboratory and based on the results, an experimental setup was created in an assembly shop of electric meters and plastic toys, the real work area.

3. Experimental set-up

The main aim of this experimental set-up was to find out the reflectance of various colours. To find out the reflectance of the various colours, an experimental set-up was prepared. A cabin of size 4ft x 4ft x 4ft was fabricated as shown in Figure 1. The walls were painted by various colours for the different set of observations.

A bulb of 60W was illuminated in the cabin. By varying the voltage, intensity of the incident light (i.e., illumination) was varied. Observations were taken for the four different intensities 0.60 lux, 2.67 lux, 6.85 lux and 20.20 lux directly measured at the bulb.

For entire experiment surface finish of the wall was maintained constant. Intensity of incident light on the walls was varied. The luxmeter was used to measure the reflected light on observation spot. Four readings were taken for each colour. The experiment was performed for the red, orange, yellow, green, blue, indigo, violet, white and black colours. Observation data are shown in the Table 1.

Similarly, the second set of experiment was performed in which the direction of lux meter was exposed to direct as well as reflected light on the lux meter. The observations were taken for reflectance for each set of colours. Figure 2 shows the relation between various colours and intensity of reflected light. Figure 3 shows the reflectance of colours when lux meter is exposed to reflected light as well as reflected and direct light.

Although the reflection of light depends on the shining of the surface and other factors, but it also depends upon the type of colour painted on the surface. From Fig.3, it is clear that amongst the various colours, the yellow colour is most reflective. The order of reflectance in descending order is: yellow, white, orange, red, blue, green, violet, indigo and black. The colour black, generally assumed as with zero reflectance, but it is not so. It is also function of surface shining. The black colour have reflectance, but minimum amongst the all colours, that's why colour black is assumed as absorbing cent percent light.

3.1. Discussion

When the light falls on the coloured object or wall, it is reflected back. Different colours have different reflectance, hence the overall illumination of the working environment vary with the colours used, while the other factors are constant. This reflective and absorption nature of the colour can be utilized in the colour scheme of walls of the offices, industries, workshops, machines, equipment etc. Various colours paint the walls of the office or the factories, the machines etc; the curtains, which create the working environment for a person working in it. A person working in the office or the factory, need the illumination, which is done by industrial lighting. Appropriate selection of colour may lead to the better results, wherever surrounding environment is having colours.

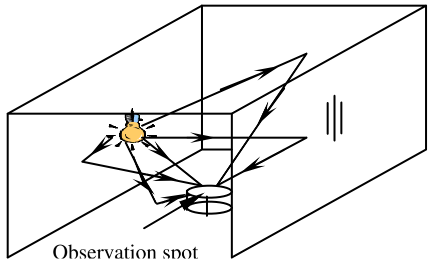

Figure 1. Experimental set-up for measurement of reflectance of different colours.

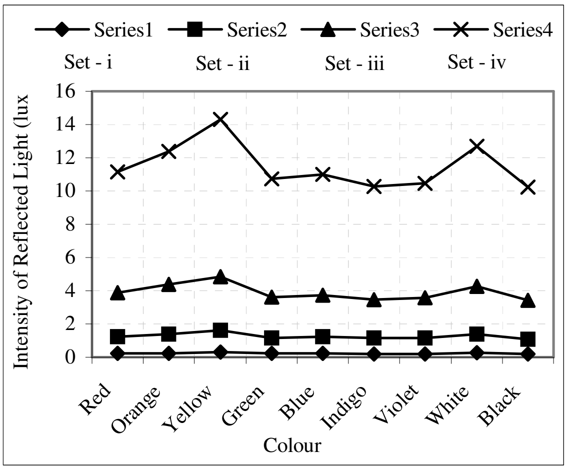

Figure 2. Colour v/s intensity of reflected light.

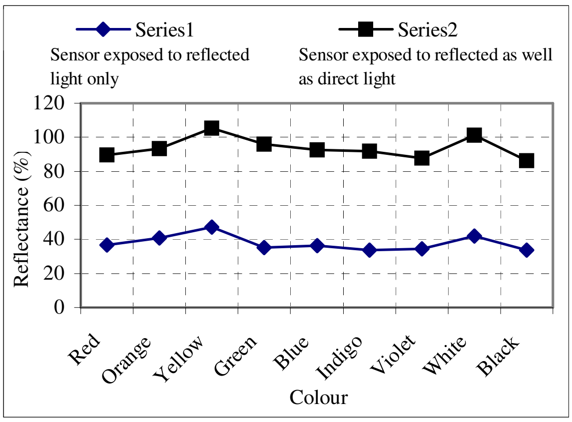

Figure 3. Colour v/s reflectance.

Table 1. Intensity of reflected light with varying colours at different intensity of incident light on walls.

S. No.	Colour	Intensity of incident light (i.e., light reflected form walls) on the observation spot (unit: lux)				Total (lux)	Reflectance of Colours (%)
		Set – i (0.60)#	Set – ii (2.67)#	Set – iii (6.85)#	Set – iv (20.20)#	30.32 lux	
1.	Red	0.24	1.01	2.65	7.25	11.15	36.77
2.	Orange	0.25	1.12	3.01	8.01	12.39	40.86
3.	Yellow	0.31	1.30	3.25	9.45	14.31	47.20
4.	Green	0.22	0.95	2.45	7.11	10.73	35.39
5.	Blue	0.23	1.01	2.50	7.27	11.01	36.31
6.	Indigo	0.20	0.95	2.31	6.82	10.28	33.91
7.	Violet	0.21	0.93	2.45	6.86	10.45	34.47
8.	White	0.26	1.14	2.88	8.40	12.68	41.82
9.	Black	0.20	0.88	2.36	6.81	10.25	33.81

Intensity of incident light in lux, measured at light source for each set of colour.

Table 2. Measurement of eyestrain for one day.

Experiment No. : 1		Colour used: Red				
Date and Day : Feb. 7, 2005 (Monday)		Exp. Set No.: 1				
S. No.	Questionnaires asked	Weighting of the Factor				
		Very less (25)	Less (50)	High (75)	Very High (95)	Total
1.	Eyes' pain		√			50
2.	Tearing in eyes			√		75
3.	Redness of eyes				√	95
4.	Vision problem	√				25
5.	Concentration problem			√		75
Total						**320**

4. Methodology and Observations

To understand the effects of colours, three experiments were performed in factories. Two shops were selected for the study, one shop for assembly of the electric meters and another for the assembly of Plastic-Toys. The colour of walls, tabletop and items to be assembled were taken as variables.

A healthy person was selected for the experiment. A set of experiment was performed for five days by considering the following parameters as constant: Age: 32 years, Eye sight of the person: 6/6 & 6/6; Colour of uniform: Gray; Temperature of surrounding: 22^{o}C to 27^{o}C; The sunlight illumination: considered constant throughout the experiment; Industrial lighting: two florescent light of 40W each and Working period: 8:00 hrs per day (i.e., standard time).

An assembly shop was taken for study. The walls were painted and colour of table top was changed by covers of different colours. Study was done for five days for the each colour. For the each set of experiment, observations were taken for eyestrain and number of items assembled per day. The worker was given all the usual work allowances. Same working conditions were given for all the set of experiments for each colour.

4.1. Effect of colours on industrial ctivities

To study the effects of various colours on industrial activity, three experiments were performed. These experiments are being explained as follow:

4.1.1. Experiment – I

The aim of this experiment was to study the effect of colour on eyestrain and rate of production in an assembly shop of the electric meters. In the assembly shop, main work was counting of the small items and joining them for assembly of the electric meter. The worker and other parameters were selected as explained above. The first set of experiment was done with red colour. At the end of first day worker was asked the questions and answers were noted down as shown in Table 2.

4.1.1.1. Measurement of eyestrain and production

The eyestrain was measured by subjective study. For this a questionnaire was prepared like eyes' pain, tearing in eyes, redness of eyes, vision and concentration problem. Then some weighting factors were assigned for the various levels viz. very less, less, high and very high. The production was measured by number of items produced per day. Only complete assembled meters were counted for items produced. Table 2 shows the method for measurement of eyestrain.

Similarly five sets of experiments were performed and average of weighting factor for eyestrain for five days was taken for each set of experiment for the same colour.

In Table 3, the average eyestrain and production for five days is shown as 67.2 and 10.8 respectively. The same methodology was followed for the other set of experiments and the data were recorded for the each set of experiment for each colour.

The study was performed for five days for each colour. The constant parameters were considered as above in experimental set-up. The variable parameters were colour of walls and tabletop. Observations were taken for eyestrain and number of meters assembled per day.

The same experiment was repeated for five days and average eyestrain and production was calculated. The average data observed for five colours are shown in the Table 4 and Fig.4.

4.1.1.2. Results

By analysis of the above Table 4 and Fig.4, it is clear that maximum production and minimum eyestrain were recorded when yellow colour is used for walls and tabletop, while minimum production and maximum eyestrain were recorded for the green colour.

Table 3. Measurement of average eyestrain and production for five days.

Experiment No.: 1		**Colour: Red**	
S. No.	**Days**	**Ave. Weighting Factor for one day**	**Production per day**
1.	Day – 1	64	11
2.	Day – 2	74	10
3.	Day – 3	62	10
4.	Day – 4	66	11
5.	Day – 5	70	12
Total		336	54
Average of five days		**67.2**	**10.8**

Table 4. Measurement of average eyestrain and average production for five set of colours.

S. No.	Colour	Average eyestrain	Work output Average of five day (no. of meters)
1	Red	67.2	10.8
2	Yellow	55.3	11.2
3	Green	82.1	8.8
4	Blue	74.8	9
5	White	64.3	10.6

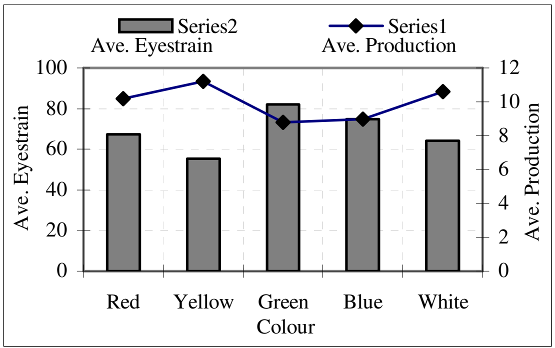

Figure 4. Average production per day and average eyestrain for five sets of colours.

4.1.2. Experiment – II

The aim of this experiment was to study the effects of varying colours on eyestrain and rate of production for the assembly of Toys – a Car. Experiments were performed in a small-scale industry, manufacturing the toys' parts and assembling their. Each toy contain nearly 20 parts and driven by mechanical power (i.e. operated by key and spring). To find out effects of colour on the work output, the assembly shop was considered for the study. The assembly work was totally table work and need the hand tools for the work. Two florescent lights were used to illuminate the work area.

The colour of toy was taken constant, i.e., light green. The variable Parameters are: colour of walls, and colour of tabletop. An observation table was prepared to record the eyestrain and work output. The eyestrain was recorded by subjective study. After every five days, the colour of walls and tabletop was changed. By this experiment, the observed data are shown in Table 5 and Fig. 5.

Table 5. Measurement of average production and average eyestrain for five set of colours.

S. No.	Colour	Average Eyestrain	Average production per day (no. of Toys)
1	Red	76.4	86.7
2	Yellow	95.3	82.1
3	Green	69.1	91.2
4	Blue	66.7	92.4
5	White	73.5	89.8

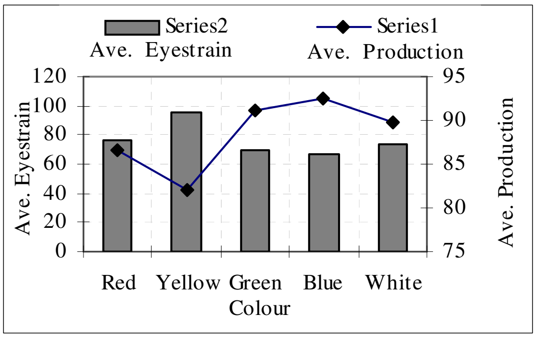

Figure 5. Colour v/s average eyestrain and average production.

4.1.2.1. Results

By analysis of the above Table 5 and Fig.5, the maximum production and minimum eyestrain were recorded when blue colour is used for walls and tabletop; while minimum production and maximum eyestrain were recorded, when yellow colour was used.

4.1.3. Experiment – III

In this experiment, the effect of 'colour contrast' on eyestrain and rate of production were studied. Colour contrast depends on the colour of the parts and its immediate back ground. A worker was selected as explained above in methodology. An assembly shop of toys was selected for study. The colour of toy was taken green and the colour of walls, yellow. The colour of tabletop was taken as variable to change the colour contrast. The variable colours selected were: red, yellow, green, blue and white. After every five days, the colour of tabletop was changed and data were recorded as shown in Table 6 and Fig.6.

Table 6. Effect of colour contrast on average eyestrain and average production.

Colour	Colour of Tabletop for contrast effect	Average Eyestrain	Average Production per day (no. of toys)
Wall: Yellow Toy: Green	Red	83.5	83.2
	Yellow	84.3	83.7
	Green	86.7	82.6
	Blue	80.1	85.5
	White	78.5	86.8

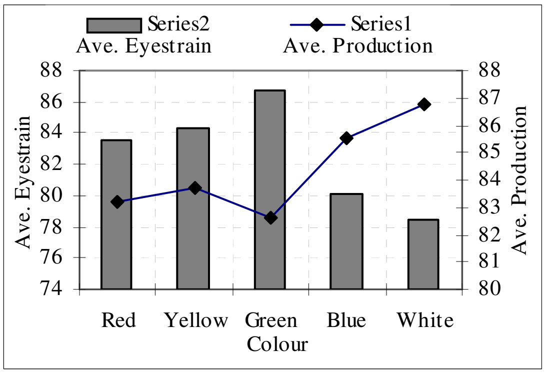

Figure 6. Colour v/s average eyestrain and average production per day with varying colour contrast (Colour of wall – Yellow and toy – Green).

4.1.3.1. Results

By analysis of the above Table 6 and Fig.6, it was found that when walls, toys and tabletop were selected Yellow, Green and Yellow colours respectively - maximum production and minimum eyestrain was recorded; while when walls, toys and tabletop were selected Yellow, Green and Green colours respectively for the toys of Green colour - minimum production and maximum eyestrain was recorded.

4.1.4. Experiment – IV

In this experiment, the effect of 'colour contrast' on eyestrain and rate of production were studied by considering the different colour of Toys, i.e., Yellow.

A worker was selected as explained above in methodology. An assembly shop of toys was selected for study. The colour of toy was taken Yellow and the colour of walls, yellow. The colour of tabletop was taken as variable to change the colour contrast. The variable colours selected were: red, yellow, green, blue and white. Eyestrain was measured by subjective study and per day production in terms of number of toys assembled. After every five days, the colour of tabletop was changed and data were recorded as shown in Table 7 and Fig.7.

4.1.4.1. Results

By analysis of the above Table 7 and Fig.7, it was found that when colours of walls, toys and tabletop were selected Yellow, Yellow and Green colours respectively - maximum production and minimum eyestrain was recorded; while when walls, toys and tabletop, were selected Yellow colour – the minimum production and maximum eyestrain was recorded.

Table 7. Effect of colour contrast on average eyestrain and average production.

Colour	Colour of Tabletop for contrast effect	Average Eyestrain	Average Production per day (no. of toys)
Wall: Yellow Toy: Yellow	Red	84.2	78.4
	Yellow	89.7	74.1
	Green	79.7	85.6
	Blue	80.1	83.2
	White	81.3	79.3

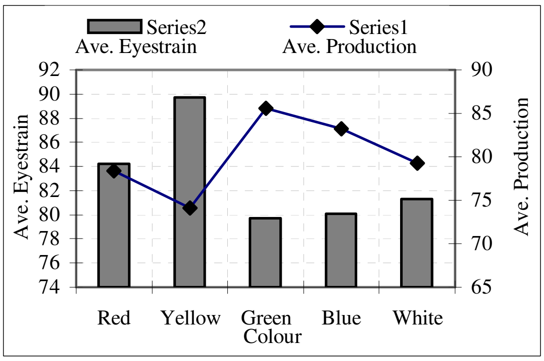

Figure 7. Colour v/s average eyestrain and average production per day with varying colour contrast (Colour of wall and Toy – Yellow).

5. Conclusions and Recommendations

Colour is the part of visible light. The colours have its own wavelength; hence the different amount of energy content in the light.

5.1. Conclusions

After conducting exhaustive experiment, results were obtained which shows the effect of varying colours on the human working and production output. If a worker works in the healthy environment, he/she will work with more enthusiasm, better moral value and hence, overall better productivity. The following conclusions were drawn from the above experiments:

- Reflectance is the percentage of light, reflected from a surface of body when light falls on it. When other parameters remain constant, the reflectance depends on colours used. The reflectance of colours in descending order is: yellow, white, orange, red, blue, green, indigo, violet and black.
- For assembly of small parts and precise work, more illumination is required. To illuminate the working environment and simultaneously to save energy, the yellow colour is better for walls and the tabletop for the assembly of small parts. It gives better illumination and less eyestrain.
- Comparatively large parts need less concentration and hence, less illumination will produce less fatigue in eyes. For the assembly of comparatively large parts, light green, blue or gray colour can be used.
- The colour contrast also affects the human working, hence productivity. Colour contrast depends on the colour of the items to be assembled and its immediate background. When the objects and the background are selected of the same colour, it gives the worst situation. High contrast is important for fine detail work.

5.2. Recommendations

Experimentally it was found that yellow colour has maximum reflectance and that of black colour minimum. Based on the above industrial experiments and conclusions, the following recommendations are given:

- Precise work needs more illumination. For this yellow and white colour is most suitable.
- Assembly of comparatively large work pieces need less illumination. For this light green and light blue colour is most suitable, which give minimum eyestrain.
- Colour contrast depends on the colour of the parts and its immediate back ground. The background colour should be light for dark object or vice-versa.
- In industries machineries (e.g., lathe machine, drilling machine, shaper machine, boilers, air compressors etc.) should be painted with cool colours (i.e., blue, green). It reduces glaring and eyestrain. But signals and emergency levers should be painted red or yellow for better perception.

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