Effects of Bicycle Taillight Shape and Lighting Patterns on Nighttime Conspicuity

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Abstract. Objective: This study examined the effects of bicycle taillight shape (circular vs. elongated) and lighting pattern (steady, flashing, dynamic) on nighttime conspicuity and their interaction. Methods: Thirty drivers rated six taillight conditions using a 100-mm visual analog scale (VAS). A Williams Latin square controlled order effects. Data were analyzed using a two-way repeated-measures ANOVA. Results: Significant main effects were found for shape, $F(1, 29) = 13.17$, $p = 0.001$, partial $\eta^2 = 0.312$, and lighting pattern, $F(1.54, 44.70) = 54.35$, $p < 0.001$, partial $\eta^2 = 0.652$, with flashing > dynamic > steady. No interaction effect was observed, $F(2, 58) = 0.11$, $p = 0.896$. Conclusion: Flashing enhances conspicuity through temporal modulation, while circular shapes enhance spatial intensity; their effects are independent.

Keywords: Bicycle taillight; Conspicuity; Dynamic lighting effects; Visual analog scale (VAS)

1 Introduction

Cyclists are vulnerable road users, and failures in driver detection are a major cause of accidents, particularly at night [1-3]. Enhancing cyclist visibility, such as through bicycle taillights, is therefore critical for improving safety [4].

With increasing diversity in taillight design, both shape and lighting pattern may influence visual recognition. However, existing studies have largely examined these factors separately, lacking systematic evidence on their combined effects. This study investigates the independent and interactive effects of taillight shape and lighting pattern on conspicuity.

2 Literature review

2.1 Theoretical Framework of Conspicuity

Conspicuity refers to the ability of an object to attract attention within its environment, involving both sensory salience and cognitive processes [5]. In nighttime driving, taillight conspicuity directly affects detection and hazard avoidance [6].

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2.2 Research on Bicycle Taillights

Previous research has mainly focused on installation position and lighting patterns. Flashing lights have been shown to enhance detection by capturing attention more effectively [7,8]. However, most studies have examined single factors or simple dynamic patterns, with limited attention to more complex dynamics or combined effects of shape and lighting pattern. Therefore, a multifactorial approach is needed to systematically examine how these factors jointly influence conspicuity.

3 Methods

3.1 Experimental Material

Six 10-second video clips depicting a dark-colored bicycle in a nighttime street scene were created. The taillight conditions included circular steady (A1), circular flashing (2 Hz; A2), circular dynamic (A3), and elongated steady (B1), elongated flashing (2 Hz; B2), elongated dynamic (B3). The "dynamic" pattern involved spatially moving illumination across the taillight surface (sequential activation), whereas flashing referred to global on–off luminance without spatial movement. To control for confounding variables, both shapes had identical luminous areas and consistent luminance under steady conditions. Flashing frequency was set to 2 Hz, and dynamic patterns completed one cycle within 0.5 s. All videos were standardized in terms of background, bicycle position, and ambient illumination. The stimuli are shown in Fig. 1.

Fig. 1. Experimental video frames for the six taillight conditions (A1–B3).

3.2 Participants

Thirty licensed drivers (15 males, 15 females; aged 22–59 years, M = 38.4, SD = 11.4) participated. All had night driving experience and normal or corrected-to-normal vision, with no color vision deficiencies. Informed consent was obtained prior to the experiment.

3.3 Experimental Procedure

A Williams Latin square design was used to counterbalance order effects. Participants were randomly assigned to six groups and viewed all six conditions in predefined sequences. Each video was presented for 10 s, followed by an immediate conspicuity rating (Fig. 2). Conspicuity was assessed using three items (detection, recognition, and noticeability) on a 100-mm visual analog scale (VAS), adapted from previous studies on roadway visibility [9]. The mean of the three items was used as the composite conspicuity score. The experiment was conducted in a dark indoor environment (< 5 lx). Additional subjective feedback on scenario realism was collected after the experiment.

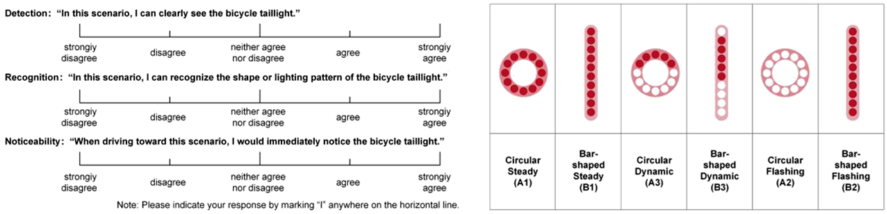

Fig. 2. VAS questionnaire and bicycle taillight conditions used in the experiment.

4 Results

4.1 Reliability Analysis

Internal consistency was assessed using Cronbach’s α. Values ranged from 0.837 to 0.921 (M = 0.902), indicating high reliability and supporting the use of a composite conspicuity score.

4.2 Descriptive Statistics

Descriptive statistics are presented in Table 1. Overall, flashing patterns yielded higher conspicuity scores than dynamic and steady patterns, and circular taillights were rated higher than elongated ones.

Table 1. Descriptive statistics of conspicuity scores across taillight conditions

Lighting Pattern	Circular	Bar-shaped
Constant	60.94±17.66	54.74±19.40
Flashing	83.62±9.53	75.92±16.64

Lighting Pattern	Circular	Bar-shaped
Dynamic	71.13±14.47	65.15±17.16

Note: n = 30 for each condition. M = mean; SD = standard deviation.

4.3 Inferential Statistical Analysis

A 2 × 3 repeated-measures ANOVA was conducted to examine the effects of taillight shape and lighting pattern on conspicuity. Mauchly's test indicated a violation of sphericity for lighting pattern ($p = 0.007$); therefore, Greenhouse–Geisser correction was applied. The main effects and interaction pattern are shown in Fig. 3. Significant main effects were found for shape, $F(1, 29) = 13.17$, $p = 0.001$, partial $\eta^2 = 0.312$, and lighting pattern, $F(1.54, 44.70) = 54.35$, $p < 0.001$, partial $\eta^2 = 0.652$.

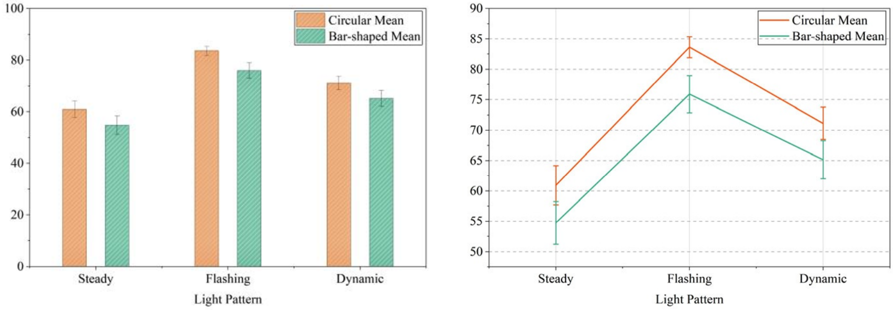

Fig. 3. (A) Main effects. (B) Interaction effect (mean ± SE).

Post hoc comparisons (Table 2) showed that flashing produced higher conspicuity than both dynamic and steady conditions, and dynamic was higher than steady (all $p < 0.001$).

Table 2. Post hoc pairwise comparisons of lighting patterns (Bonferroni corrected).

Comparison	Mean Difference	SE	p	95% CI
Flashing vs. Steady	21.93	2.62	<0.001	[15.28, 28.57]
Flashing vs. Dynamic	11.63	1.78	<0.001	[7.10, 16.15]
Dynamic vs. Steady	10.30	1.81	<0.001	[5.70, 14.90]

Note: SE = standard error, CI = confidence interval. p-values adjusted using Bonferroni method.

The interaction between shape and lighting pattern was not significant, $F(2, 58) = 0.11$, $p = 0.896$, partial $\eta^2 = 0.004$, indicating that the effect of taillight shape on conspicuity was consistent across different lighting patterns. Therefore, no further simple effects analysis was conducted. The results of the ANOVA are summarized in Table 3.

Table 3. Summary of two-way repeated measures ANOVA results.

Source	Correction	F	df_1	df_2	p	partial η^2
Shape	Sphericity Assumed	13.17	1	29	0.001	0.312
Lighting Pattern	Greenhouse–Geisser	54.35	1.54	44.70	<0.001	0.652
Shape×Lighting Pattern	Sphericity Assumed	0.11	2	58	0.896	0.004

Note: df_1 = numerator degrees of freedom, df_2 = denominator degrees of freedom, η_p^2 = partial eta squared.

4.4 Hypothesis Testing

Based on the above analyses, the results of hypothesis testing are as follows:

H1 (flashing advantage): Supported. The main effect of lighting pattern was significant, with the flashing condition yielding significantly higher conspicuity ratings than both the steady and dynamic conditions ($p < 0.001$).

H2 (shape advantage): Supported. The main effect of shape was significant, with circular taillights receiving significantly higher conspicuity ratings than elongated taillights ($p = 0.001$).

H3 (interaction effect): Not supported. The interaction between shape and lighting pattern was not significant ($p = 0.896$), indicating no moderating effect of shape on lighting pattern.

5 Conclusion

This study investigated the effects of bicycle taillight shape and lighting pattern on nighttime conspicuity using subjective ratings from 30 participants and a two-way repeated-measures ANOVA. The results indicate that taillight conspicuity is independently influenced by temporal characteristics (lighting pattern) and spatial characteristics (shape). Specifically, flashing patterns and circular designs both significantly enhance conspicuity, and their effects operate independently without interaction.

From a practical perspective, circular flashing taillights are recommended for improving nighttime conspicuity in cycling at night. This study was conducted using a video-based experimental paradigm and did not involve complex real-world traffic conditions. Future research should incorporate driving simulators or field experiments and include objective measures such as eye-tracking to further validate the findings.

6 Discussion

Flashing patterns produced higher conspicuity than both dynamic and steady patterns, suggesting that transient signals with abrupt onset and offset are more effective in capturing visual attention than smooth motion or steady illumination. This indicates that not all temporal variations enhance conspicuity, and that abrupt temporal modulation plays a critical role. In addition, circular taillights yielded higher conspicuity than elongated ones, possibly due to greater spatial concentration of luminous intensity.

No significant interaction between shape and lighting pattern was observed, indicating additive rather than multiplicative effects. The stronger effect of lighting pattern compared to shape may have reduced the likelihood of detecting an interaction.

Several limitations should be noted. First, the video-based simulation in a controlled dark environment may not fully reflect real-world nighttime driving conditions with motion, distance variation, and attentional distraction. Second, the use of subjective ratings, although reliable, does not directly represent objective driving performance measures. Therefore, the results should be interpreted as perceptual tendencies under controlled conditions rather than direct predictors of driving safety outcomes. Future studies should incorporate driving simulators or field experiments and include objective indicators such as reaction time and eye-tracking.

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