Improvement of lighting ambience on board trains: experimental results on the combined effect of light parameters and seat colours on perception

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Summary
For the time being, lighting specifications for train interiors include only functional parameters of illuminance (level and uniformity) and standards are more oriented on security than on comfort target. Since three years now, SNCF has developed a research program on visual comfort in order to better understand customer's perception and expectations about lighting ambience and improve specifications for new trains and refurbishing for existing ones.

The paper presents experimental results on the combined effect of light parameters and seat colours on passengers’ perception. The results confirmed thus obtained from commercial inquiries concerning the illuminance levels which are perceived as too high. Our results show that if a level <150 Lux is proposed, the lighting ambience is perceived as relaxing and soft while it is perceived as glaring, aggressive and tiring if the illuminance is >200 Lux which is usually the case in actual train interiors.

1. Introduction
For the time being, lighting specifications for train interiors include only functional parameters of illuminance (level and uniformity) and standards are more oriented on security than on comfort target.

The EN 13272 standard [EN 13 272, 2002] suggests to fix the illuminance in train coaches at least at 150 Lux. No maximum thresholds are proposed and some train configurations can reach in actual practice 200 Lux as 400 Lux without any specification.

Since three years now, SNCF has developed a research program on visual comfort in order to better understand customer's perception and expectations about lighting ambience and improve specifications for new trains and refurbishing for existing ones. The project started with an extensive study on passengers’ perception. The method consists in collecting passengers' discourses about their travel and their feeling of visual comfort with the help of a questionnaire based on open questions and filled during commercial journeys. Both diurnal and nocturnal conditions have been tested, both during journeys in the morning and in the evening to be representative of typical conditions for passengers. Diurnal inquiries have been realized in October and nocturnal ones in December. A psycholinguistic method developed through a previous research program on passengers’ global comfort [Delepaut, 2007] has been used. From linguistic analysis of passengers' answers, cognitive interpretation has been proposed and allows the determination of visual parameters pertinent in passengers’ perception. This method leans on the comparison between situations which are perceptively contrasted in passengers’ perception. Different situations of TGV on one way and on regional trains in another way have been chosen. For each travel situation (regional or TGV), the differences on each configuration rest on visual parameters like seat colours, seat arrangement implying different perception of space, lighting source and implantation, materials used in the interior [Talotte and al, 2008].

The main visual parameters of comfort spontaneously quoted by people when open questions about visual agreement and disagreement are asked were colour and light. Colour is the first input in passengers’ judgment of a train interior but can not be easily operate for specification. No consensus can be easily found because among other things colour evaluation seems to be highly correlated with light and with age of train. For example, grey colour of seat can be appreciated for renovated interior while it is badly evaluated for an older train.

As for the light, passengers’ evaluation is essentially associated with the activity they practice (to read, to work, to rest) and people highly asked for an individual adjustment. The more consensual result on lighting ambience evaluated by passengers in all train and travel configurations is that the lighting level is too high to sleep and rest [Talotte, 2009].

Following these results, two experiments have been defined to study in more details:
- The combined effect of light parameters and seat colours on perception,
The need of individual adjustment of light.
The paper will present the results of the first experiment carried out on board an experimental train. The section 2 pointed out the bibliographical and laboratory results which have been used to define the experimental protocol which is presented in section 3. The section 4 gives a discussion on the main results and perspectives of results exploitation are proposed in section 5.

2. Bibliographical results
The main reference on the combined effect of colour temperature and illuminance on pleasantness of lighting is the work of Kruithof [Kruithof, 1941]. This work has been carried out when fluorescent lighting has just emerged. As shows Figure 1, Kruithof proposed a zone of colour temperature and illuminance combinations where illumination can be considered as pleasant. He considered that users would find pleasant high correlated colour temperature and high illuminance and low colour temperature with low illuminance.

![Kruithof diagram about combined effect of colour temperature and illuminance on lighting judgment, from Kruithof, 1941](image)

This work is still used by lighting engineer but recent studies tends to opposed this conclusion [Cuttle and Boyce, 1998], [Davis and Ginther, 1990]. A more recent study used LED clusters that deliver continuous light spectra with a very high colour rendering index CRI which favoured the consistency of the subjects’ responses [Vienot and al, 2009]. This work opposed partially Kruithof rules. There is indeed no indication that high colour temperature is judged more pleasant than low colour temperature at higher illuminance levels. Figure 2 shows that observers find the least pleasant the low illumination and the most pleasant the low colour temperature of lighting.

![Perceived pleasantness under 9 combinations of colour temperature and illuminance obtained in laboratory with LED clusters, from Vienot and al, 2009](image)

3. Experimental Protocol
The combined effect of colour temperature, illuminance and colour of seats on perception has been studied in an experimental train, IRIS 320. IRIS 320 is the TGV train that measures the track parameters and watches regularly infrastructure network [Foeillet, 2008]. One coach of this train set is arranged with first class TGV seats and can be modified for our experiments.
The objective of this experimentation is to study the combined effect of three parameters:
- The colour temperature of light,
- The illuminance,
- The colour of seats.

We have explored the mechanisms by which the change in lighting and seat colour might change the perception. The values of experimental parameters have been defined following these assumptions:
It has been demonstrated in the literature and confirmed in our first experiments on commercial trains that the outcome of lighting is not easily characterized by people when lighting stays in conditions commonly assessed for a defined context. Then passengers should be placed in the experiments in “pushed” conditions compared to the usual ones on board commercial trains. Then it has been chosen to define combinations of the three parameters which are not usual for a train configuration but which are known by passengers in other situations (office, museum, hospital, home, trendy bar). The evaluation was realized in comparison with TGV configuration which has been also tested as reference. The value of illuminance and colour temperature of light has been fixed following standard (for working places or hospital) or measurement carried out in different places (museum, home, trendy bars). The Figure 3 shows the parameters’ values which have been chosen.

<table>
<thead>
<tr>
<th>Ambience</th>
<th>Illuminance (Lux)</th>
<th>Color temperature (K)</th>
<th>Seat color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home (red seats)</td>
<td>50</td>
<td>2350</td>
<td>red</td>
</tr>
<tr>
<td>Home (blue seats)</td>
<td>50</td>
<td>2350</td>
<td>blue</td>
</tr>
<tr>
<td>Museum</td>
<td>150</td>
<td>3550</td>
<td>grey</td>
</tr>
<tr>
<td>TGV</td>
<td>150</td>
<td>2800</td>
<td>grey</td>
</tr>
<tr>
<td>Trendy bar</td>
<td>200</td>
<td>3500</td>
<td>red</td>
</tr>
<tr>
<td>Office (red seats)</td>
<td>425</td>
<td>3500</td>
<td>red</td>
</tr>
<tr>
<td>Office (blue seats)</td>
<td>425</td>
<td>3500</td>
<td>blue</td>
</tr>
<tr>
<td>Hospital</td>
<td>500</td>
<td>4600</td>
<td>blue</td>
</tr>
</tbody>
</table>

Two situations have been added to study cross conditions when warm colour of seat (red) is illuminated by cold light (office red seats) and symmetrically cold colour of seat (blue) is illuminated by warm light (home blue seats) to check if the practical rules of lighting engineer can be applied in train interior.

The colour temperature and illuminance variations have been obtained with fluorescent tubes. As colour has been identified as one of the most important parameters of visual comfort on board a TGV coach, a very good colour rendering index has been used (CRI>92) to neutralize this effect. Filters have been added for two configurations to obtain the target of colour temperature. Illuminance and colour temperature have been calibrated by measurements on the train coach. Figure 4 shows the calibration measurements carried out with a Minolta CS-1000 spectroradiometer aimed at a white spectralon tile placed on the table.
The coach arrangement which can be seen in Figure 5 allows 11 persons to be seated. Each configuration has been tested by 22 recruited passengers in two sessions. The experiments have been carried out in the evening (between 5.00 and 8.30 pm) which correspond to typical journey and in December to assess nocturnal conditions. Each session lasted one hour: passengers were asked to practice one activity as in a real journey and to fill in a questionnaire at the end of the session. This questionnaire started by two open questions whose results complete our knowledge acquired during commercial inquiries and carried on with closed questions which are the main issue of this experiment. In these questions, people were asked to choose 4 or 5 words in a choice of ten to qualify their perception of seat colour, light and lighting ambience. The words used in the questions are thus which have been mentioned spontaneously by passengers in commercial inquiries completed by other words used by subjects in laboratory experiments presented in section 2.

The analysis of the answers uses Simple Correspondence Analysis (CA) method which allows to project data from an n-dimension space on a 2D map and therefore a synthetically presentation of the results and an easier interpretation. Each axe has a percentage of representation of all the information contained in the n-space. This percentage is an indicator of relevance of its interpretation with the obtained map. The main results obtained are then discussed in section 4.

4. Results and discussion

Seat colour
The map represents 87% of the information contained in the answers. The analysis allows gathering the tested ambience by seat colours as shown in Figure 6.
- The grey seats are characterized by a drab and dark colour.
- The red seats contrast with grey seats in the first axe: they are characterized by bright and warm colour. The colour is all the more qualified as bright since the illuminance is higher.
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- The blue seats are qualified as cold. These results do not show explicitly that a colour is preferred compared to another one but can nevertheless be used by marketing department to check if their intention fit with the terms quoted for a chosen combination of seat colour and illuminance. These results are of course not exhaustive because only 8 combinations have been tested, they can just be considered as a tendency.

![Figure 6: Simple Correspondence Analysis of answers on seat colour perception](image)

**Light**
The map represents 95% of all information contained in the answers. The different ambiances are contrasted following the illuminance level as shows the Figure 7:
- The light is qualified as neutral, pale and dim for illuminance lower than 150 Lux (home, museum, TGV).
- It is qualified as bright and strong for illuminance higher than 200 Lux (office, trendy bar and hospital).

![Figure 7: Simple Correspondence Analysis of answers on light perception](image)
**Lighting ambience**

The map represents 94% of all information contained in the answers and the first axe 90% on its own. As for the previous question on light perception, answers are highly correlated with illuminance as shown in Figure 8:

- The lighting ambience is perceived as relaxing and soft for illuminance lower than 150 Lux (TGV, museum and home).
- It is perceived as glaring, aggressive and tiring for illuminance higher than 200 Lux (office, trendy bar and hospital).

![Figure 8: Simple Correspondence Analysis of answers on lighting ambience](image)

The analysis of these two answers tend to suggest that the value of 150 Lux is more relevant to fit passengers' perception rather as a maximum than a minimum as advocated in the standard. Concerning the results of the "cross combinations" of warm and cold seat colour and light: the office combination (425 Lux, cold colour temperature of 3500 K) is more appreciated with blue seats (described as cold) as with red seats (described as warm) which confirm the practical rules adopted by lighting engineers. For home configuration (50 Lux, warm colour temperature of 2350 K), the difference between the two seats colours is less outstanding and the practical rule seems to be less relevant maybe because of the low level of illuminance. This rule should then be used carefully for railway interiors.

5. **Conclusion and perspectives**

The paper presented the results of an experiment which studied the combined effect of seat colour, colour temperature and illuminance level on passengers' perception. The results confirmed thus obtained from commercial inquiries concerning the illuminance levels which are perceived as too high. Our results show that if a level <150 Lux is proposed, the lighting ambience is perceived as relaxing and soft while it is perceived as glaring, aggressive and tiring if the illuminance is >200 Lux which is usually the case in actual train interiors.

These results confirm the relevance of the choice of reducing the light during the journey which has been taken recently in TGV Est line. The research project will end with a study on the individual needs of passengers to adapt their own light.

6. **References**

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