Towards the integration of personal task-lighting in an optimised balance between electric lighting and daylighting: A user-centred study of emotion, visual comfort, interaction and form-factor of task lights

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Abstract. Task-lighting is a well-known strategy to save energy by bringing light where it is most needed, providing adaptable localised light conditions of special interest in the current home-office context. Despite these benefits and in addition to negatively impacting biological rhythms, the generalization of backlit screens has made task lights less demanded, with screen users tending to accept significantly lower amounts of the illuminance standards. In parallel, the advantages of task-lighting may contradict the energy benefits of presence-driven lighting or blinds automation. This pilot experiment aims at evaluating the task light usage patterns and characteristic preferences for both paper and computer work from a user-centered perspective to provide guidelines in terms of luminaires characteristics. Thirteen participants evaluated three different task lights in both paper and computer conditions. Our results emphasize the role of the luminaire’s form factor, interface and lighting control characteristics, providing general recommendations on luminaire design.

1. Introduction

Given that the energy consumption of lighting loads represents, worldwide, almost 20% of the building energy demand of office buildings \cite{1}, lighting in buildings offers promising energy-saving potential \cite{2}. Numerous research efforts pursuing this aim focused on developing adaptive systems according to the standards \cite{3, 4}, for instance by increasing the daylighting share \cite{5}. An alternative and promising pathway could lie in fostering a user-centered approach to challenge the normative framework \cite{6} and reach beyond standards to maximize occupants’ visual comfort and minimize energy consumption. In this regard, task-lighting is a well-known energy-saving strategy, bringing light where it is the most needed while remaining in the occupants’ control.

Recently, the generalization of backlit screens emitting direct light in the users’ eyes has notably reduced the use of task lights in office buildings \cite{7}. In addition to harmful impacts on biological rhythms \cite{8, 9}, we recently showed that such screens as the sole lighting source in the proximal working environment causes users to select a significantly lower amount of light...
than recommended by existing standards [10]. In such cases, the poor ratio brought by backlit screens between screen luminance and global illuminance leads to sore eyes, among others [11].

A strategy to counteract the adverse effects of backlit screens aims at increasing desk illuminance through the reintroduction of task lights. Indeed, task-lighting competes with the screen illuminance, involving lower energy expenses than general lighting [12], while enabling to personalize the proximal environment [13, 14]. This strategy is well suited to the current home office context, providing adaptable localised light conditions to support occupants’ satisfaction [12]. However, some studies highlight the need to use task lights with caution, as their prolonged use without general lighting cause visual fatigue [15].

Task-lighting, being user-controlled, may also contradict the benefits of presence-driven lighting or blind automation. The present study is part of the LUCIDELES research project aiming to study the potential for an energy-efficient user-centered light automation preserving the advantages of task-lighting while overcoming the disadvantages of backlit screens. This pilot experiment was set up to evaluate the task light usage patterns and characteristic preferences for paper and computer work from a user-centered perspective. This approach aims at providing task luminaires guidelines regarding form-factors, interface characteristics, and lighting controls.

2. Method

2.1. Participants
13 participants – 6 females; 11 right-handed (age \(M = 31.69, SD = 10.44\)) – took part in this study. All participants were used to office work. Before the experiment, most participants were in a good mood, calm, and comfortable. They all gave informed consent to participate in this study and were informed that they could withdraw their data by the end of the study.

2.2. Room, Task lights characteristics and Measurements
The experimental space was rectangular, with a table at the centre facing the entrance door and two large windows fitted with blinds on both the north and south sides. The space had dimmable LED beams for general lighting. The three luminaires used in this user study were:

- **Luminaire A**: a luminaire with a smart bulb allowing both intensity and correlated colour temperature (CCT) control.
- **Luminaire B**: a luminaire allowing both intensity and CCT control independently.
- **Luminaire C**: a luminaire with intensity and CCT control combined.

Figure 1 represents pictures of the luminaires and two users’ chosen setup before each task. The room was also provisioned with global electrical lighting and daylight contribution. The initial light conditions were set by manipulating general lighting and daylight through the blinds. The amount of desktop illuminance was set to probe action from participants (\(M = 142.00, SD = 33.52\)) and a CCT of 5500 Kelvin (\(M = 5553.00, SD = 314.19\)). Two Hagners SD2 illuminance meters, placed on each side of the laptop, were dedicated to illuminance measurement. The laptop was plugged to power, and the screen brightness was kept fixed for the whole experiment duration at a brightness level of 120 cd/m² as recommended by ISO 3664:2009 [16].

2.3. Procedure
Participants first completed a short questionnaire designed to gather socio-demographical data as well as their feeling and comfort before the experiment. Then, participants were presented with each luminaire in a random order, with the experimenter explaining the luminaire’s functionalities. After a short testing period, participants had to set lighting conditions as comfortable as possible to conduct two short reading tasks on computer and paper (order randomized). Task performance was not recorded as tasks provided tangible artefacts mimicking

1 A: Tolomeo (Artemide) with Trädfrí bulb and interface (IKEA); B: Joker (Regent); C: John (Tobias Grau)
ecological working conditions. Upon optimal light conditions found by the participant, desktop illuminance and colour temperature were recorded. After each luminaire testing, participants answered a questionnaire, including the selection of adjectives among a list to map participant’s sentiment using the circumplex method of affects [17] (see Section 2.4). After luminaires testing, participants answered an additional questionnaire comparing the luminaires preference. The study duration was about half an hour.

2.4. Data Analysis
Luminaire questionnaire data was collected for each task light after task completion. To compare the task lights with each other, Friedman tests compared the difference in luminaire’s ratings, with Wilcoxon tests Bonferroni-corrected for multiple comparisons. Furthermore, task lights were separated in two groups: the “preferred” and the “not-preferred” (median score of the two not-preferred luminaires), with differences between them assessed using Wilcoxon tests.

To analyse participant sentiment toward their emotion, the aspect of the luminaire itself and the light provided by the luminaire, we used the circumplex method of affects [17]. We inferred three circumplexes (for emotion, object and light), using the method described in [18], which will be described in a subsequent publication. Adjectives selected by the participants in the questionnaires were mapped within each circumplex space. Rayleigh tests assessed whether the selected adjectives indicated a direction or resulted in a uniform distribution around the circumplex space. When at least two groups exhibited a direction, a CM test assessed the significance of the difference in directions. Again, we here divided the circumplexes data into preferred and not-preferred task lights.

Finally, the illuminance and the CCT were compared across luminaires and task conditions with repeated measures ANOVAs. To meet the ANOVAs assumption of normality, data were visually inspected and outliers winsorised. When the sphericity assumption was violated, the Greenhouse-Geisser correction was applied. Differences between task lights were assessed through Bonferroni-corrected post-hoc tests. One participant was excluded from this analysis for having wrong sensor readings. The data was analysed in python and JASP [19].

3. Results
3.1. Setup
All participants moved the three task lights, except one participant who moved only the task light C. The main reasons to move the luminaires were, according to participants’ comments, to avoid glare or change light direction to illuminate the working area properly. Participants place luminaires in idiosyncratic ways, directing light toward or away from them, close or far from the paperwork (see Figure 1).
3.2. Questionnaires

Every participant noticed the ability to control task lights’ intensity with the three luminaires. However, the CCT control ability of task light C was not clear to participants as eleven participants did not have the impression they were able to change CCT. The interaction effect between task lights and the ability to change CCT revealed a significantly greater number of participants that did not perceive the change in CCT with luminaire C, whereas the two other luminaires exhibited a higher number of participants that perceived CCT changes (see Table 1).

| Questions | Luminaire | Descriptives | Statistics | Comparison |
|-----------|-----------|--------------|------------|------------|
| Notice a change in (choice between yes, no and not sure): | A | yes: n=12, no: n=1, not sure: n=0 | $\chi^2(4) = 24.96, p < .001$ | - |
| CCT | B | yes: n=11, no: n=1, not sure: n=1 | - | - |
| | C | yes: n=1, no: n=11, not sure: n=1 | - | - |
| Ranking (scale from 1 the worst to 5 the best): | Ease of use | A | $Mdn = 5.00, CI_{95} = [4.60, 5.00]$ | $\chi^2(2) = 7.30, p = .026$ | A vs B: p=.03 |
| | B | $Mdn = 5.00, CI_{95} = [1.00, 5.00]$ | - | - |
| | C | $Mdn = 4.00, CI_{95} = [2.00, 5.00]$ | B vs C: N.S. | - |
| | Ease of understanding | A | $Mdn = 5.00, CI_{95} = [4.00, 5.00]$ | $\chi^2(2) = 13.41, p = .001$ | A vs B: p=.008 |
| | B | $Mdn = 2.00, CI_{95} = [1.00, 5.00]$ | A vs C: N.S. | - |
| | C | $Mdn = 5.00, CI_{95} = [2.00, 5.00]$ | B vs C: N.S. | - |
| Preference (choice) | Luminaire | A | n=8 | - |
| | B | n=3 | - |
| | C | n=2 | - |
| Interface | Button | A | n=8 | - |
| | Application | n=3 | - |
| | Not sure | n=2 | - |

Table 1. Results of questionnaires

The task lights differed significantly in the rating of ease to use and understand to use with luminaire A having higher ratings than luminaire B, whereas the luminaire C did not differ significantly from the two others. There was no significant difference between task light rated comfort (see Table 1).

Regarding the light’s ranking, there were no significant differences across preference, interface, working and comfort ranking.

There were significantly more participants preferring task light A over the two other task lights. Moreover, participants would rather interact with a task light through a button than an application (see Table 1).

3.3. Circumplex evaluation of emotion, object, and light

No significant differences were found between luminaires’ emotional perception within the three circumplexes spaces.

Regarding the circumplexes analysis between the preferred and not-preferred luminaire, the circumplex for emotion revealed that only the preferred luminaire indicates a specific direction toward pleasant. Interestingly, in the circumplex for object, the preferred luminaire point toward common, whereas the not-preferred luminaire point between common and artificial and this difference was statistically significant (see Table 2 and Figure 2). Finally, regarding the circumplex for light, both preferred and not-preferred task lights indicated a common direction toward relaxing.

3.3.1. Light usage across luminaires and tasks

Results from Table 3 and Figure 3 reveal that both the luminaire and the task conditions impact significantly on the illuminance. The principal effect of the task light condition reveals that overall, the luminaire C was dispatching a significantly higher illuminance than the two other luminaires. Regarding the task condition, participants increased the illuminance significantly from the starting condition in both the paper and computer task. Interestingly, the illuminance set during the paper task was significantly
Table 2. Results of Circumplexes method of affects

| Circumplex type | Luminaire | Direction | Comparison of directions |
|-----------------|-----------|-----------|-------------------------|
| Emotion Preferred | Toward pleasant (S= 4.31, p=.011) | Not Evaluated |
| Object Not-preferred | Toward common (S= 9.97, p < .001) | P = 3.85, p=.049 |
| Light Preferred | Toward relaxing (S= 4.84, p=.006) | N.S. |
| Not-preferred | Toward relaxing (S= 5.45, p=.003) |

Table 3. Results of light usage across luminaires and task

| Condition | Lux | M | SD | Principal | Interaction | Post-hoc | P-value |
|-----------|-----|---|----|-----------|-------------|---------|---------|
| Luminaire A | 475.28 | 343.49 | F(1.13,11.26)=8.57, p=.012, η²=.10 | F(1.36,13.57)=7.52, p=.011, η²=.11 | A vs B | N.S. |
| Luminaire B | 613.31 | 441.69 | | | A vs C | .002 |
| Luminaire C | 996.82 | 1203.62 | | | B vs C | .021 |
| Task Start | 137.08 | 36.31 | F(1.34,13.35)=32.53, p<.001, η²=.39 | F(1.34,13.35)=32.53, p<.001, η²=.39 | Start vs Paper | <.001 |
| Task Paper | 1278.92 | 1023.46 | | | Start vs Computer | .003 |
| Task Computer | 669.41 | 439.11 | | | Paper vs Computer | .001 |
| CCT Luminaire A | 4435.79 | 1080.21 | F(2.20)=10.27, p<.001, η²=.06 | F(4.40)=6.22, p<.001, η²=.03 | A vs B | N.S. |
| Luminaire B | 4449.92 | 987.12 | | | A vs C | .004 |
| Luminaire C | 3861.77 | 1231.17 | | | B vs C | .002 |
| Task Start | 5553.00 | 314.10 | F(2.20)=119.84, p<.001, η²=.73 | | Start vs Paper | <.001 |
| Task Paper | 3512.00 | 576.52 | | | Start vs Computer | <.001 |
| Task Computer | 3682.49 | 908.36 | | | Paper vs Computer | N.S. |

Figure 2. Depiction of differences between preferred and not-preferred task lights within the three circumplexes space.

higher than the computer task. Finally, the interaction effect indicates that the difference between starting illuminance, the computer, and the paper task were the biggest for luminaire C and the smallest for luminaire A (see Table 3 and Figure 3).

The luminaire and the task condition also impacted significantly on the CCT level. Specifically, post-hoc tests show that luminaire C was dispatching a significantly warmer light than luminaire A and B. Additionally, participants set a significantly warmer light than from the starting condition in both the paper and computer task. Finally, the interaction effect indicates that the difference between the starting condition and the computer and paper task differed more for luminaire C than the two other luminaires (see Table 3 and Figure 3).

4. Discussion and conclusion

Overall, most participants preferred the classic luminaire with a smart bulb (the luminaire A), while not scoring the highest either in terms of visual comfort or amount of light. Participants’
reasons for preference lie in usage and interface simplicity. In terms of interface, participants would rather use a button over an application for task-lighting but would consider an application for general electric lighting control.

The luminaire A allows independence in CCT and illuminance control, which appears to be crucial as CCT control remained ignored from participants when CCT and illuminance were bound (Luminaire C), this even though luminaire C was set to provide a warmer light than the two others. Altogether, the binding of those light characteristics restrict participants’ degree of freedom to achieve optimal visual comfort and conceal there impact on light.

The circumplex analyses revealed that the preferred luminaire brought on average a “pleasant” emotion, a “relaxing” and “direct” light, and was felt as “common”. This result reflects the preference of participant for a classic and straightforward luminaire providing a slightly warm and well focused light.

In terms of light characteristics, the participants needed less light when reading on a computer screen than on paper, while CCT appeared the same between these conditions. This confirms our previous results [10] and additionally reveals that solely the amount of illuminance appears to be affected by backlit screen luminance.

The study provides the following recommendations for task luminaires: The luminaire should be easy to use and understand, with a simple and common form factor. It should have the ability to be moved and provide a relaxing light avoiding either too gloomy or exciting atmospheres; with the ability to adapt both CCT and intensity independently through tangible buttons.

Our results should be appraised taking into account the variation of daylight throughout the experiment, hence modifying light quantity and quality during the tasks. While meant to preserve an ecological value, this could have led to different light settings across participants. However, we assumed that the variation in daylight was marginal, since the blinds were, in most cases, closed to reach the starting conditions (2 participants with both blinds closed; 4 with one blind close completely and the other partially, 5 with both blinds partially close and 3 with blinds open). Another limitation could arise from the use of a laptop computer. Indeed, prolonged laptop usage was found to lead to postural issue and consequently neck, back or wrist pains [20, 21]. However, in the current experiment, the laptop was mainly for the participant to set up the lighting when using a backlit screen for a short period of time. Consequently, we do not think using a desktop computer with screens, keyboard and mouse would have substantially changed our results.

Future studies should complement the presented pilot experiment in evaluating other task light designs with focus on the interplay of desktop illuminance with backlit screens usage and including daylighting. The overall goal is to provide energy saving recommendations for the use of task lighting next to backlit displays without compromising occupant comfort.

Figure 3. Violin plots of the color and illuminance levels within each task conditions and for each task light. Notes: * $p < .05$, ** $p < .01$ and *** $p < .001$. 
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References

[1] Gago E, Muneer T, Knez M and Köster H 2015 Renewable and Sustainable Energy Reviews 41 1–13
[2] Roisin B, Bodart M, Deneyer A and D’Herdt P 2008 Energy and Buildings 40 514 – 523 ISSN 0378-7788
[3] 2002 Lighting of indoor work places Standard International Organization for Standardization Geneva, CH
[4] 2002 Light and lighting - Lighting of work places - Part 1 : Indoor work Standard European Committee for Standardization Brussels, BE
[5] Bodart M and Herde A D 2002 Energy and Buildings 34 421 – 429 ISSN 0378-7788
[6] Andersen M 2015 Building and Environment 91 101–117 ISSN 0360-1323
[7] Escuyer S and Fontonyont M 2001 Lighting Research & Technology 33 77–94
[8] Begemann S, Van den Beld G and Tenner A 1997 International Journal of Industrial Ergonomics 20 231–239
[9] Wakamura T and Tokura H 2000 Nursing & Health Sciences 2 41–49
[10] Papinutto M, Nembrini J and Lalanne D 2020 Building and Environment 186 107356 ISSN 0360-1323
[11] Sheedy J E, Smith R and Hayes J 2005 Ergonomics 48 1114–1128 ISSN 00140410
[12] Dubois M C and Blomsterberg Å 2011 Energy and buildings 43 2572–2582
[13] Loe D 2009 Lighting Research & Technology 41 209–218
[14] Loe D 2003 Society of Light and Lighting, London
[15] Küller R 2004 Building issues 1
[16] 2009 Viewing conditions—graphic technology and photography Standard International Organization for Standardization Geneva, CH
[17] Russell J A 1980 Journal of personality and social psychology 39 1161
[18] Rogoza R, Cieciuch J and Strus W 2019 Personality and Individual Differences 109775
[19] JASP Team 2020 JASP (Version 0.14.1)[Computer software] URL https://jasp-stats.org/
[20] Farias Zuniga A M and Côté J N 2017 Human factors 59 546–563
[21] Price J M and Dowell W R 1998 Proceedings of the Human Factors and Ergonomics Society Annual Meeting vol 42 (SAGE Publications Sage CA: Los Angeles, CA) pp 629–633