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OFFICE LIGHTING FOR LIGHT-SENSITIVE INDIVIDUALS: A PILOT TEST

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Abstract

Employees with light sensitivities may find conventional office lighting to be unacceptable, leading to requests for accommodations ranging from delamping to relocation. This paper reports a pilot test of an innovative LED luminaire to provide a suitable lit environment for light-sensitive individuals. Fourteen volunteers with either self-identified or medically diagnosed light sensitivities and seven volunteers from the general population (all Canadian public servants) worked for two days in a room lit with recessed luminaires with prismatic lenses and LED lamps (4000 K R_a ~ 84) (reference lighting) and two days in another week in a room with LED luminaires (3500 K, R_a = 90) with innovative optics and dimming control (test lighting). All participants judged the test lighting to have higher lighting quality than the reference lighting. Participants with light sensitivity experienced less intense visual symptoms over the workday in the test lighting, and began the following day with less intense symptoms.

Keywords: light sensitivity; office lighting; lighting quality; well-being; visual comfort

1 Introduction

A subset of the general population is subject to health problems triggered by light exposure. This diverse group includes people who experience migraines and those who experience asthenopia (Perenboom et al., 2018), which is a constellation of symptoms of eye fatigue including dry eyes, itchy eyes, blurry vision and headache. For the most part the causes of these problems are unknown and they appear early in life, but these problems can also arise later, for example as a result of traumatic brain injury. Whatever the cause, some of these problems are severe enough in response to common office lighting that the individual seeks a workplace accommodation to ensure a healthful workplace that supports their needs.

In open-plan spaces, accommodations for those with special needs can include removing the light source from the luminaire directly over the cubicle (a solution that is not available for integrated LED luminaires); relocation to another place in the building; or, working from home. This pilot project tested the feasibility of using an innovative LED luminaire to provide a more suitable lit environment for light-sensitive individuals.

2 Method

2.1 Participants

All participants were employees of the Government of Canada. Light-sensitive participants were recruited by e-mail to an existing network of employees championing workplace accessibility. General population participants were recruited by e-mail to staff at the National Research Council of Canada. Table 1 shows the group characteristics.

Table 1 – Characteristics of participants

	Age	Sex			Light Sensitivity		Leiden Visual Sensitivity Scale Mean (SD)
		men	women	prefer not to say	Medical diagnosis	Self-ID	
Light-sensitive	18-59	4	8	2	9	5	17,57 (7,57)
General pop'n	18-59	2	5				6,86 (4,06)

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The Leiden Visual Sensitivity Scale (Perenboom et al., 2018) is a validated 9-item questionnaire on which respondents indicate the severity of any visual symptoms they experience, each on a scale from 0-4; the score is the sum of the answers to each item, and the maximum possible score is 36. There was a clear difference between the groups in their scores on this scale.

2.2 Setting and Lighting Conditions

This experiment took place in two windowless rooms normally used as classrooms in an employee learning centre in an office building in Ottawa, Canada, loaned to the project because no courses were offered during the COVID-19 pandemic. The rooms could seat as many as 12 people, but were occupied for this project by a single person at a time because of pandemic restrictions. The two rooms were very similar except for the lighting systems (Figure 1). Sit-stand desks were installed for the participants.

The reference lighting system consisted of non-dimmable prismatic-lensed recessed luminaires 0,3 m wide by 1,2 m long equipped with 4000 K LED retrofit tubes having R_a of ~84 (R_f = 84), delivering ~420 lx on the desk.

The test lighting consisted of dimmable recessed LED luminaires 0,6 m wide by 1,2 m long with a proprietary optical design. This system was selected partly on the basis of advice from the advisory panel to this project, which included a light-sensitive individual who viewed an installation of this luminaire in a local building, and reported that this distribution appeared more comfortable than the reference lighting. For the pilot test, the luminaire was equipped with 3500 K, R_a ~94 (R_f = 89) LEDs and dimming control (from a wall switch near the entrance) that applied to the whole room. The test lighting had a possible illuminance range of ~50 lx to ~800 lx, chosen deliberately for this pilot test. The dimmer was set to maximum at the start of each test day. This combination of lighting characteristics was chosen based on the office lighting quality literature (Papamichael et al., 2016, Veitch et al., 2010).

Figure 1 – Views of the two rooms, from the vantage point of the sitting occupant. The left photo shows the reference room, and the right photo shows the test room.

The team conducted extensive physical measurements of all lighting conditions before and after the data collection period (July – December 2021). Table 2 summarizes the light source characteristics, and Table 3 characterizes the light distribution.

Table 2 – Light source characteristics

Condition	T_{cp} (K)	D_{uv}	R_a	R_f	P^{st}_{LM}	SVM
Reference	3916	0,0003	84	84	0,0743	0,0069
Test 100%	3302	-0,0008	94	89	0,0099	0,0130
Test 80%	3302	-0,0011	94	89	0,0493	0,0104
Test 60%	3290	-0,0011	94	89	0,0558	0,0149
Test 40%	3286	-0,0015	94	89	0,0702	0,0191
Test 20%	3283	-0,0018	94	89	0,0322	0,0225

Note. Spectral irradiances used for colour quantities were measured vertically for a seated occupant and with the computer monitor off. The temporally resolved illuminances used for the calculation of P^{st}_{LM} and SVM were measured horizontally on the desk.

Table 3. Light levels and light distribution in the two rooms, averages of measured values on two occasions.

Condition	Average desk illuminance, seated height (lx)	Horizontal illuminance uniformity (minimum:average), seated height	Vertical illuminance, seated height, facing monitor (lx)	V:H illuminance ratio, seated height
Reference	411	0,44	226	0,55
Test 100%	796	0,88	567	0,71
Test 80%	632	0,88	433	0,69
Test 60%	487	0,85	334	0,69
Test 40%	345	0,84	247	0,72
Test 20%	194	0,77	154	0,79

2.3 Dependent Measures

All the self-reported data were collected using online questionnaires that participants accessed using their own laptops, but often viewed on the monitor supplied by the project. Light sensitivity was assessed using the Leiden Visual Sensitivity Scale (Perenboom et al., 2018). Sleep quality was assessed with questions adapted from Smolders et al. (2013): the times of going to bed and waking (to determine sleep duration), a rating of the ease of falling asleep (-3 very difficult to +3 very easy), and a rating of how they had slept (sleep quality, -3 very badly to +3 very well). The mood assessment used a single-item affect grid to record pleasure and arousal (Russell et al., 1989). Visual symptom severity (VS) and physical symptom severity (PS) were each rated in terms of how the participant felt at that moment, on a scale from 0 = “not at all” to 4 = “extremely”. The four visual symptoms rated were: smarting, itchy, or aching eyes; sensitivity to light; teary eyes; dry eyes. The seven physical symptoms were :sore back, wrists or arms; excessive fatigue; headache; difficulty thinking; emotionally upset; anxious; hypersensitivity to stimulation. The visual symptom severity scale has been used previously by our group (Veitch et al., 2010); the physical symptom list used here was expanded following advisory board feedback, to ensure coverage of symptoms experienced by these light-sensitive people. The VS score was the average score for the four visual symptoms; the PS score was the average of the seven physical symptoms.

Ratings of the lighting used the 10-item forced-choice Office Lighting Survey (Eklund and Boyce, 1996) and the NRC Lighting Quality scale (Veitch and Newsham, 2000). The NRC Lighting Quality scale returns ratings of overall lighting quality (0-4, higher values are better quality) and bothersome glare (0-4, higher values are more bothersome). Participants also rated their own appearance as viewed in a mirror with low-iron glass on five semantic differentials: natural — unnatural; colourful — colourless; unhealthy — healthy; beautiful — ugly; pleasing – displeasing, scored from 0-100 and averaged into one score for which higher values mean better appearance (Veitch et al., 2012). Similarly, they judged room appearance on nine semantic differentials (Veitch et al., 2012) from which four scales were created, following de Vries et al. (2020): like – dislike; ugly – beautiful; subdued – pleasant; attractive – unattractive [Attractiveness score]; natural colours— unnatural colours; colourful — colourless [Colourfulness score]; radiant – gloomy; distinct – vague [clarity score]; dim – bright [brightness score]. The room appearance scores with more than one contributing rating were averaged, and all were scored from 0-100 with higher values indicating better appearance.

At the end of the fifth day (their last in-person day in the experiment), participants also completed a set of questions to determine what beliefs they held about the effects of lighting and what knowledge they held about lighting technologies. These were updated versions of the Lighting Beliefs Questionnaire and the Lighting Knowledge Questionnaire (Veitch and Gifford, 1996). They also were asked to provide their “personal light recipe” of preferred conditions.

2.4 Procedure

2.4.1 Experimental protocol

Participants were recruited by e-mail, and scheduled to participate on either a Monday/Tuesday in two successive weeks, or a Thursday/Friday. If possible, two people were scheduled for each testing block, and the same experimenter ran all four days for a given block.

On the first morning, participants completed consent forms in a large common area, and then were randomly assigned to one of the two rooms as their starting condition. Participants worked alone in the same room for both days in a week, different rooms for the first and second weeks.

Participants did their own work on their own laptops. At 8:45, 11:30, and 15:30 they received an e-mail prompt to complete a questionnaire presented on a secure NRC server Table 4 displays the schedule of questionnaires, which were detailed in section 2.3.

2.4.2 COVID-19 considerations

The data were collected between July and November 2021, during which time most Canadian public servants worked from home. Few people were present in the building in which this study took place. Other COVID protocols were: Wednesdays were left open to permit a thorough cleaning between pairs of participants. All staff were required to wear a medical mask at all times while indoors and to maintain physical distance as much as possible; antiseptic lotion was available if needed. Apart from the experimenter, the only other person near the test area was a commissionaire who was present to assist in the case of emergency (so that if one participant needed assistance, the other would not be left unattended).

2.5 Data analysis plan

The data for the light-sensitive and general population groups were analysed separately, there being no intention to compare the groups. The questionnaire data were analysed with linear mixed models (LMM) with a first-order autoregressive structure with homogeneous variance, reflecting the repeated measures time sequence of the responses. LMM accepts differences in the number of participants at different levels, which allowed us to use all of the data even if some individuals did not complete participation on all four days. Noting the fact that this was a pilot project, and therefore exploratory, we accepted all data without regard for the normality of the distributions. Each dependent variable was analysed in a separate analysis. We report means and standard deviations, inferential test scores, and the Cohen’s d effect size indicator (Cohen, 1988) using Cohen’s suggested convention for interpreting the size: small effects have $d \sim= 0.20$, medium effects have $d \sim= 0.50$, and large effects have $d \sim= 0.80$.

Table 4 – Questionnaire schedule

Time	Day 1 Test or Ref Room	Day 2 Test or Ref Room	Day 3 At home	Day 4 Test or Ref Room	Day 5 Test or Ref Room	Day 6 At home
8:45	Demographics Leiden Visual Sensitivity Scale					
8:45	Sleep Mood Visual symptoms (VS) Physical symptoms (PS)	Sleep Mood VS PS	Sleep Mood VS PS	Sleep Mood VS PS	Sleep Mood VS PS	Sleep Mood VS PS
11:30	Mood VS PS Office Lighting Survey (OLS)	Mood VS PS OLS		Mood VS PS OLS	Mood VS PS OLS	
15:30	Mood VS PS OLS NRC Lighting Quality (NRC-LQ) Personal Appearance (PA) Room Appearance (RA)	Mood VS PS OLS NRC_LQ PA RA		Mood VS PS OLS NRC_LQ PA RA	Mood VS PS OLS NRC_LQ PA RA Lighting Effects Lighting Tech Personal preferences	

The varying frequency of the different questionnaires gave rise to three LMM models. Pleasure, arousal, VS and PS during the testing days had been measured three times. We used the morning responses as baseline values, and calculated change scores for the midday and afternoon responses. Thus, there was a 3-way analysis of these change scores: 2 lighting X 2 day x 2 time. The NRC-LQ scores and the PA and RA ratings were available for the afternoon of each testing day, and were analysed in a 2 lighting x 2 day model. To assess any possible aftereffects of exposure to the lighting conditions, the scores on sleep (duration, quality, and ease of sleeping), mood (pleasure and arousal), VS and PS on the mornings after testing days (i.e., days 2, 3, 5, and 6) were analysed in a 2 lighting x 2 morning model.

The Office Lighting Survey responses were compared to each other (reference vs test lighting) and each was also compared to the normative data for this questionnaire (Eklund and Boyce, 1996). We judge that the recessed lensed troffers with LED lamps in the reference room were not visibly different to participants from the recessed lensed troffers with fluorescent lamps that were judged in the original publication.

3 Results

Space limitations prevent us from providing every detail of the results in this paper. Omitted details are available in Veitch et al. (2023).

3.1 Participation rate and order effects

Of the 14 participants in the light sensitive group, 12 experienced both lighting conditions for at least one day. One person experienced the reference lighting condition for one day, and then withdrew from the study. Three others did not return for a second day in the reference lighting but did return for two days in the test lighting. Two people had time only to participate in one week; one of these experienced only the reference lighting, and one experienced only the test lighting. One person missed a day in the test lighting for reasons unrelated to the investigation. Thus, the reference lighting had 13 participants on day 1 and 9 on day 2; the test lighting had 12 participants on day 1 and 11 on day 2. Six of the participants in the general population group completed all four days. One person missed one day in the reference lighting condition for reasons unrelated to the investigation.

The schedule was constructed to try to balance order effects, with half of the sample starting in the reference room and half in the test room. The balance was nearly achieved: In the light-sensitive sample, eight people experienced the reference room first, and six people experienced the test room first. In the general population sample, three experienced the reference room first and four experienced the test room first.

3.2 Lighting choices

Illuminance was monitored throughout the data collection period using illuminance sensors and a data logger on a nearby desk, to avoid tampering. These values were related to the participant location using the detailed photometric data collected without participants present. Equipment failures meant that we lost these data for two of the light-sensitive individuals. Eight of 12 light-sensitive individuals adjusted the light levels in the test room at least once; three of seven in the general population group made changes.

Table 5 shows the conditions experienced in the reference room and chosen in the test room, expressed as photopic illuminance and five alpha-opic equivalent daylight illuminance (EDI) values. Although the test lighting was capable of being set to provide a much higher illuminance than the reference lighting (full power for the test lighting provided ~800 lx on the desk surface, whereas the reference lighting produced ~410 lx), participants in the light sensitive group tended to reduce the level in the test lighting to levels lower than the reference lighting: The median desk illuminance was 353 lx, which means that for more than half of the light-sensitive people, the desk illuminance was considerably lower than the ~404 lx for the reference lighting. The light level was considerably higher for the general population group because fewer than half of them reduced the level from the starting point, which was an unexpected outcome to us, based on prior experience (Boyce et al., 2006, Veitch and Newsham, 2000).

3.3 Lighting and room appearance

As described above, separate 2 lighting X 2 day LMM analyses were conducted for the light-sensitive group and the general population group. The statistically significant results for the lighting effects on lighting and room assessments are reported here in Table 6. See Veitch et al. (2023) for the full results. Both groups found the test lighting to have higher lighting quality than the reference lighting, and rated their own appearance as more attractive. In addition, the general population group found the test lighting to be brighter and the room more attractive. The effect sizes are medium to large.

There was also a statistically significant effect (not shown in the table) in the comparison of lighting quality ratings on the two days in a room, for the light-sensitive people only. The rating was higher on the second day than the first (3,62 [SD 1,03] versus 3,14 [SD 0,99]), regardless of the lighting type. This might be an artefact of the participation rate; four people did not return for a second day in the reference lighting because they disliked it so much.

Table 5. Average light levels in the reference lighting and summary statistics for light level choices in the test lighting

	Photopic illuminance (lx)	S-cone-opic EDI (lx)	M-cone-opic EDI (lx)	L-cone-opic EDI (lx)	Rhodopic EDI (lx)	Melanopic EDI (lx)
Reference lighting						
Desk surface	404	239	357	404	282	257
Vertical, seated eye height	222	139	197	221	157	143
Test lighting – Light-sensitive (N=12)						
Desk surface						
Mean (SD)	485 (280)	212 (122)	411 (237)	489 (282)	316 (182)	284 (164)
Median	353	154	299	356	230	207
Minimum / Maximum	62/ 795	27 / 348	52 / 674	62/ 802	40 / 519	36 / 466
Vertical, seated eye height						
Mean (SD)	371 (209)	232 (131)	329 (185)	370 (208)	262 (147)	239 (134)
Median	272	171	241	271	192	175
Minimum / Maximum	55 / 602	34 / 378	49 / 534	55 / 600	39 / 425	35 / 388
Test lighting – General Population (N=7)						
Desk surface						
Mean (SD)	657 (186)	287 (81)	557 (157)	663 (187)	428 (121)	385 (109)
Median	783	342	663	790	510	459
Minimum / Maximum	254 / 785	111 / 343	215 / 665	256 / 792	166 / 512	149 / 460
Vertical, seated eye height						
Mean (SD)	499 (138)	313 (87)	442 (123)	498 (138)	352 (98)	321 (89)
Median	593	372	526	591	419	382
Minimum / Maximum	198 / 595	124 / 373	176 / 527	198 / 593	140 / 420	128 / 383

Table 6. Descriptive statistics and inferential test results for lighting effects on lighting and room appearance judgements.

	Means (SD)		**LMM Test Results**			
	Reference Lighting	**Test Lighting**	***df***	***F***	***p***	**Cohen's d**
Light sensitive (N=14)						
Lighting Quality	3,09 (1,06)	3,61 (0,96)	37,08	9,53	0,00***	0,50
Personal Appearance	43,39 (14,30)	55,82 (19,87)	38,40	5,42	0,03*	0,68
General population (N=7)						
Lighting Quality	3,77 (0,92)	4,34 (0,51)	22,33	5,14	0,03*	0,73
Room Brightness	51,46 (20,29)	68,00 (14,04)	21,92	5,08	0,04*	0,87
Room Attractiveness	38,04 (17,64)	48,60 (15,02)	20,11	5,68	0,03*	0,62
Personal Appearance	53,07 (15,49)	73,64 (16,34)	22,53	9,33	0,01**	1,09

3.4 Office Lighting Survey

The OLS is a forced-choice survey for which nonparametric comparisons are used. The sample size was too small for a comparison between the rooms using chi-squared, but the responses for each room and day were compared to the normative data (Eklund and Boyce, 1996) using chi-squared tests.

For the light-sensitive group, on both days in the reference lighting many more people than expected by the norms agreed that “the lighting is uncomfortably bright”, and that “the light fixtures are too bright”. In this sample, ~50% agreed with these two statements, whereas the normative value is ~15%. The reference room also had a much lower-than-expected agreement with the statement “Overall the lighting is comfortable” on the first day (38%, vs 68% expected), but not on the second day. Four people did not return for a second day in the reference lighting, presumably because they had not found it comfortable. The final question “Is the lighting here worse, the same, or better than on other places?” showed a statistically-significant increase in “better” ratings on the second day in the test room, with 9% rating it “worse” (vs 19% normative), 33% “the same” (vs 60% normative) and 55% “better” (vs 22% normative).

For the general population sample, the only differences from the normative data were in the reference room, for which on both days participants were more likely to say that “the light fixtures are too bright” (43% and 67% agreed, vs 14% normative) and on the second day there was more agreement that “my skin is an unnatural colour under this light” (33% vs 9% normative). It is striking that they did not consider the test room to be too bright, even though for most people in the general population sample the illuminance was much higher than in the reference room. They had chosen the higher level by not adjusting the wall dimmer.

3.5 Workday effects

Workday effects include the ratings of visual and physical symptoms and mood (pleasure and arousal). These outcomes were measured at the start of the day, before lunch, and at the end of the day, on both days in each room. The first score of the day was used as a baseline, and change scores from this value were analysed in a 2 x 2 x 2 (lighting X day X time) LMM analysis.

The only statistically significant effect of lighting was in the light-sensitive group and involved the change in visual symptoms (F = 5,85; df = 48, 73; p = 0,02; Cohen’s d= 0,52). Overall, a day in the reference lighting resulted in a small increase in visual symptom severity (mean change = 0,20 [SD 0,50]) on a scale from 0-4), whereas a day in the test lighting resulted in a small decrease in visual symptom severity (mean = -0,09 [SD = 0,60]). There was also a small difference for the light-sensitive people involving the change in arousal on day 1 versus day 2 in each room (day 1 showed a drop in arousal, day 2 showed an increase). For the general population group there were no effects of light, but there were effects of time of day on arousal change and visual symptom change (a drop in arousal and an increase in visual symptoms in the afternoon); see Veitch et al. (2023) for details.

3.6 Morning-after effects

This analysis used the responses for sleep (duration, quality, and ease), mood (pleasure and arousal), visual symptom severity and physical symptom severity reported after each day in each lighting condition, in 2 Lighting x 2 Day LMM analyses.

For the light-sensitive people there was one statistically significant difference between the lighting conditions, in the visual symptom severity (F = 4,72; df = 38, 10; p = 0,04; Cohen’s d= -0,40). Visual symptoms were less severe on the morning after a day in the test lighting (mean = 0,48 [SD = 0,40]) than on the morning after a day in the reference lighting (mean = 0,71 [SD = 0,70]). There were also statistically significant effects of Day on sleep quality, ease of falling asleep, pleasure, and physical symptom severity, all of which were better on Day 3 (after two days in the experiment) than on Day 2. For many participants, Day 3 was a Saturday, and for the others it was a mid-week day of working at home (see Veitch et al., 2023).

There were no statistically significant morning-after effects in the general population sample.

4 Discussion

This small experiment was conducted to solve an applied problem: How to improve the lighting conditions for employees who seek office accommodations to resolve problems of light sensitivity. In the past, most Government of Canada offices had very large switching zones and non-dimmable fluorescent lighting systems. The only practical way to change the lighting for an individual in an open-plan area was to remove the lamps in the luminaire(s) nearest to the individual's assigned cubicle. With integrated LED luminaires being installed in activity-based workplaces lacking assigned seating, this approach (which left the affected individual in a dark cave) is no longer available. A different lighting approach would be needed, ideally one that would both help the light-sensitive employee and improve lighting conditions for other employees. The study reported here was the first step in a two-stage process to evaluate this new lighting solution. The project began as an exploration for a solution for the light-sensitive population, and later it was decided to add a small sample of people from the general population in order to verify that the novel solution did not cause unintended problems for the majority.

The results were more promising than we had hoped. The novel lighting solution worked well for both groups. Lighting quality scores were higher for the test lighting for both the light-sensitive group and the general population group, and the statistical effect sizes were medium to large. The light distribution for the test lighting resulted in a more uniform light distribution with a less intense direct downward light (Figure 1 and Table 3), which appears to have been more pleasing. The OLS results, with the ratings of the reference lighting fixtures being too bright, are consistent with this interpretation. Both groups also rated their personal appearance as better under the test than the reference lighting .This is probably associated with the higher colour fidelity of the test lighting (Aston and Bellchambers, 1969, Boyce and Simons, 1977).

For the light-sensitive group, the test lighting led to less intense visual symptoms at work, an effect that carried through to lower visual symptom severity on the following morning. Similarly, prior research has shown that lighting conditions that are judged to be of higher quality are associated with better health (Veitch et al., 2008, Veitch et al., 2010). Furthermore, four of the participants in this group chose not to return for a second day in the reference lighting, citing feeling unwell. No one failed to return for a second day in the test lighting.

Overall the results suggests that the novel lighting solution could be a good fit for the needs of the light-sensitive population while also providing well for the needs of the majority of employees without these vision problems. Nonetheless, this pilot project has obvious limitations. The sample sizes, particularly for the general population group, were small. The space had been loaned for a limited time, but COVID-19 protocols limited the number of people who could be present on any day and the number of days per week when testing could take place. The lighting solution combined several improvements to lighting quality to try to maximize the likelihood that one solution could prove satisfactory to the whole group, which makes isolating which of the improvements caused the benefits impossible, although (as noted above) the scientific literature can provide guidance. Finally, there was no way to prevent participants from having expectations about which lighting condition was expected to be better. As public servants with years of experience, it was clear to all which room was the reference lighting and which was the test lighting.

The next step will be a field trial designed to overcome some of these limitations. A baseline floor, lit with contemporary LED luminaires and controls following the current Government of Canada office lighting requirements, will be compared to two test floors lit with the innovative luminaire tested here, one with the usual colour rendering (R_a ~ 82) and one with high colour rendering (R_a ~ 90). Online surveys of all employees and photometric evaluations will occur in four seasons. We hope that the results will enable an update to office lighting guidance to support accessibility needs while providing better lighting for all.

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