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THE PERCEPTION OF LIGHT COLOUR IS RELATIVE – A PILOT STUDY
DESCRIBING PERCEIVED LIGHT COLOUR

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Abstract

Perceived light qualities of lighting products are generally insufficiently described, reflecting that perception-based qualities, such as light colour, are not considered to the same extent as physical measures when creating light environments. It is well known that perceptual impressions are affected by, and relative to, surrounding stimuli. To develop descriptions of perceived light colour of white light sources, new concepts were evaluated in a pilot study combining paired comparison tests and descriptive sensory analysis. The findings confirmed that the perception of light colour is relative, demonstrated by cool light sources being perceived as warm/yellowish/reddish in relation to other cool light sources – which was well captured by the combined sensory methods with simultaneous light sources. The newest concepts, cyanish and magentaish light colour, were found to be useful in describing the perceived differences, showing that more concepts than warm, neutral and cool are needed for a richer description of light colour.

Keywords: visual perception; light colour; lighting assessment; sensory analysis; paired comparisons; analytical assessment

1 Introduction

Perceived light qualities of consumer lighting products are generally insufficiently described (e.g. Collier & Bernecker, 2018), reflecting that perception-based qualities are not considered to the same extent as physical measures when creating light environments. Previous studies have demonstrated that only fulfilling technical requirements, for instance in standards, increases the risk for less appealing environments (Dutson, 2010; Boyce & Wilkins, 2018), showing that other aspects, such as, contrasts and light distribution, can have a greater influence on the perceived light level and experience in the room than the actual measured illuminance (Cuttle, 2013; Fridell Anter, 2011; Küller, 2006). Hence, two light sources with similar physical performances can create different experiences depending on how the light is distributed (Boyce & Wilkins, 2018). This applies also to the perceived light colour observed by the human eye, which is not exactly connected to the physically measured colour temperature. That is, two light sources with the same correlated colour temperature can appear to be different with regard to light colour (Durmus, 2022; David et al., 2019). This may be due to physically measurable deviations from the light distribution from an ideal blackbody (Luo & Ma, 2019; Ohno, 2014), to human perception (Rea & Freyssinier, 2013a; Feng et al., 2016) or to human eyesight being very sensitive to these colour differences (David et al., 2019; Valberg, 2005), as is known from colour research (Chaparro et al., 1993; Hárd et al., 1995). Altogether, there is a lot pointing towards that physical measures do not give the complete description of how a light environment is experienced, and even less how appealing it is to people. Therefore, technical requirements need to be complemented with perceptual qualities in order to promote good light environments.

However, well-defined quality requirements, in addition to the quantifiable requirements in the standards, are not common when planning and procuring lighting for indoor environments for example. A common terminology is also largely lacking (e.g. Collier & Bernecker, 2018), which makes it particularly challenging for those with less expertise in lighting design to consider as well as motivate perceptual and aesthetic qualities of lighting (Fridell Anter, 2012; Petersdottir, 2002; Pertola, 2012). The concepts that do exist, for example warm, neutral and cool light
colour, are often too general to be completely useful in describing a perceived light quality (Rea & Freyssinier, 2013b).

Furthermore, perception in general, and not least colour vision, is also context-dependent (Köster, 2003; Royer, 2021). This means that the experiences of colour, and other visual perceptions, are relative to their surroundings (explored and explained by many, e.g. Arnkil, 2015; Liljefors, 2005; Fridell Anter, 2000; Billger, 1999). For example, it is well known that two stimuli next to each other, such as two colours, interact and influence our experience, which can be referred to as the simultaneous contrast effect (e.g. explained in Valberg, 2005; Albers, 2013). This effect demonstrates that qualities typically are affected by its opposites. For example, a visual stimulus will appear lighter when placed next to a darker one, warmer next to a cooler, and more intense next to its complementary colour (Pridmore, 2021). This (visual) phenomenon can be used purposely to enhance or moderate a product quality, affecting consumer behaviours (e.g. Peng et al., 2022). Similarly, intentional or unintentional differences between two light sources side by side may in this way impact the visual perception of one another and the impression of the room as a whole or parts of it, especially regarding perceived light colour.

To contribute to the development of description of perceived qualities of light, and in particular how to describe small differences in perception of light colour, new concepts are introduced and evaluated by analytical sensory analysis in a pilot study combining paired comparison tests and descriptive sensory analysis. Sensory analysis has been successfully used in various commercial and academic areas for many decades to study perceived qualities of products (Stone, 2012; Lawless & Heymann, 2010). A paired comparison test identifies whether there is a difference or not between the products, and where contrasts between the light sources can become more apparent when they are next to each other, as described above. A descriptive analysis is particularly suitable for describing people's non-subjective perceptions, leaving out personal preferences that are not relevant in general descriptions and when developing a common terminology. Paired comparison tests have previously been applied to lighting and colour qualities, as well as visual experiences (Huang et al., 2023; Huang et al., 2020; Jost-Boissard et al., 2015; Katayama et al., 2007; Houser & Tiller, 2003), and descriptive analysis has been applied to lighting products (Nordén et al., 2015; Boork et al., 2022; Hiller et al., 2023), while the combined approach is new, and of interest to investigate.

1.1 Objective

The objective of the study is to explore how perceived light colour of two white light sources, which are simultaneously compared, can be described using a combination of sensory methods.

2 Methodology

Analytical sensory methods, in the form of paired comparison tests in combination with quantitative descriptive analysis, were used to explore and describe perceived differences in light colour between pairs of light sources. Quantitative descriptive analysis of individual light sources has been used before (e.g. Boork et al., 2022; Hiller et al., 2023), but a combined method have not commonly been employed and would potentially both capture how the individual light sources are perceived as well as how they are affected by the light sources next to them. The set-up was introduced on a workshop with lighting experts/practitioners, showing that (small) differences could be discovered in this way. To apply the set-up scientifically, the current study was conducted as a pilot study with limited number of pairs and light sources. The study was carried out in January 2022.

2.1 Assessments and concepts

The chosen sensory methods are suitable for describing the perception of the light in a non-subjective way. This is done by a trained panel that assesses a set of qualities analytically, that is without taking personal preferences or opinions into account. Panellists with well-developed senses, in combination with training before performing the actual assessments, are thereby a prerequisite for obtaining robust and usable sensory data (Albinsson et al., 2017). In this study there were eight panellists (a number typical for descriptive tests) who individually performed the assessments of each pair of light sources.
Concepts to describe the light colour were introduced to the analytical panel during training. Warm, reddish, bluish, yellowish and greenish light colour were concepts already known to the panel, while magentaish and cyanish light colour were new. These comprise the primary and secondary colours according to additive colour mixing seen in the RGB colour wheel in Figure 1. The later concepts were chosen based on the outcome of the workshop with lighting experts/practitioners, performed as a pretrial to this study. Each concept was assessed considering to what extent the light is experienced to shift towards a specific colour (red/blue/yellow/green/magenta/cyan), which was marked on unipolar line-scales from 0 to 100, anchored at 10 (indicating “little”) and 90 (indicating “to a great extent”). This design of the protocol is typical for descriptive tests, where each product, here light source, is assessed on a separate protocol (Albinsson et al., 2017). Commonly, paired tests report differences on a joint protocol. The assessments were carried out in three test booths, each supplemented with two white boxes with round openings through which indirect light was visible, see Figure 2. The assessments were performed in triplicate and in a randomized order.

Additionally, the panellists were asked to give their feedback on how they experienced the combined sensory methods.

Figure 1 – RGB colour wheel
(Attribution: DanPMK at English Wikipedia)

Figure 2 – The set-up of the tests

2.2 Lighting products and physical measurements

The experimental design comprised common consumer products of white LED lighting set-up in pairs. To explore whether there were perceivable differences between the products within each pair, pairs of similar, cool and warm light sources were investigated.

Physical measurements were performed in connection with the sensory assessments. Spectra and colour parameters were measured using an Ocean Optics QE65000 spectrometer. The colour parameters included the correlated colour temperature (CCT) and colour rendering index (Ra/CRI), verifying the product specifications of the lighting products. The properties of the lighting products in each pair are specified in Table 1; all products were omnidirectional light sources.
Table 1 – Properties of the lighting products

<table>
<thead>
<tr>
<th>Pair</th>
<th>Properties, including spectral distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>Light source A</strong> 3720 K, R&lt;sub&gt;a&lt;/sub&gt; 88, 270 lm*, Clear</td>
</tr>
<tr>
<td></td>
<td><img src="image1" alt="Radiant Power" /></td>
</tr>
<tr>
<td></td>
<td><strong>Light source B</strong> 3980 K, R&lt;sub&gt;a&lt;/sub&gt; 88, 270 lm*, Clear</td>
</tr>
<tr>
<td></td>
<td><img src="image3" alt="Radiant Power" /></td>
</tr>
<tr>
<td>2</td>
<td><strong>Light source C</strong> 3840 K, R&lt;sub&gt;a&lt;/sub&gt; 88, 250 lm*, Frosted</td>
</tr>
<tr>
<td></td>
<td><img src="image5" alt="Radiant Power" /></td>
</tr>
<tr>
<td></td>
<td><strong>Light source D</strong> 3922 K, R&lt;sub&gt;a&lt;/sub&gt; 86, 400 lm*, Frosted</td>
</tr>
<tr>
<td></td>
<td><img src="image7" alt="Radiant Power" /></td>
</tr>
<tr>
<td>3</td>
<td><strong>Light source E</strong> 2616 K, R&lt;sub&gt;a&lt;/sub&gt; 87, 400 lm*, Frosted</td>
</tr>
<tr>
<td></td>
<td><img src="image9" alt="Radiant Power" /></td>
</tr>
<tr>
<td></td>
<td><strong>Light source F</strong> 2620 K, R&lt;sub&gt;a&lt;/sub&gt; 86, 250 lm*, Clear</td>
</tr>
<tr>
<td></td>
<td><img src="image11" alt="Radiant Power" /></td>
</tr>
</tbody>
</table>

*From product specification, that is not measured.

2.3 Statistical analysis

The data from the assessments were analysed using descriptive statistics, meaning that mean values were calculated for all the assessments by all panellists (triplicate assessment x no. of panellists) of a certain concept of a specific lighting product. The differences between assessments of the light sources within each pair, for each light colour-related concept, were compared by Student’s t-test.

3 Results

The results from the assessments of the concepts are presented for each pair of light sources in the figures below.

*Pair 1* (Figure 3): There were significant differences between the light sources in the perception of warm, as well as cyanish light colour (*p* ≤ 0.05). In general, although not always statistically significant, one light source (B) was perceived to be more cyanish, bluish, and greenish, and the other light source (A) as more warm, reddish, and yellowish. This split between the light sources was in line with the traditional concepts of cool and warm colours. These differences were confirmed by the physically measured colour temperatures, where light source B had a slightly higher colour temperature than light source A. This was also shown in the spectral
distribution curves, with a somewhat higher dominance of short-wave frequencies for light source B.

Figure 3 – Mean values (on a scale 0-100) of the assessed concepts for pair 1, i.e. light sources A and B. The significance levels of the t-test comparisons for $p \leq 0.1$ are shown in brackets. NS means not significant.

Pair 2 (Figure 4): Magentaish light colour was perceived significantly different between the light sources in this pair ($p \leq 0.05$). The split between the two products was that one (C) was to a greater degree perceived as more magentaish, reddish, and bluish, while the other (D) was perceived as more greenish, yellowish, and cyanish (not all significant). Again, in spite of very similar colour temperatures, the perceived light colour of the two light sources differed.

Figure 4 – Mean values (on a scale 0-100) of the assessed concepts for pair 2, i.e. light sources C and D. The significance levels of the t-test comparisons for $p \leq 0.1$ are shown in brackets. NS means not significant.
**Pair 3** (Figure 5): This pair demonstrated that there were significant differences for the perceived bluish light colour ($p \leq 0.05$), although the degree of bluishness was at a lower level than for the other two, cooler, pairs. The light sources split into higher bluish, reddish, and magentaish for one of the light sources (F), and into warm, yellowish, and greenish for the other (E). The spectral distribution curves showed that light source F had a somewhat higher peak in the short-wave frequency, which might explain the perceived difference to some extent. In addition, the light source with lower luminous flux (F) was perceived as more bluish, while the one with higher luminous flux (E) was perceived as more yellowish (not significant for $p \leq 0.05$). This was also in parallel to pair 2. The fact that light source E was frosted, while light source F was clear might also have added to the different experiences of light colour.

![Figure 5](image_url)

Figure 5 – Mean values (on a scale 0-100) of the assessed concepts for pair 3, i.e. light sources E and F. The significance levels of the t-test comparisons for $p \leq 0.1$ are shown in brackets. NS means not significant.

The panel was generally positive about the new concepts. However, it felt like some colour hues were missing, such as orangish. There were mixed experiences as to whether the pairwise comparisons were easier or more difficult than individual tests where only one light set-up is assessed at a time.

### 4 Discussion

This pilot study investigated how perceived light colour of lighting products can be described. The focus has been on describing small differences in the perception by simultaneously assessing light sources with a combination of the sensory methods paired comparison test and quantitative descriptive analysis.

The concepts of reddish, bluish, yellowish and greenish light colour were introduced and assessed together with the completely new concepts of magentaish and cyanish light colour. The results showed that the light sources could be perceived in line with the traditional concepts of cool and warm colours (pair 1), but also along the division of magentaish, reddish, and bluish versus greenish and yellowish (pair 2 and 3). Although all the differences between the concepts were not significant, the results showed that the traditional division into warm and cool was not enough to describe the perception of light colour, which is also illustrated in a previous study (Hiller et al., 2023). Other studies are also attempting to expand the descriptions of light colour. Precisely the concepts of reddish, bluish, yellowish and greenish light colours are initially included in the tests in (Davis et al., 2011); however, the concepts are considered too difficult for the participants to assess. In particular, the bluishness of the light is not that clearly understood. Even though the number of concepts had increased in the present study compared to previous studies performed by the authors, the panel still felt that some colour hues were
missing, such as orangish, which would then represent a tertiary colour in the RGB colour wheel.

That further hues were desirable is possibly understandable as minor differences can become clearer in a set-up with paired tests. That the panel perceptually picked up on differences in comparison of the two similar light sources (pair 1) is in line with previous studies which also discovered that subtle differences are revealed by participants (e.g. Besenecker et al., 2018). Several other studies stress the relativeness of perception as the surrounding environment and nearby stimuli can have a great influence, not the least on the perception of colour (Fridell Anter, 2000; Billger, 1999). The relative perception and the differences between stimuli can both be scaled up and down, which is particularly demonstrated by the simultaneous contrast effect (Albers, 2013). In the current study, this was shown by that the cooler light sources (CCT around 4000 K) could be perceived as warm/yellowish/reddish next to another cool light source (pair 1), although not to the same degree as light sources with lower CCT (pair 3). The simultaneous contrast effect was also observed in the present study as the pairs of light sources were assessed opposite to one another with respect to the complementary colours in the RGB colour wheel. That is, cyanish in contrast to reddish (pair 1), bluish in contrast to yellowish (pair 1 and 3), greenish in contrast to magentaish (pair 2). The importance of “complementarism” for the visual perception, not least related to colour contrast, is thoroughly described in (Pridmore, 2011).

The combined sensory methods paired comparison tests and quantitative descriptive analysis seemed to work. The later method was known to the panellists, while the paired test was new and there were mixed experiences as to whether this set-up was easier or more difficult than individual tests where only one light set-up is assessed at a time. Most paired comparison studies ask the participants to compare stimuli with each other by assessing and reporting the actual differences, either through predefined attributes with forced-choice options (e.g. Atlı et al., 2020) or by self-reported attributes for which the stimuli differ (Houser & Tiller, 2003). Disadvantages of only assessing predefined attributes are that other qualities that differentiate the stimuli may be missed and there is also a risk that the participants do not understand the meaning of the attributes (Houser & Tiller, 2003). Whether predefined or non-predefined attributes are suitable depends on the question posed in a study. For instance, a study can have an exploratory approach where all kinds of differences are of interest, or a study’s objective could be more precise where a specific quality is in focus, such as light colour in the current study. In terms of participants not understanding attributes, that risk is minimised in studies using analytical sensory methods, as in the present study, since the panellists are trained and jointly defining the attributes. Furthermore, a paired comparison test can involve presenting the stimuli simultaneously, as in the current study, or presenting them consecutively (e.g. Tazehmahaleh et al., 2022). One study has been found with a similar combined set-up as in the study in this paper; that is, stimuli are shown at the same time, but each stimulus is rated separately on a linear scale (Yu et al., 2023). The study by Yu et al. also demonstrates that the set-up works well, which seems promising as this imply that the combined method can work in different contexts and applications. In (Yu et al., 2023) six stimuli (colour patches) are shown simultaneously and colour preferences are rated.

5 Conclusions and further studies

This study explores how perceived light colour of two white light sources, which are simultaneously compared, can be described using a combination of sensory methods.

The perception of light colour is shown to be relative, demonstrated by cool light sources are perceived as warm/yellowish/reddish in relation to other cool light sources. The significance of the relative experience is also revealed by differences between two similar products are perceptually picked up on when they are placed next to each other. Additionally, even if physically measurable differences contribute to the experiences, they do not with clarity explain and describe the complete perceived differences. These interactions between two stimuli are well captured by the combined sensory methods with simultaneous light sources.

The newest introduced concepts, cyanish and magentaish light colour, are found to be useful in describing the perceived differences for two of the assessed pairs, which shows that more concepts than warm, neutral and cool are needed for a richer description of the light colour.
The current study was conducted as a pilot study with limited number of pairs and light sources. As the results indicate that a combined method of paired comparison tests and descriptive sensory analysis is applicable, it would be useful to perform a more comprehensive study to verify the feasibility of this set-up more thoroughly, as well as to further explore terminology to describe small perceived differences in light colour.

References


Hiller, C. et al. THE PERCEPTION OF LIGHT COLOUR IS RELATIVE – A PILOT STUDY DESCRIBING...


