ORIGINAL SCIENTIFIC PAPER
RECEIVED: 24-03-2014
ACCEPTED: 17-04-2014

ACTA GRAPHICA 223

Legibility of Pictograms on Coloured Surfaces Under Different Illuminants

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Abstract:

Ambient lighting conditions, under which the packaging is viewed, determine to a large extent the visual perception of the information which it carries. This paper investigated how different illuminants affect the legibility of pictograms intended for the application on different coloured packaging. 87 participants observed the pictograms on blue, red and yellow coloured backgrounds in a viewing booth which assured controlled lightning conditions. The results indicated that the legibility of pictograms varied in dependence of the background colour used. The best performance was obtained by pictograms designed on a yellow background. Furthermore, it was found that the pictograms were significantly more legible under illuminant 'A' compared to the other tested illuminants.

Keywords:

Legibility, Illuminant, Pictogram, Colour

1. Introduction

Pictograms are simplified graphic representations of objects, concepts or actions, whose meaning is understandable to most people. The main advantage of the use of pictograms is the picture superiority effect, since the pictorial content is easier to notice and to recall compared to the text (*Lidwell, et al., 2010*) and it thus overcomes potential language barriers. To achieve the effective information transmission, the pictograms should be quickly noticed and well understood. There is substantial amount of research on pictogram comprehension (*Chan and Ng, 2010; Erdinc, 2010; Lesch, 2003; McDougald and Wogalter, 2011; Waterson, et al., 2012*). However, comprehension cannot be achieved without the legibility of the presented message. In the context of pictorial communication, legibility is defined as the degree of visual clarity of presented signs (*Wogalter, et al., 2002*). There are numerous factors affecting legibility, such as the size of the visual form, viewing distance, figure-background contrast, print quality (*Wogalter, et al., 2006*). Schieber and Kline (1994) noticed decreasing legibility of signs due to illumination reduction from daytime to night-time luminance, especially with older observers. Furthermore, it was found that glossy coating or metallic inks in certain illumination conditions can produce specular reflectance which negatively affects the legibility (*Nilsson, 1991*). Legibility was also investigated in the domain of prohibitive symbols, where it was revealed that pictorial size and circle-slash thickness influence the legibility in deteriorated viewing conditions (*Shieh and Huang, 2004*). Circle-slash was investigated by Murray et al. (1998) who noticed that reduced legibility could be one of the reasons for participants' non-preferability of translucent slash in negation symbols.

By achieving good legibility of the pictograms, there is a greater possibility of noticing them. Some researchers investigated the noticeability of pictograms (*Bzostek and Wogalter, 1999; Horberry, et al., 1997*), but relatively small amount of them has been interested in their noticeability on the packaging (*Kovačević, et al., 2013; Laughery, et al., 1993*).

The most common application of the pictograms onto the packaging is for the purpose of safety warning or illustrating the instructions for the proper use of the product placed in the packaging. The variety of products in the market results in a wide range of packaging colours. Warm colours, such as red, orange or yellow, are commonly used for food products. In that case, the pictograms mostly have a role of instructions for use (e.g. how to prepare food, how to store it). The way of presenting this information can affect the users' success in preparing the food, and thereby influence their product satisfaction (*Levis, et al., 1996*). Pictograms are also used on detergents and maintenance products, and they mainly have a safety role. Packaging colours for these products are usually blue or green.

Besides the colour of the packaging, lighting conditions, under which the packaging is viewed, can also determine the legibility of pictograms. For example, fluorescent lamps are used as typical store lighting at the point of sale, when pictograms may affect the decision to purchase an item. After the purchase, the packaging can be viewed under daylight, especially if the product is intended to be used outdoors (e.g. gardening products). Finally, instructions on the packaging, including the pictograms, are mostly observed indoors, at home, immediately before using the product.

According to Klein (2010), some of the illuminants listed below can be used as a simulation of the mentioned lighting conditions. Illuminant A is recommended for simulation of home lighting. Because of its bulb which contains bromine, this light source has increased light efficacy and true colour temperature from about 2800 to 3000 K. For the simulation of typical store lighting, the cold white light of the fluorescent lamp CWF is useful. Its wavelengths cause a neutral white light with correlated colour temperature (CCT) about 4200 K. Fluorescent lamps have better luminous efficacy and a longer lifespan compared to tungsten lamps, which is the reason of their frequent use. For daylight illumination, the standard illuminant D65, with CCT of 6500 K, is recommended. Colours illuminated with D65 are perceived in a similar way as under daylight at midday on cloudless north sky. If this illuminant is unavailable, xenon lamps with CCT of 5000 K or 5500 K can be used.

Some studies have explored the influence of illumination on human perception. Pinto et al. (2008) investigated the CCT that produce the best visual impression of the painting. In their experiment, the observers adjusted the CCT of illumination according to individual preferences. It was found that daylight illumination with temperature of about 5100 K represent observers' preferences when appreciating art paintings. Studies show that lighting can also influence human emotions and behaviour (*Vogels, 2008*). Warm white light (2800 K) was perceived as cosier than cold white light (6000 K). Hawes et al. (2012) have manipulated different illuminants (3345 K, 4175 K, 5448 K, 6029 K) while investigating the influence on visual perception through three tasks; two of them measuring colour recognition and one measuring visual acuity. Although only one of the tasks showed performance improvement at higher colour temperatures, it was found that higher temperatures affect mood positively and increase arousal states, which leads to better cognitive performances. Furthermore, dependence of colour appearance on illumination was investigated by using flowers (*Yang, et al., 2014*). The perception of flower colours under 2800 K warm white fluorescent lamps, 3500 K plant growth lamps, and 6500 K light-emitting diodes was compared with that under 6500 K fluorescent lamps. The results showed that the colour differences were highest under 3500 K lamps.

2. Problem statement

The starting point of this study lies in discrepancy of illuminants under which the packaging is viewed on its way from the store to the place of product use, usually in the consumer's home. Illuminant is of crucial relevance in perception of packaging, because we see the coloured surfaces of the packaging as a result of light reflected from it. Visual impression of colours is affected by numerous factors. Factor of particular importance is the spectral power distribution emitted of the light source (*Klein, 2010*). One coloured surface can produce a different colour impression due to the changing illumination condition. For example, coloured surface seems to look greenish if viewed under the fluorescent illuminant, whilst, under the tungsten illuminant, tends to look reddish. It can be stated that colour perception varies with changes in illumination. Human visual system easily adapts to these changes, and consequently enables reliable visual impression of colours when viewed in different lighting conditions. The ability to maintain constant perception of one colour despite large changes in the illumination is known as colour constancy. This phenomenon is best achieved if coloured surface covers a large part of the visual field and if adaptation time lasts at least 1 minute (*Kulikowski, et al., 2009*). In everyday activities, during which consumer uses the product packaging, the adaptation time is long enough to provide colour constancy. However, human visual system does not achieve constancy in every possible situation and under every possible illuminant condition (*Kalderon, 2008*). Besides, constant perception of a packaging colour is not the only requirement for the legibility of pictograms applied on the coloured surface.

The legibility of pictograms is also determined by observer's subjective impressions. Previous researches have demonstrated that lighting conditions can influence subjective impressions. For example, blue colour is perceived to be more positive under the fluorescent illuminant than under the incandescent illuminant. On the contrary, red colour is perceived to be more positive under the incandescent illuminant (*Hegde and Rogers, 2012*). Subjective emotions can also be stimulated by colour temperature of the light source. Most studies have confirmed the positive effect of medium colour temperatures. According to Chang et al. (2009), people prefer colour temperature at 3000 K in the interior for all kinds of psychological states. In the study that manipulated light colours of fluorescent lamps, it was shown that colour presentation of beverage packaging is affected by colour temperature of white light (Wang, et al., 2010). It was found that consumers' buying desire is weaker in the lighting conditions of high colour temperatures, and that low colour temperatures produce a relax and pleasant atmosphere.

The objects of this study were the pictograms on the packaging which illustrate instructions for use of the product. Unlike the ones placed in the spatial surroundings (e.g. airport, bus), the pictograms placed on the packaging are reduced in size. Smaller pictograms are less legible (*Frantz, et al., 1999*), and therefore, it is important to consider some other potentially negative influences on their legibility, such as lighting conditions. In line with this, the following research questions are formulated. First, does the legibility of pictograms change relate to the colour of the background? Since it was found that changes in illumination affect colour appearance (*Bäuml, 1994*), the second question is: does the illuminant also affect the legibility of pictograms applied on backgrounds coloured differently? For the investigation the most common colours of the packaging were used, which include pictorial instructions for use. Simulations of typical lighting under which the packaging is observed on its way from the store to the consumers' home were also used. The purpose of the investigation was to determine the combination of background colour and illuminant that enables the best results in terms of the legibility of pictograms.

3. Methodology

Nine rectangular specimens of 60x60 mm were used for the examination of legibility. Each specimen consisted of a pictogram and coloured background. In every specimen pictograms were printed in black (C:0%, M:0%, Y:0%, K:100%), while the backgrounds differed according to colour. Three of the backgrounds were blue (C:75%, M:25%, Y:0%, K:70%), three were red (C:0%, M:75%, Y:75%, K:70%) and three were yellow (C:0%, M:10%, Y:75%, K:70%). These colours were chosen for the study based on the preliminary test which included 60 specimens; 10 specimens for each background colour, on two different types of paper. The selection of specimens was made by visual assessment according to the criterion that it had the most questionable legibility of pictograms.

In order to eliminate the possibility of memorizing the pictogram appearance as the potential influence on its legibility, for each specimen a different pictogram was designed (Figure 1). The pictograms were designed according to the parameters defined for the purpose of this study. These parameters referred to the lines representing the structural elements of the pictograms. Each pictogram consisted of five lines differing in the thickness. The example is shown in Figure 2. Line thickness was adjusted to the level of complexity of presented forms; thick lines were used for more complex forms, and thin lines were used for less complex forms. Generally, pictograms comprising simple forms are preferred (Mullet and Sano, 1995), so the pictograms in this study were designed as uncomplicated and concrete forms. The specimens were designed in Adobe® Illustrator® CS6 and printed on Canon PIXMA Pro9000 Mark II with resolution of 300 dpi on HP Photopaper Semi-glossy 170 gm^{-2}.

Figure 1. Pictograms used in the study

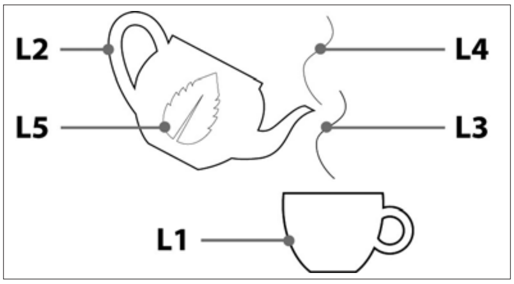

Figure 2. Example of structural elements of the pictograms; five lines differing by thickness (L1, L2, L3, L4 and L5 represents line thickness of 0.7pt, 0.5pt, 0.3pt, 0.2pt and 0.1pt, respectively).

Viewing conditions were set according to the recommendations for the visual colour measurement (Billmeyer and Saltzman, 1981). The experiment took place in the XRite Macbeth Judge II-S Light Booth located in a dark windowless room. Overhead lighting was turned off. The observers were asked to adapt to the illumination for 60 seconds between each of the stages of the experiment. They viewed the specimens at an angle of approximately 45° at a distance of around 30 cm. Specimens were placed on the floor of the booth. Booth's interior walls were matte and neutral. In the first stage of the experiment the specimens were illuminated by D50 (5000 K) which simulated daylight. In the second stage they were illuminated by CWF (4150 K) which simulated typical store lighting. In the final stage of the experiment they were illuminated by illuminant A (2856 K), simulating the most common home lighting conditions. Luminance level was approximately 1200 lux for all the sources.

Participants were students of the Faculty of Graphic Arts at the University of Zagreb. 87 observers participated in the study; 52 were female and 35 were male. Their ages ranged from 21 to 24 years (M=21.93 years, SD=0.99 years). They had normal or corrected-to-normal vision.

Observers were asked to take the Ishihara Colour Vision Test before the experiment to ensure that they did not have any colour defects. Before they started with the visual assessment, participants were briefed about the experimental procedure by using two specimens similar to those used in the experiment. The participants' task was to look at each of the specimens and identify the discerned lines of the pictogram. They were also informed that there was no time limit on their assessment, and that there was no need for analyzing the meaning of the pictograms. The experimenter showed them each specimen in randomized order. To assure accuracy, the participants' answers were recorded using an audio-recorder (upon obtaining participants' permission). Based on the recorded answers from every participant, a numerical score was assigned for each specimen according to the following criteria; 5 was assigned when the participant identified five differently thick lines of the pictogram, 4 was assigned when only four differently thick lines were identified, 3 was assigned when only three differently thick lines were identified, 2 was assigned when only two differently thick lines were identified and 1 was assigned when only one line was identified. This evaluation method was chosen to reduce the subjectivity of the results.

4. Results

The results of descriptive statistics showed that the highest level of legibility was in the case of yellow background and illuminant A (M=4.92, SD=0.313). The lowest level of legibility was in the case of blue background and illuminant D50 (M=3.85, SD=0.708).

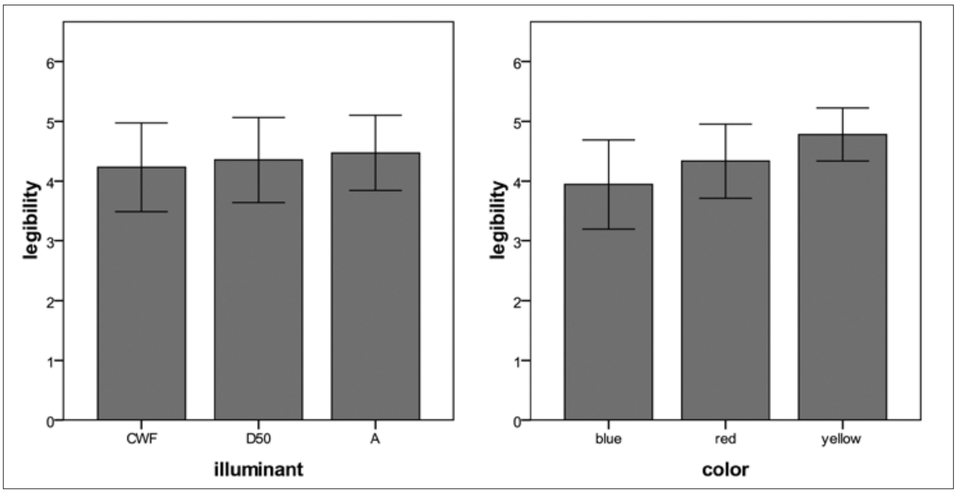

Figure 3. Means and their corresponding standard deviations of legibility of pictograms

The resulting data were analyzed with a Friedman test which showed a significant difference in legibility of pictograms depending on which light source was illuminated the pictograms ($\chi2(2)=23.49$, $p<0.05$). Furthermore, there was a significant difference in legibility depending on the colour used as background for the pictograms ($\chi2(2)=204.26$, $p<0.05$). Figure 3. shows means and standard deviations of legibility of pictograms for all illuminating conditions and all background colours.

Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at $p<0.017$. The results showed that the legibility of pictograms viewed under illuminant A was significantly better than the legibility of pictograms viewed under two other illuminants (Z=-5.295, r=-0.40 between illuminant A and CWF, Z=-2.605, r=-0.20 between illuminant A and D50). There was no statistically significant difference between the legibility of pictograms viewed under illuminants CWF and D50 (Z=-2.255, r=-0.17).

While comparing the legibility of pictograms on different background colours, the legibility was significantly better on the yellow background comparing to the red (Z=-8.619, r=-0.65) and the blue (Z=-12.263, r=-0.93). There was also significant difference in legibility between pictograms on the red and the blue background (Z=-6.601, r=-0.50).

5. Discussion

This study investigated the legibility of pictograms depending on the background colour and the illuminant under which the pictograms were viewed. The results indicated that the most important variable affecting the legibility was background colour. This was expected, since the background colour in the specimens deferred not only in hue, but also in brightness. Depending on the brightness of the colour, different contrasts were created between the pictogram and the background, and these contrasts mostly determined the legibility of pictograms. Some colours, such as yellow, are brighter than other colours, such as blue. Accordingly, the best legibility was achieved with pictograms on the yellow background, since yellow in combination with black provides the most enhanced contrast. Unlike yellow, blue colour with lower brightness level reduced the contrast, which led to poor legibility. These results are in accordance with the suggested guidelines for colour combinations for user interfaces (*Brown and Cunningham, 1989*), in which black colour is listed as the best choice for the application on yellow background, but also as the worst choice for blue background.

The results also indicated that the legibility is affected by the illuminant. Even though this influence was less prominent compared to that of background colour, it was found that under the illuminant A, which emits light of yellowish colour, pictograms become significantly more legible. This is consistent with previous researches which showed that people prefer colour temperature at 3000 K (*Wang, et al., 2010*). Furthermore, it was found that illuminant A has bigger colour gamut volume compared to illuminant CWF (*Spiridonov, et al., 2012*), which can indirectly be associated with the perception of the background colour in this study.

The results showed no significant difference in the legibility between the pictograms viewed under illuminants CWF and D50. One of the possible explanations for this could be uneven differences in the colour temperature between tested illuminants. The difference between colour temperatures of illuminants CWF and D50 is namely notably smaller compared to the differences between these two illuminants and illuminant A. This could also explain why the influence of illuminant CWF is considerably larger than illuminant D50 when compared with illuminant A.

6. Conclusions

By comparing the effects of illuminants on the legibility of pictograms it was found that illuminant A provides the best results. Since this illuminant simulates typical home lighting, it can be expected that pictorial instructions for the use on the packaging will be more legible and easier to view in the household, just before using the product. On the other side, there is a possibility of reduced legibility of pictograms on packaging of products for outdoor use, mainly because of different lighting conditions. Besides the difference in colour temperature, there is also the issue of instability of weather conditions (time of the day, season and cloudiness). Considering that in this study the simulation of daylight illumination was held constant, even a greater decrease in legibility can be expected in realistic conditions. Typical store lighting can also reduce the legibility of pictograms. This should be taken into account when there is a need for reading the instructions for product use before buying the product.

Although it was found that the illuminant may be one of the factors affecting the legibility, the most important determinant is the background colour. Since the pictograms on a blue background tend to be the least legible, blue packaging should be designed with special care, especially the ones for the product that can be hazardous if used improperly. In that case it is advisable to enhance the contrast between the pictograms and their background, enlarge their size and design them by using thicker line.

It should be noted that these conclusions represent just a few guidelines that should be taken into account while designing the pictorial instructions for use. The reason is that the legibility of visual information on the packaging is affected by the variety of circumstances in which users view the packaging. Some of them are changes in light intensity due to the power of the bulb or distance of the illuminant from the subject. Another factor is the quality of print, which can vary depending on producer, print technique, or ink specification. Finally, individual characteristics of the users, such as age or vision acuity, should not be ignored.

This study investigated only three hues of the coloured surfaces. The obtained results cannot therefore be generalized to other hues and colour ranges. Besides that, the pictograms used in this study differed by the level of structural complexity. Future research should examine the legibility of the pictograms with equable level of complexity. They should also include other structural elements of the pictorial information such as point or planes.

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