



Color Perception under Low Light and Varying Spectra: A Literature Review

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Agenda

- 1 Background
- 2 Motivation
- 3 Importance
- 4 Literature Review
 - Pedestrian studies
 - Vision studies
- 5 Limitations & Gaps

Background Light Pollution



<https://www.linkedin.com/pulse/what-light-pollution-how-reduce-ruby-jiang>

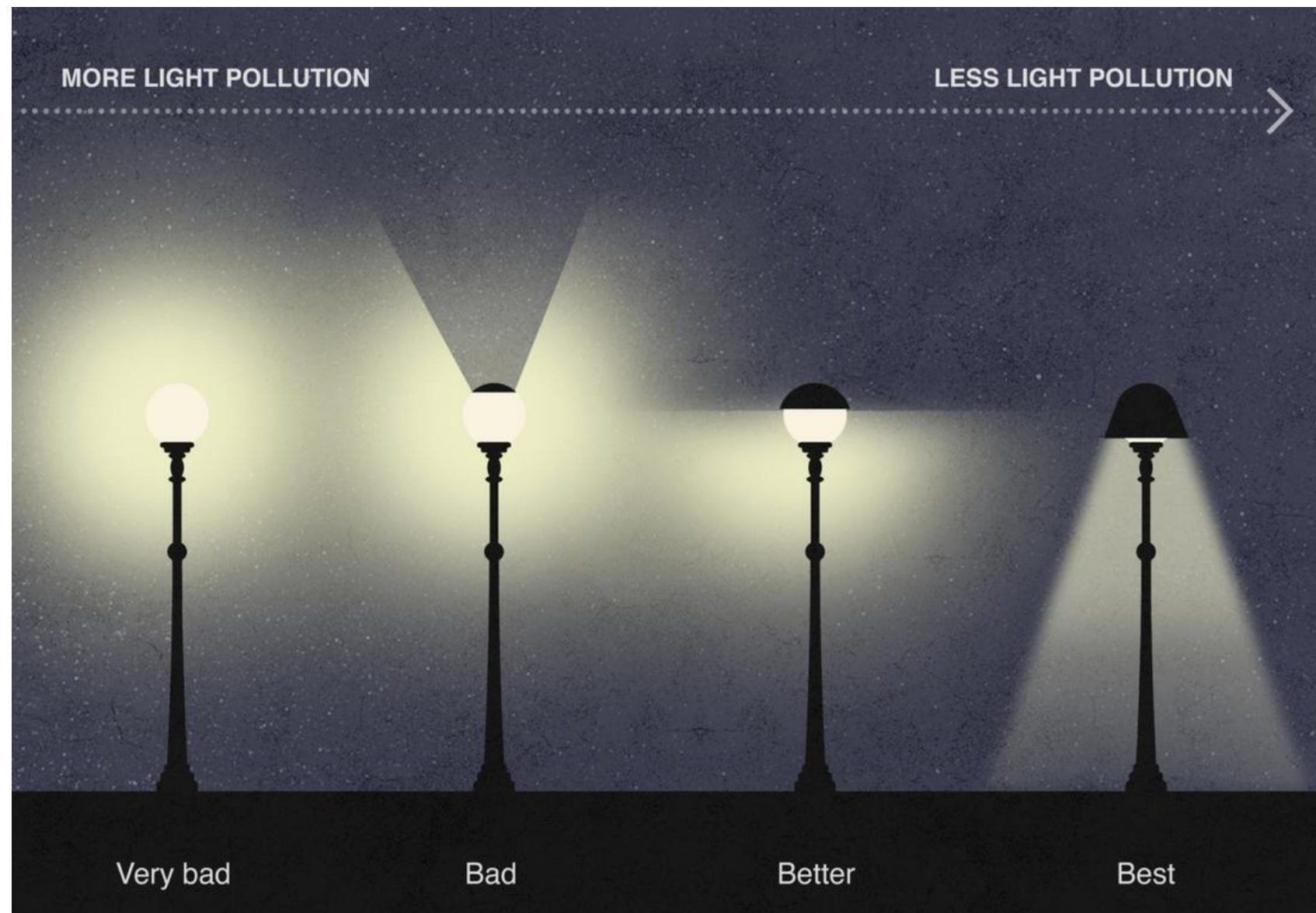
What is...

- Light trespass
- Sky glow

It affects...

- Human circadian rhythm
- Astronomical observation
- Plant and animal behavior

Background Light Pollution



<https://www.archdaily.com/977131/how-to-reduce-light-pollution-with-street-light-design/620fe0403e4b31046c000009-how-to-reduce-light-pollution-with-street-light-design-photo>

Proposed Common Solutions:

- Light only where you need
 - limit the number of lights
 - shield lights and direct down
 - consider application (e.g., national park)
- Light only when you need
 - use timer, sensor
- Limit short wavelength energy
 - Amber, red, warm wight

Motivation

Warm light
to reduce environmental impact

VS

reduced human perception,
color discrimination

at low light levels



<https://www.archdaily.com/977131/how-to-reduce-light-pollution-with-street-light-design/620fd4063e4b31a6a3000010-how-to-reduce-light-pollution-with-street-light-design-image>

Importance

Perception of Safety:

Identify the color of clothes, faces or car

Navigation and Identification:

Distinguish between different paths or landmarks, identify species or objects

Mood and Perception:

Occupant's mood and color perception



<https://www.shutterstock.com/image-photo/police-cars-night-car-chasing-fog-1419212960>

<https://www.istockphoto.com/videos/criminal>

Literature Review

Scope:

Visual experiments investigating color and visual perception in low lighting condition

Studies with human factors experiment (not computational).

Independent variable is lighting.



Resource:

Google Scholar

Total number of studies:

$n = 22$

Pedestrian



(Fotios, Steve. 2015)

Vision



O'Connor, D. A., & Davis, R. G. (2005)



Pedestrian Studies

Independent Variable

Average participants: 50

Illuminance: horizontal 0.5 lx – 50 lx,
vertical 5-15 lx

CCT: 1800 K – 5600 K, red light

CRI R_a : -44 to 90

Lighting technologies: LPS, HPS, LED, MH



(Lin, Yandan & Fotios, Steve. 2015)



Pedestrian Studies

Dependent Variable

Methods:

2-alternative force choice (2AFC), Color grouping, Color naming, Scaling, Reading tasks

Outcomes:

Obstacle detection, Saliency, Acuity, Fixation, Color discrimination, Facial recognition

1. Gender?	Male, female, unsure
2. Ethnicity?	African-American, Asian, Caucasian, Indian, unsure
3. Height?	Short, average, tall, unsure
4. Body type?	Thin, average, heavy, unsure
5. Hair colour?	Black, brown, blonde, grey, other—, unsure
6. Hair length?	Long, short, unsure
7. Clothing type (top)?	Jacket, ski (or outdoor sportswear), long coat, hooded sweatshirt, sweater, unsure
8. Colour of clothing (top)?	Black, brown, red, blue, green, white, yellow, tan, other —, unsure
9. Clothing (bottom) colour?	Black, brown, red, blue, green, white, yellow, tan, other —, nsure
10. What colours 'bib' did the person wear?	Red-green, blue-yellow, red-blue, yellow-green, red-yellow, green-blue, unsure
11. What number did the person have on their back?	—, unsure
12. Facial hair?	None, beard, moustache, both, unsure
13. Head covering?	None, cap, knit hat, scarf, earmuffs, other —, unsure

(Rea, M.S., Bullough, J.D. and Akashi, Y., 2009)



Pedestrian Studies

Findings

👁️ Visual task performance:

- Young people perform better than old people in obstacle detection tasks.

(Rahm, J., & Johansson, M. 2018)

- No gender effects in fixation pattern across relative luminance or saliency.

(Jiang, X., Li, J. and Yang, B., 2021)

	Process	Location
	Introductory meeting	Waiting room
	Measurement of baseline walking speed	Corridor
Lighting presentation #1	Vision tests	Laboratory
	Measurement of walking speed	
	Affect grid	
	Valence & arousal scales	
	POLQ	
	Waiting / self-report of background data	Waiting room
		Laboratory
	Obstacle detection	Laboratory
	Facial recognition	
	Sign reading	
	Waiting	Waiting room
Lighting presentation #2		Laboratory
	Measurement of walking speed	Laboratory
	Affect grid	
	Valence & arousal scales	
	POLQ	
	Waiting	Waiting room
		Laboratory
	Obstacle detection	Laboratory
	Facial recognition	
	Sign reading	
	Waiting	Waiting room
Lighting presentation #3		Laboratory
	Measurement of walking speed	Laboratory
	Affect grid	
	Valence & arousal scales	
	POLQ	
	Waiting	Waiting room
		Laboratory
	Obstacle detection	Laboratory
	Facial recognition	
	Sign reading	
	Debriefing and conclusion	Waiting room

<https://doi.org/10.1371/journal.pone.0204638.t002>

(Rahm, J., & Johansson, M. 2018)



Pedestrian Studies

Findings

👁️ Visual task performance:

- Lower frequency of fixation on other people after dark compared to daytime. (Fotios, S., Uttley, J., Cheal, C. and Hara, N., 2015)
- Higher frequency of fixation on the path after dark than during the day. (Fotios, S., Uttley, J., Cheal, C. and Hara, N., 2015)
- Higher proportions of fixations on people and vehicles than did all fixations. (Fotios, S., Uttley, J., Cheal, C. and Hara, N., 2015)



Figure 2. Photographs of the four route sections. Clockwise from top-left: route section A, B, C and D.

(Fotios, Steve. 2015)



Pedestrian Studies

Findings

Color perception:

- Chromatic information was unimportant for facial recognition under vertical

illuminances of 8 lx. (Rea, M.S., Bullough, J.D. and Akashi, Y., 2009)

- Both illuminance and color rendering were important for color identification.

(Rea, M.S., Bullough, J.D. and Akashi, Y., 2009)

Table 2 Brightness, safety and social acceptability judgements for the subjective impression experiments. Values in *italics* represent statistically significant differences ($p < 0.05$) according to Chi-square tests. For each experiment the resolution is defined as 100% divided by the number of subjects

	Condition 1 (lx)	Condition 2 (lx)	(%) Rating condition 2 brighter	(%) Rating condition 2 safer	(%) Rating condition 2 more social
Experiment 1 <i>n</i> = 24, resolution ≈ 4%	HPS 5	HPS 15	100	100	62
	HPS 5	MH 5	67	88	62
	HPS 5	MH 15	96	96	58
	HPS 15	MH 5	21	38	67
	HPS 15	MH 15	71	92	54
	MH 5	MH 15	100	96	46
Experiment 2 <i>n</i> = 16, resolution ≈ 6%	HPS 7	MH 7	56	88	63
	HPS 7	MH 10	100	100	56
	HPS 7	MH 15	100	88	75
	HPS 10	MH 7	50	56	56
	HPS 10	MH 10	81	81	50
	HPS 10	MH 15	94	94	63
	HPS 15	MH 7	19	38	38
	HPS 15	MH 10	19	56	38
	HPS 15	MH 15	94	94	63
Experiment 3 <i>n</i> = 31, resolution ≈ 3%	HPS 5.1	MH 3.1	16	42	–
	HPS 5.1	MH 3.6	42	55	–
	HPS 5.1	MH 4.5	52	48	–
	HPS 5.1	MH 5.2	74	65	–
	HPS 10.4	MH 6.1	16	39	–
	HPS 10.4	MH 7	45	52	–
	HPS 10.4	MH 8.8	61	52	–
	HPS 10.4	MH 10.3	77	74	–
	HPS 15	MH 9	23	29	–
	HPS 15*	MH 10.4*	29 (45) ^a	45 (55) ^a	–
	HPS 15*	MH 13.0*	55 (55) ^a	61 (64) ^a	–
	HPS 15*	MH 15*	81 (78) ^b	74 (78) ^b	–

For the conditions in Experiment 3 marked with an asterisk (*), the condition was replicated by locating filters at the luminaire's lens to compare viewing in the booth with viewing in the open condition used in Experiments 1 and 2. The data for the replicated condition are given in parentheses.

^a*n* = 11, resolution ≈ 9%, ^b*n* = 9, resolution ≈ 11%.

(Rea, M.S., Bullough, J.D. and Akashi, Y., 2009)

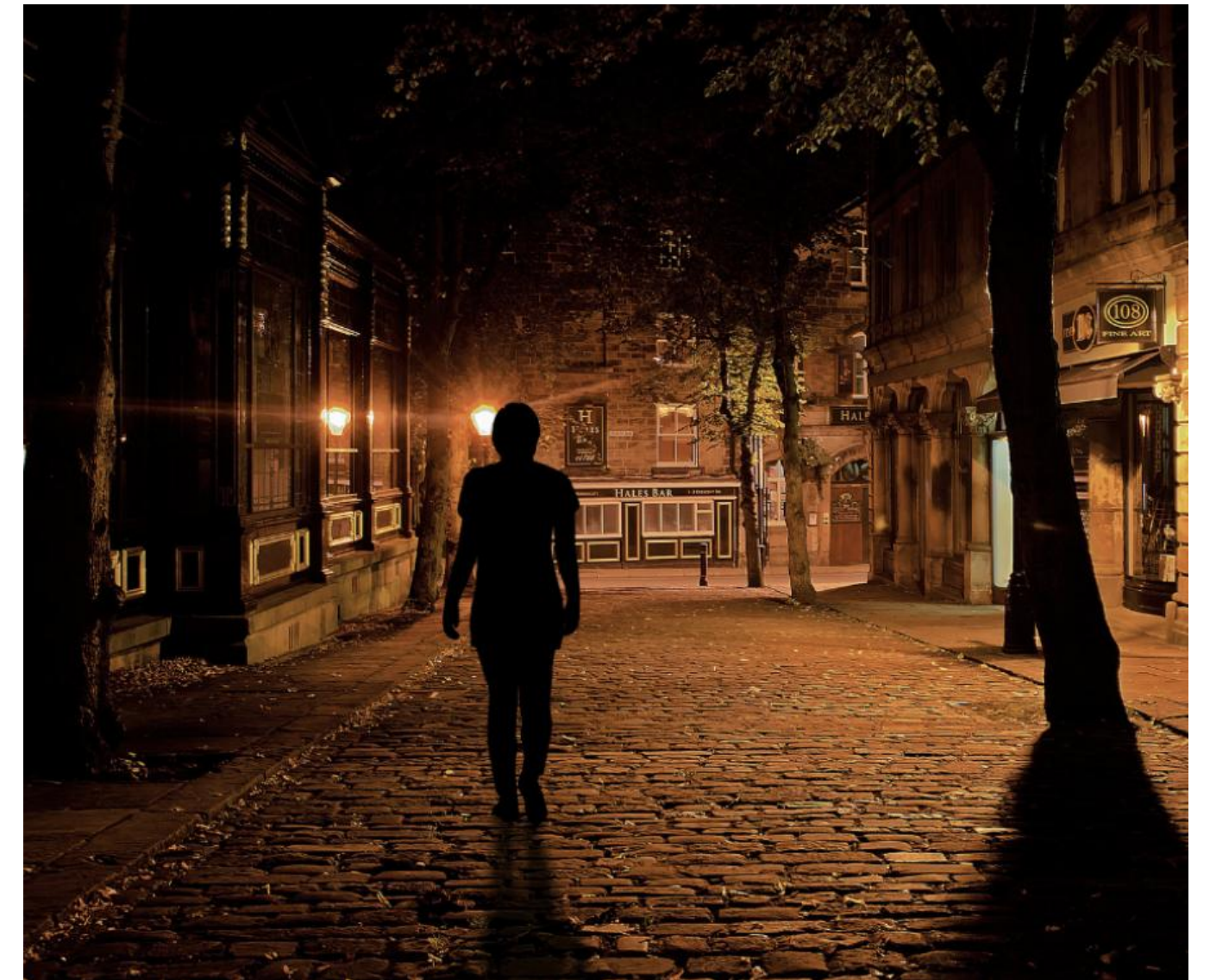


Pedestrian Studies

Findings

⚠ Safety:

- There's trend for looking more at the near path than the far path. (Fotios, S., Uttley, J., Cheal, C. and Hara, N., 2015)
- MH is relatively brighter and feeling safer than HPS. (Rea, M.S., Bullough, J.D. and Akashi, Y., 2009)
- Greater feelings of safety in warm white light than amber light. (Himschoot, Elizabeth A., et al. 2024)
- Greater feelings of safety at intensity levels 5 lx or higher. (Himschoot, Elizabeth A., et al. 2024)
- Urban kids are more sensitive to safety than the kids borne in rural area. (Himschoot, Elizabeth A., et al. 2024)



<https://www.solar-eye.com/blog-does-outdoor-lighting-at-night-improve-public-safety/>

Vision Studies

Independent Variable

Average participants: 25

Illuminance: 5 lx – 1000 lx, no vertical lighting reported

CCT : 2900 K – 5000 K

CRI R_a : 80-95

Lighting technologies: Fluorescent, LED, Halogen



<https://www.rebuildyourvision.com/blog/vision-training/what-is-vision-science/>

Vision Studies

Dependent Variable

Methods:

Color sorting, Color matching, Scaling

Outcomes:

Color discrimination, human perception of the importance of luminance intensity

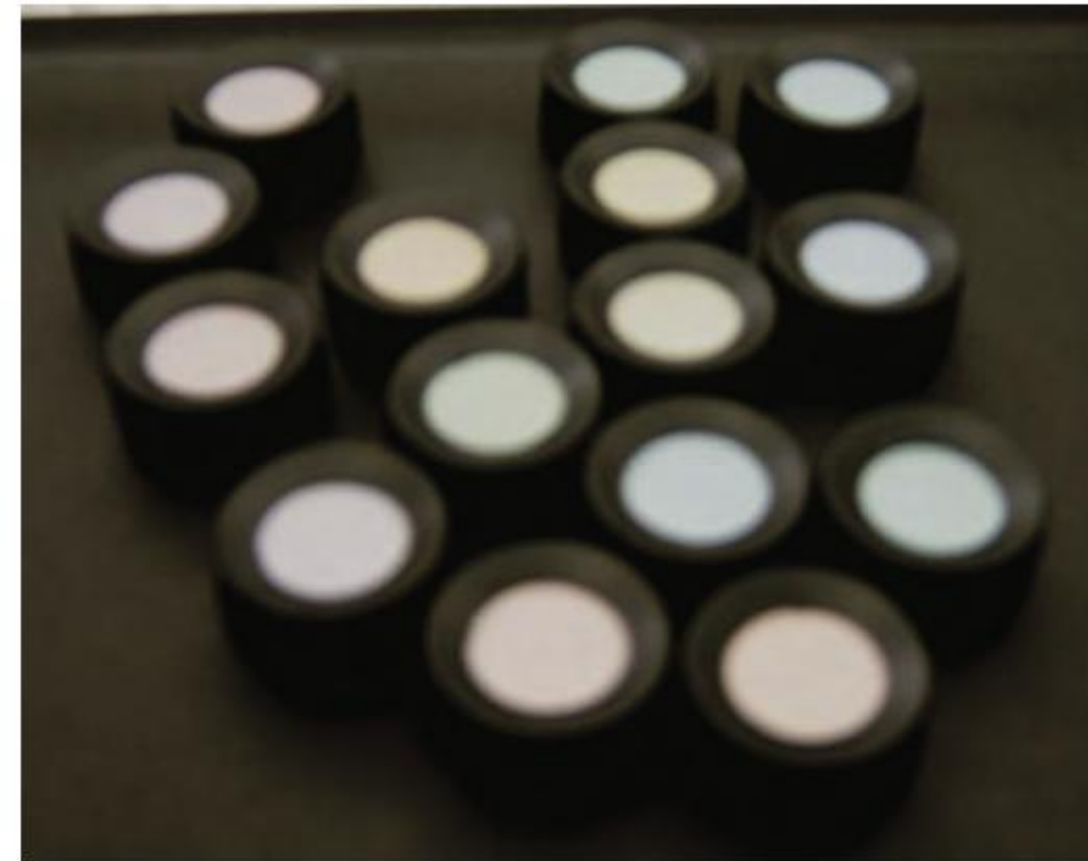


Fig. 2. L'Anthony Color Test.

O'Connor, D. A., & Davis, R. G. (2005).

Vision Studies

Findings

💡 Light level:

- Low light cause desaturation (hunt effect) (Hunt, R.W.G., 1952)

(The reduction in test chips saturation is because of the decrease in output of the color opponent channels with decrease in illuminance level.)



<https://www.flickr.com/photos/volvob12b/9252673241>

Findings

Age:

- Increasing illuminance increase the task performance for both age groups. (O'Connor, D. A. and Davis, R. G. 2005)
- Elderly people require higher illuminances to perform tasks at the same level as young people. (O'Connor, D. A. and Davis, R. G. 2005)

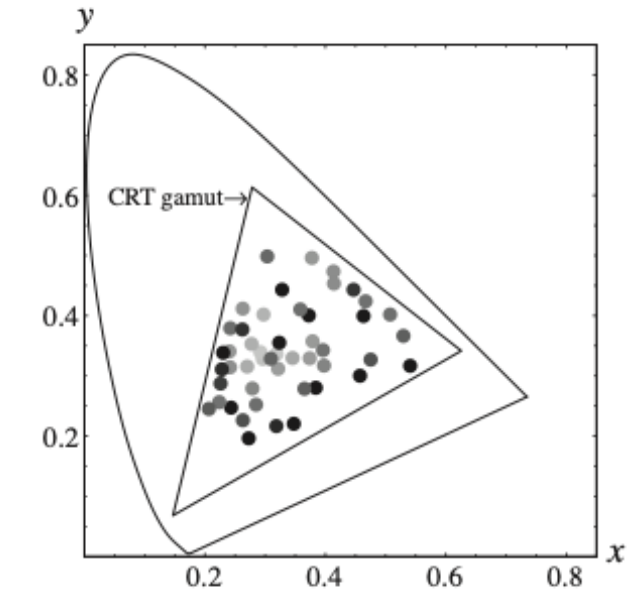


Fig. 1. The chromaticities of 48 test color chips on xy -chromaticity diagram with the gamut of the CRT for matching stimulus.

Table 1. 48 test color chips

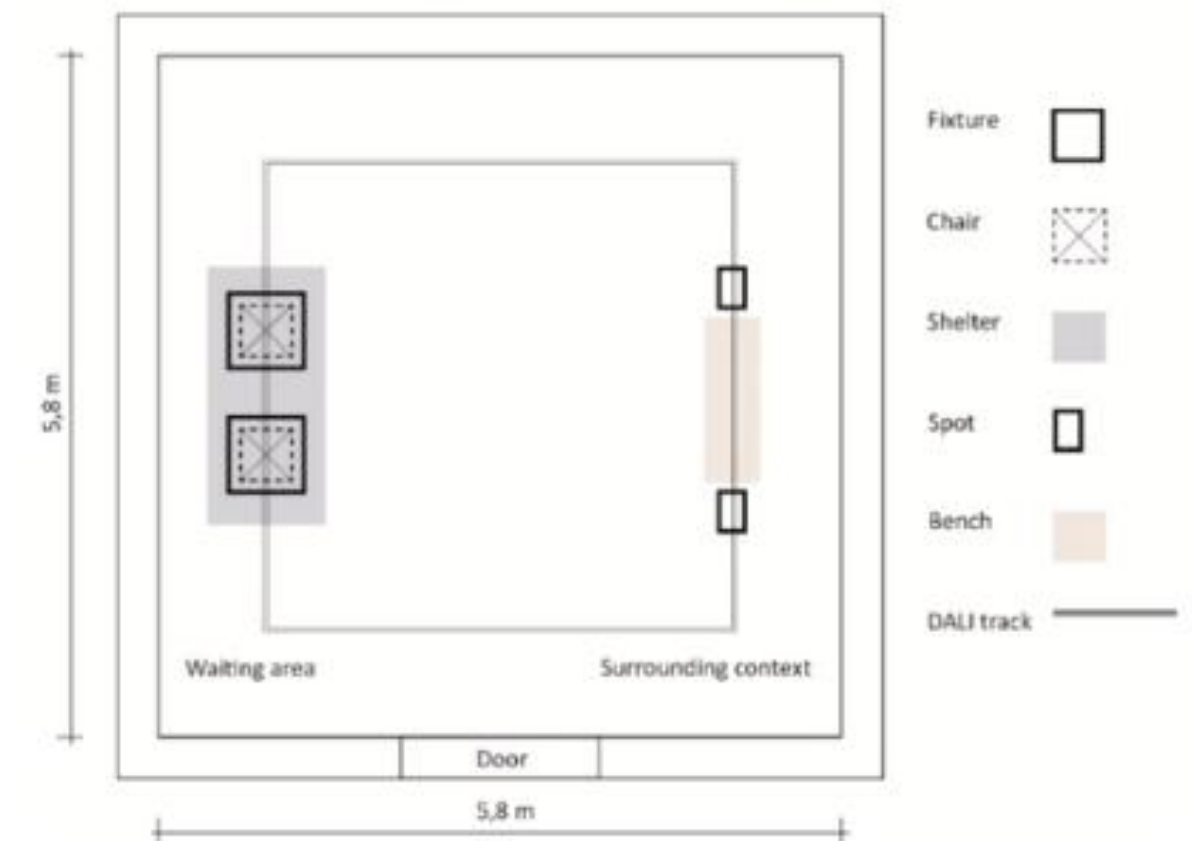
No.	Color chip	No.	Color chip	No.	Color chip
1	10.0Y 8/10	17	5.0RP 4/8	33	10.0BG 9/3
2	7.5Y 8/8	18	2.5RP 6/10	34	10.0BG 5/6
3	5.0Y 5/4	19	10.0P 4/12	35	7.5BG 7/6
4	2.5Y 6/8	20	7.5P 8/4	36	5.0BG 4/6
5	10.0YR 7/10	21	5.0P 4/12	37	2.5BG 8/4
6	7.5YR 5/8	22	2.5P 6/8	38	10.0G 6/8
7	5.0YR 7/14	23	10.0PB 5/10	39	7.5G 5/6
8	2.5YR 8/4	24	10.0PB 3/12	40	5.0G 7/8
9	10.0R 6/14	25	7.5PB 7/6	41	2.5G 8/6
10	7.5R 7/6	26	5.0PB 4/10	42	10.0GY 6/10
11	5.0R 6/12	27	2.5PB 6/8	43	7.5GY 5/6
12	5.0R 4/14	28	10.0B 9/3	44	5.0GY 8/10
13	2.5R 8/6	29	10.0B 5/8	45	2.5GY 7/4
14	10.0RP 4/10	30	7.5B 8/4	46	N9
15	7.5 RP 7/8	31	5.0B 5/6	47	N6.5
16	5.0RP 8/4	32	2.5B 7/6	48	N1.5

Vision Studies

Findings

■ Spatial:

- Space: Lowered illuminance in the waiting area will have a positive impact on the perception of the atmosphere of the spa (200 lx, 100 lx, 30 lx, 20 lx, 5 lx)
- Copresence: Lower lighting levels will be motivating for socialization.
- Surroundings: Lower ratios between luminance in the waiting area and in the surrounding context will have a positive impact perception of the surroundings, including for the visibility of objects.



Hvass, M., Van Den Wymelenberg, K., Boring, S., & Hansen, E. K. (2021).

Vision Studies

Findings

👍 Preference:

- Study suggests in general, participants indicated that they liked the lowest illuminance the least and the highest illuminance the best. (3 lx, 700 lx, 900 lx) (O'Connor, D. A. and Davis, R. G. 2005)
- The younger age group rated the 5000 K compact fluorescent source as more disliked than the 3000 K compact fluorescent at all light levels (O'Connor, D. A. and Davis, R. G. 2005)



O'Connor, D. A., & Davis, R. G. (2005).

Limitation & Gap

- Conflicting results in human perception at low light level
- No experiments of comparing different light levels of amber LED and white LED
- Balance the reduced human perception, color discrimination at night

Conclusion

- Environment-friendly outdoor lighting design solutions may sacrifice human perception.
- The study shows higher the light level and CRI, better the color identification.
- literature suggest. greater feelings of safety in warm white light than amber light.
- Future studies will focus on improving safety and enhancing color discrimination conditions in outdoor areas

References

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- **Slide 10:** Rahm J, Johansson M (2018) Assessing the pedestrian response to urban outdoor lighting: A full-scale laboratory study. *PLoS ONE* 13(10): e0204638.
- Jiang, X., Li, J. and Yang, B., 2021. Luminance and saliency have impact on pedestrians' fixation distribution during natural walking: Evidence from mobile eye-tracker. *Lighting Research & Technology*, 53(4), pp.359-372.
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Thank You

Questions?