

## Research Article

# Drivers' Risk Perception and Risky Driving Behavior under Low Illumination Conditions: Modified Driver Behavior Questionnaire (DBQ) and Driver Skill Inventory (DSI)

Jing Liu,<sup>1,2</sup> Cheng Wang,<sup>3</sup> Zhipeng Liu,<sup>4</sup> Zhongxiang Feng ,<sup>5</sup> and N. N. Sze<sup>6</sup>

<sup>1</sup>School of Mechanical and Electrical Engineering, Anhui Jianzhu University, Hefei, Anhui, China

<sup>2</sup>National Engineering Research Center for Water Transport Safety, Wuhan, Hubei, China

<sup>3</sup>School of Civil and Hydraulic Engineering, Hefei University of Technology, Hefei, Anhui, China

<sup>4</sup>School of Automobile and Traffic Engineering, Hefei University of Technology, Hefei, Anhui, China

<sup>5</sup>School of Transportation, Southeast University, Nanjing, Jiangsu, China

<sup>6</sup>Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

Correspondence should be addressed to Zhongxiang Feng; [fzx@hfut.edu.cn](mailto:fzx@hfut.edu.cn)

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Most road crashes are caused by human factors. Risky behaviors and lack of driving skills are two human factors that contribute to crashes. Considering the existing evidence, risky driving behaviors and driving skills have been regarded as potential decisive factors explaining and preventing crashes. Nighttime accidents are relatively frequent and serious compared with daytime accidents. Therefore, it is important to focus on driving behaviors and skills to reduce traffic accidents and enhance safe driving in low illumination conditions. In this paper, we examined the relation between drivers' risk perception and propensity for risky driving behavior and conducted a comparative analysis of the associations between risk perception, propensity for risky driving behavior, and other factors in the presence and absence of streetlights. Participants in Hefei city, China, were asked to complete a demographic questionnaire, the Driver Behavior Questionnaire (DBQ), and the Driver Skill Inventory (DSI). Multiple linear regression analyses identified some predictors of driver behavior. The results indicated that both the DBQ and DSI are valuable instruments in traffic safety analysis in low illumination conditions and indicated that errors, lapses, and risk perception were significantly different between with and without streetlight conditions. Pearson's correlation test found that elderly and experienced drivers had a lower likelihood of risky driving behaviors when driving in low illumination conditions, and crash involvement was positively related to risky driving behaviors. Regarding the relationship between study variables and driving skills, the research suggested that age, driving experience, and annual distance were positively associated with driving skills, while myopia, penalty points, and driving self-assessment were negatively related to driving skills. Furthermore, the differences across age groups in errors, lapses, violations, and risk perception in the presence of streetlights were remarkable, and the driving performance of drivers aged 45–55 years was superior to that of drivers in other age groups. Finally, multiple linear regression analyses showed that education background and crash involvement had a positive influence on error, whereas risk perception had a negative effect on errors; crash involvement had a positive influence, while risk perception had a negative effect on lapse; driving experience and crash involvement had a positive influence on violation; and age had a negative influence on it.

## 1. Introduction

Driving in low illumination conditions is comparatively harsher than daytime due to insufficient light [1]. Prior studies have suggested that both crash rate and severity are higher in low illumination conditions than in daytime

conditions [2]. In low illumination environments, it is very difficult for drivers to detect pedestrians, cyclists, or any other objects on the road. Hence, road users are more likely to be faced with unexpected accidents. Additionally, darkness may delay the driver's reaction time and failure to take timely measures to avoid or brake when a collision occurs.

As a result, driving becomes risky, the severity of crashes increases under dark lighting conditions [3–5]. Regarding crash rate, an official report concludes that 50% of road accidents occur at night due to low illumination [6]. Crash statistics report that crash rate and severity in illumination environments are 4 and 2 times higher than those in sufficient illumination conditions, respectively [7, 8]. Low illumination driving in China is also not optimistic. Many drivers are killed and injured by nighttime accidents every year in China. According to statistics maintained by the Ministry of Public Security in China, there were 187,781 road crashes and 58,022 road deaths in 2015. Of the 187,781 road crashes, 68,896 (37%) occurred at night, and more importantly, crashes at night constituted 43.6% of the total road deaths. Of the nighttime crashes, 39,906 occurred in the presence of streetlights, resulting in 10,741 road deaths (i.e., 42.4% of road deaths at night) [9]. Thus, it is crucial to examine the effect of lighting conditions on the risks for crashes and injury, especially at night.

Nighttime accidents are relatively frequent and serious compared with daytime accidents, mainly because the visual environment is different. Drivers' acquisition of driving information depends mostly on vision, and the low illumination environment at night seriously affects drivers' information acquisition and risk perception abilities. Risk perception is a driver's ability to discern information about potential hazards in the traffic environment that could result in actual accidents [10–12]. Specifically, risk perception is a driver's ability to distinguish distance, speed, and object size. Cobn et al. [13] found that inherent risk perception could affect the cognitive judgment of drivers and, in turn, reduce the propensity for risky driving behavior. Borowsky et al. [14] also revealed that risk perception is correlated with driver's age and driving experience, which are both correlated with crash occurrences. Therefore, risk perception plays an important role in road safety [15], especially in low illumination environments. The Driver Skill Inventory (DSI) is used to measure self-reported risk perception and safety skills. Safety skills refer to the driver's ability to drive in a safe manner [16], and perceptual-motor skills refer to the driver's ability to handle the car. Using the DSI, Ostapczuk et al. [17] and Warner et al. [18] found that perception and safe driving are associated with traffic penalties and accidents.

Factors contributing to the incidence of road crashes are generally categorized into three groups: road design and environment; vehicle attributes; and human characteristics. Human characteristics are commonly recognized as the major contributing factor to road crashes [19]. In particular, human (driver) behaviors are sensitive to changes in the road environment, and drivers' responses to adverse environmental conditions, i.e., foggy weather, poor visibility, and poor lighting, can affect the risk of road crashes. The Driver Behavior Questionnaire (DBQ) is widely used as an effective tool to study drivers' dangerous driving behavior. Atombo et al. [20] used DBQ variables to predict drivers' intentions to speed, and Hassan [21] identified and quantified the significant factors associated with the involvement of young Saudi drivers in at-fault crashes based on the DBQ.

Previous studies have addressed the relationship between driving skills and behaviors. Martinussen et al. [22] found that perceptual motor skills were positively and negatively associated with violations and errors and lapses, while safety skills were negatively correlated with violations, errors, and lapses. Following this research, Martinussen et al. [23] concluded that both the DBQ and DSI are valuable predictors of traffic accidents. Recently, Xu et al. [24] adopted a Chinese version of the Driver Skill Inventory (DSI) and investigated its correlation with driving behaviors: both perceptual-motor skills and safety skills were positively associated with positive behaviors, safety skills were negatively associated with all risky driving behaviors, and perceptual motor skills were negatively associated with errors and lapses.

A number of inherent driver characteristics, including age [25, 26], driving experience [27], skill and knowledge, safety perception, level of alertness, and travel pattern, can affect driving performance, especially under low illumination conditions. In particular, the amount of information on the road environment, traffic conditions, and vehicle trajectory that a driver can receive can be impaired because of reductions in visibility (in terms of sight distance and visual contrast). Therefore, reductions in visibility can delay and impact the recognition and perception of hazards on the road and thus impair defensive driving performance. It is therefore essential to evaluate the effect of driver characteristics on risk perception, particularly variations in the effect across different illumination levels.

Previous studies have found that risk perception can influence driving behavior [28–30]. Cheng et al. [31] revealed that there is a relationship between driving-violation behaviors and risk perception. Risk perception increases the likelihood of defensive driving behavior [32], and increased risk perception can enhance driving performance [33]. However, research has rarely attempted to examine the intervention effect of illumination conditions on the relationship between risk perception and driving performance. Additionally, the confounding effects of driver characteristics, including age and driving experience [34], should be taken into account.

This study attempted to examine the effect of impaired visual performance and risk perception on the propensity for risky driving behavior under low illumination conditions at night. Previous studies have explored drivers' car-following behaviors and lane-change behaviors under low illumination conditions [5, 35]. However, no study has investigated whether the DBQ and DSI are valuable tools in traffic safety analysis under low illumination conditions. An attitudinal model using the DBQ and the DSI was developed to evaluate risk perception and the propensity for risky driving behavior. The impacts of driver demographic characteristics, driving experience, travel pattern, and road environment, especially in the presence of streetlights, were considered. The results of this study highlight the need to improve driver training and education programs, particularly for vulnerable driver groups. The remaining parts of the paper are organized as follows. Section 2 provides the details of the survey design and the method of analysis. Sections 3 and 4 present

the results and discussion, respectively. Concluding remarks and the limitations of the current study are provided in Section 6.

## 2. Data Collection and Analysis

*2.1. Questionnaire Content.* The questionnaire was divided into three parts: (i) basic personal information; (ii) the DBQ; and (iii) the DSI. The selection of items was mainly based on mature questionnaires that have been widely used. To avoid confusing respondents with professional vocabulary, the questionnaire did not define low illumination by light intensity but described a low-illumination environment as a night environment. We invited experts from the Institute of Transportation and Safety on our academic team as well as 10 professional drivers to evaluate the content of the questionnaire. Several rounds of discussion and revisions to the initial questionnaire were conducted following the workshops.

Regarding basic personal characteristics, information was collected such as driver's gender, age, education, driving experience, annual average mileage, penalty points in the last year, penalty points for night driving, driving self-assessment, and night driving self-evaluation.

The second part was the DBQ, which was used to evaluate the participants' driving behavior under low illumination. The modified DBQ (based on the original DBQ introduced in the 1990s) [36, 37] was developed in accordance with the social and cultural characteristics of China. In addition to the items on the original DBQ, items regarding the mobile phone use while driving were included. Collet et al. [38] showed that drivers who use mobile phones while driving have a higher risk of being in traffic accidents than drivers who do not use mobile phones while driving. The assessment items were customized for driving at night and under low illumination conditions. The modified DBQ consisted of 50 assessment items, of which 36 were related to variations in the prevalence of risky driving behavior in the presence (18 items) or absence (18 items) of streetlights under low illumination conditions. A five-point scale (1 indicating "never" and 5 indicating "always") was applied. Tables 1 and 2 show the mean and standard deviation of the score for every DBQ item. In general, the propensity for risky driving behavior when streetlights were present (QY15–32) was higher than that when streetlights were not present (QN15–32).

The third part was a modified DSI (based on the original DSI introduced in the 2000s) [39, 40], which was developed in accordance with the social and cultural characteristics of China. The modified DSI consisted of 44 assessment items, of which 32 were related to variations in risk perception in the presence (16 items) or absence (16 items) of streetlights. Again, a five-point scale (1 indicating "totally disagree" and 5 indicating "totally agree") was applied. Tables 3 and 4 show the mean and standard deviation of the score for every DSI item. In general, the level of perceived driver competence when streetlights were present (SY12–SY27) was higher than the level of perceived driver competence when streetlights were absent (SN12–SN27).

*2.2. Sampling Procedure.* The investigation was conducted from November to December 2017. Data were collected from a field survey via self-reports. Face-to-face investigations were conducted to ensure the authenticity of the questionnaires. The participants were invited randomly to participate in the community and at automotive 4S (Sale, Sparepart, Service and Survey) shops in Hefei city, China. The selection criterion for the driver was having a valid driver license. They were informed of the purpose of the investigation. The survey was anonymous to ensure the authenticity of the study, and participation was voluntary. Finally, a monetary reward of 10 RMB (\$1.4776 US) was given for completion of the survey.

*2.3. Sample Characteristics.* A total of 266 participants were invited to complete the questionnaire survey, and 243 valid questionnaires (with no missing information) were collected. Of the 243 valid responses, 74.9% were from male drivers, and 25.1% were from female drivers. The age of the participants ranged from 20 to 55 years, with an average age of 31.9 years and a standard deviation of 7.32. The average driving experience was 5.6 years (SD = 5.13), and the average annual mileage was 160.27 million kilometers (SD = 2.11). For further details, see Table 5.

*2.4. Data Analysis.* SPSS version 20.0 was used for data processing. First, to determine the factors of the DBQ and DSI, an exploratory factor analysis (EFA) was conducted. Items with a factor loading greater than 0.4 were retained. Cronbach's alpha was the coefficient that was utilized to evaluate the reliability of the instruments. For each factor, a Cronbach's alpha value greater than 0.6 was considered acceptable.

Moreover, Pearson's correlation test was conducted to analyze the correlations among basic information and the DBQ/DSI factors. One-way analysis of variance (ANOVA) was used to investigate the discrepancies in the DBQ and DSI between age groups. Multiple linear regression analysis was performed to evaluate the effect of the study variables on risky driving behaviors under low illumination conditions.

## 3. Results

### 3.1. Factor Structure

*3.1.1. Factor Structure and Correlations of the DBQ.* For the 50 DBQ items relating to the prevalence of risky driving behavior with and without streetlights under low illumination conditions, principal component factor analysis and orthogonal rotation analysis were conducted to screen out deterministic factors (in this study, 3 factors were selected) using the threshold value of 1. In particular, the cumulative variance contribution was 56.8% when streetlights were present and 58.4% when streetlights were absent. In addition, the Kaiser–Meyer–Olkin (KMO) values were 0.904 and 0.896 (all greater than 0.5) when streetlights were present and absent, respectively. According to the results of Bartlett's spherical test, all variables considered were statistically

TABLE 1: Summary of the results for the DBQ with streetlights in low illumination.

	DBQ items	Mean	S.D.
Q1	In low illumination, drive close to the vehicle ahead and find it difficult to stop in an emergency	1.55	0.65
Q2	In low illumination, when distracted or preoccupied, realize belatedly that the vehicle ahead has slowed and have to slam on the brakes to avoid collision	1.79	0.82
Q3	In low illumination, speed up and cross at lights that will turn yellow	2.03	0.96
Q4	In low illumination, do not give way to pedestrians who have already walked at a zebra crossing without traffic lights	1.50	0.68
Q5	In low illumination, disregard the speed limit on a residential road	1.50	0.73
Q6	In low illumination, use a mobile phone when driving	1.92	0.85
Q7	In low illumination, race nearby vehicles away from traffic lights and try to overtake them	1.72	0.81
Q8	In low illumination, honk the horn to show annoyance with another driver	1.64	0.78
Q9	In low illumination, have an aversion to a particular class of road user and indicate your hostility by whatever means you can	1.64	0.74
Q10	In low illumination, disregard the speed limit on a motorway	1.20	0.50
Q11	In low illumination, cross a junction knowing that the traffic lights have already turned against you	1.23	0.57
Q12	In low illumination, forget where you left your car in a car park	1.72	0.77
Q13	In low illumination, brake sharply on a slippery road	1.56	0.67
Q14	In low illumination, intend to switch on the windshield wipers but switch on the lights instead, or vice versa	1.58	0.71
QY15	With streetlights in low illumination, fail to notice someone stepping out from behind or in front a vehicle until it is nearly too late	1.57	0.62
QY16	With streetlights in low illumination, hit something when reversing that you had not previously seen	1.52	0.63
QY17	With streetlights in low illumination, misjudge your gap in a car park and nearly (or actually) hit an adjoining vehicle	1.53	0.63
QY18	With streetlights in low illumination, misread the signs and exit from a roundabout on the wrong road so that you get into the wrong lane	1.69	0.64
QY19	With streetlights in low illumination, miss 'give way' signs and narrowly avoid colliding with traffic that has the right of way	1.48	0.61
QY20	With streetlights in low illumination, on turning right, nearly hit a cyclist who is traveling on the right	1.49	0.65
QY21	With streetlights in low illumination, underestimate the speed of an oncoming vehicle when overtaking	1.59	0.64
QY22	With streetlights in low illumination, fail to notice pedestrians crossing when turning onto a branch road from a main road	1.58	0.64
QY23	With streetlights in low illumination, overtake a slow driver on the right	1.91	0.80
QY24	With streetlights in low illumination, fail to check your rear-view mirror before pulling out, changing lanes, etc.	1.46	0.67
QY25	With streetlights in low illumination, when distracted or preoccupied, fail to notice someone running at a zebra crossing	1.60	0.64
QY26	With streetlights in low illumination, attempt to overtake someone that you had not noticed signaling a left turn	1.44	0.65
QY27	With streetlights in low illumination, realize that you have no clear recollection of the road along which you have just been traveling	1.73	0.72
QY28	With streetlights in low illumination, get into the wrong lane at a roundabout or when approaching a road junction	1.65	0.70
QY29	With streetlights in low illumination, in a queue of vehicles turning right onto a main road, pay such close attention to the traffic approaching from the main road that you nearly hit the car in front	1.52	0.69
QY30	With streetlights in low illumination, misjudge your gap with a nearby vehicle and narrowly miss colliding	1.34	0.55
QY31	With streetlights in low illumination, stay in a motorway lane that you know will be closed ahead until the last minute before forcing your way into the other lane	1.53	0.69
QY32	With streetlights in low illumination, turn left onto a main road into the path of an oncoming vehicle that you had not seen or whose speed you had misjudged	1.50	0.61

significant at 1% level. In this study, the criterion for selecting a DBQ item was having a loading greater than 0.4. Given the above, 12 DBQ items were selected for subsequent analyses (Q1, Q2, Q10, Q11, Q13, Q14, QY15/QN15, QY23/QN23, and QY25/QN25 were deleted).

Cronbach's alpha value was 0.927 when streetlights were present and 0.936 when streetlights were absent. These results indicated the robustness of the overall structure of the questionnaire. Table 6 presents the factor structure and factor loadings based on the results of Cronbach's alpha estimates. As shown in Table 6, the DBQ items were classified into three categories: (1) violations; (2) lapses; and (3) errors. For instance, factor 1 ( $\alpha = 0.866/0.866$ ) consisted of 7 items and explained 10.57% of the variance for the presence of streetlights and 11.17% of the variance for the absence of

streetlights. Factor 2 ( $\alpha = 0.855/0.878$ ) consisted of 7 items and explained 6.34% of the variance for the presence of streetlights and 5.68% of the variance for the absence of streetlights. Factor 3 ( $\alpha = 0.902/0.905$ ) consisted of 9 items and explained 39.92% of the variance for the presence of streetlights and 41.54% of the variance for the absence of streetlights.

Based on the results of the principal component analysis, possible attributes affecting the propensity for risky driving behavior were classified into three categories. In addition, possible correlations between the factors and the relationship between each factor and overall propensity were assessed using Pearson's correlation analysis. Pearson's correlation analysis was employed to measure the correlation between the subscales and the total scale. The total scale



TABLE 2: Summary of the results for the DBQ without streetlights in low illumination.

	DBQ items	Mean	S.D.
Q1	In low illumination, drive close to the vehicle ahead and find it difficult to stop in an emergency	1.55	0.65
Q2	In low illumination, when distracted or preoccupied, realize belatedly that the vehicle ahead has slowed and have to slam on the brakes to avoid a collision	1.79	0.82
Q3	In low illumination, speed up and cross at lights that will turn yellow	2.03	0.96
Q4	In low illumination, do not give way to pedestrians who have already walked at a zebra crossing without traffic lights	1.50	0.68
Q5	In low illumination, disregard the speed limit on a residential road	1.50	0.73
Q6	In low illumination, use a mobile phone when driving	1.92	0.85
Q7	In low illumination, race nearby vehicles away from traffic lights and try to overtake them	1.72	0.81
Q8	In low illumination, honk the horn to show annoyance with another driver	1.64	0.78
Q9	In low illumination, have an aversion to a particular class of road user and indicate your hostility by whatever means you can	1.64	0.74
Q10	In low illumination, disregard the speed limit on a motorway	1.20	0.50
Q11	In low illumination, cross a junction knowing that the traffic lights have already turned against you	1.23	0.57
Q12	In low illumination, forget where you left your car in a car park	1.72	0.77
Q13	In low illumination, brake sharply on a slippery road	1.56	0.67
Q14	In low illumination, intend to switch on the windshield wipers but switch on the lights instead, or vice versa	1.58	0.71
QN15	Without streetlights in low illumination, fail to notice someone stepping out from behind or in front a vehicle until it is nearly too late	1.58	0.70
QN16	Without streetlights in low illumination, hit something when reversing that you had not previously seen	1.60	0.72
QN17	Without streetlights in low illumination, misjudge your gap in a car park and nearly (or actually) hit an adjoining vehicle	1.51	0.71
QN18	Without streetlights in low illumination, misread the signs and exit from a roundabout on the wrong road so that you get into the wrong lane	1.87	0.90
QN19	Without streetlights in low illumination, miss "give way" signs and narrowly avoid colliding with traffic that has the right of way	1.56	0.70
QN20	Without streetlights in low illumination, on turning right, nearly hit a cyclist who is traveling on the right	1.57	0.74
QN21	Without streetlights in low illumination, underestimate the speed of an oncoming vehicle when overtaking	1.60	0.76
QN22	Without streetlights in low illumination, fail to notice pedestrians crossing when turning onto a branch road from a main road	1.59	0.80
QN23	With and without streetlights in low illumination, overtake a slow driver on the right	1.85	0.89
QN24	Without streetlights in low illumination, fail to check your rear-view mirror before pulling out, changing lanes, etc.	1.51	0.70
QN25	Without streetlights in low illumination, when distracted or preoccupied, fail to notice someone running at a zebra crossing	1.59	0.78
QN26	Without streetlights in low illumination, attempt to overtake someone that you had not noticed signaling a left turn	1.54	0.76
QN27	Without streetlights in low illumination, realize that you have no clear recollection of the road along which you have just been traveling	1.98	1.01
QN28	Without streetlights in low illumination, get into the wrong lane at a roundabout or when approaching a road junction	1.91	0.92
QN29	Without streetlights in low illumination, in a queue of vehicles turning right onto a main road, pay such close attention to the traffic approaching from the main road that you nearly hit the car in front	1.51	0.71
QN30	Without streetlights in low illumination, misjudge your gap with a nearby vehicle and narrowly miss colliding	1.54	0.76
QN31	Without streetlights in low illumination, stay in a motorway lane that you know will be closed ahead until the last minute before forcing your way into the other lane	1.58	0.81
QN32	Without streetlights in low illumination, turn left onto a main road into the path of an oncoming vehicle that you had not seen or whose speed you had misjudged	1.64	0.82

of the DBQ was positively correlated with errors ( $r=0.890/0.907$ ,  $p<0.01$ ,  $n=243$ ), lapses ( $r=0.826/0.876$ ,  $p<0.01$ ,  $n=243$ ), and violations ( $r=0.791/0.747$ ,  $p<0.01$ ,  $n=243$ ) with and without streetlights. Among the 3 dimensions of risky driving behavior, errors ( $r=0.523/0.8491$ ,  $p<0.01$ ,  $n=243$ ) and lapses ( $r=0.432/0.451$ ,  $p<0.01$ ,  $n=243$ ) were positively related to violations with and without streetlights. Likewise, errors ( $r=0.694/0.763$ ,  $p<0.01$ ,  $n=243$ ) were positively related to lapses with and without streetlights. The results showed that there was a significant correlation between the subscales and between the subscales (with and without streetlights) and the total scale, which reflected that the revised scale had good content validity.

**3.1.2. Factor Structure and Correlations of the DSI.** For the 44 DSI items relating to the presence and absence of streetlights in low illumination conditions, the cumulative variance contribution rates were 76.41% and 75.98%, respectively. The KMO values were 0.963 and 0.956 with and without streetlights, respectively. In this study, the criteria for selecting DSI items were as follows: the factor loading was greater than 0.4, and each factor included at least 3 items. Based on these conditions, 9 items (S7, SY12/SN12, SY17/SN17, SY21/SN21, and SY23/SN23) were deleted after repeated comparisons. Ultimately, a total of 22 DSI items were revised, representing 2 factors: technical driving skills and risk perception. Cronbach's alpha values were 0.980 and

TABLE 3: Summary of the results for the DSI with streetlights in low illumination.

	DSI items	Mean	S.D.
S1	In low illumination, I drive fluidly	3.36	1.13
S2	In low illumination, I drive steadily on a slippery road	3.21	1.05
S3	In low illumination, I observe the surrounding traffic before driving	3.51	1.05
S4	In low illumination, I can park my car safely and correctly on the ramp	3.47	1.12
S5	In low illumination, I drive safely and steadily	3.72	1.03
S6	In low illumination, I drive a car smoothly at night, such as slow acceleration and deceleration	3.78	1.00
S7	In low illumination, I adjust the speed of driving to the conditions	3.67	1.10
S8	In low illumination, I have mastered the methods and techniques of the emergency turn	3.27	1.16
S9	In low illumination, I have mastered braking quickly and controlling the car	3.25	1.13
S10	In low illumination, I complete the necessary driving actions in an emergency	3.44	1.08
S11	In low illumination, I skillfully use various electronic navigation equipment in the car	3.62	1.11
SY12	With streetlights in low illumination, I can plan or choose routes to avoid losing my way	3.57	1.08
SY13	With streetlights in low illumination, I always safely avoid an emergency	3.47	1.037
SY14	With streetlights in low illumination, I detect potential traffic risks	3.50	1.03
SY15	With streetlights in low illumination, when driving in a strange environment, I detect its potential risks	3.39	1.04
SY16	With streetlights in low illumination, I keep sufficient following distance	3.79	1.01
SY17	With streetlights in low illumination, I control the traffic situation around me very well	3.51	1.09
SY18	With streetlights in low illumination, I react quickly to an emergency while driving	3.54	1.01
SY19	With streetlights in low illumination, I change lanes reasonably in heavy traffic	3.82	1.09
SY20	With streetlights in low illumination, I make a decision quickly when I encounter a choice	3.49	0.99
SY21	With streetlights in low illumination, I drive reasonably by observing the movement of pedestrians and other vehicles	3.70	0.97
SY22	With streetlights in low illumination, I notice the dynamics of the roadside	3.61	0.97
SY23	With streetlights in low illumination, I overtake cars safely and reasonably	3.64	1.06
SY24	With streetlights in low illumination, I judge the safe speed according to different road conditions	3.53	1.07
SY25	With streetlights in low illumination, I pay attention to the movement around my vehicle	3.63	0.99
SY26	With streetlights in low illumination, I quickly detect the risky actions of other drivers	3.38	1.04
SY27	With streetlights in low illumination, I quickly identify pedestrians ahead crossing the road	3.62	1.06

TABLE 4: Summary of the results for the DSI without streetlights in low illumination.

	DSI items	Mean	S.D.
S1	In low illumination, I drive fluidly	3.36	1.13
S2	In low illumination, I drive steadily on a slippery road	3.21	1.05
S3	In low illumination, I observe the surrounding traffic before driving	3.51	1.05
S4	In low illumination, I can park my car safely and correctly on the ramp	3.47	1.12
S5	In low illumination, I drive safely and steadily	3.72	1.03
S6	In low illumination, I drive a car smoothly at night, such as slow acceleration and deceleration	3.78	1.00
S7	In low illumination, I adjust the speed of driving to the conditions	3.67	1.10
S8	In low illumination, I have mastered the methods and techniques of the emergency turn	3.27	1.16
S9	In low illumination, I have mastered braking quickly and controlling the car	3.25	1.13
S10	In low illumination, I complete the necessary driving actions in an emergency	3.44	1.08
S11	In low illumination, I skillfully use various electronic navigation equipment in the car	3.62	1.11
SN12	Without streetlights in low illumination, I can plan or choose routes to avoid losing my way	3.29	1.09
SN13	Without streetlights in low illumination, I always safely avoid an emergency	3.19	1.06
SN14	Without streetlights in low illumination, I detect potential traffic risks	3.15	1.07
SN15	Without streetlights in low illumination, when driving in a strange environment, I detect its potential risks	3.17	1.05
SN16	Without streetlights in low illumination, I keep sufficient following distance	3.48	1.03
SN17	Without streetlights in low illumination, I control the traffic situation around me very well	3.26	1.10
SN18	Without streetlights in low illumination, I react quickly to an emergency while driving	3.29	1.09
SN19	Without streetlights in low illumination, I change lanes reasonably in heavy traffic	3.82	1.09
SN20	Without streetlights in low illumination, I make a decision quickly when I encounter a choice	3.25	1.06
SN21	Without streetlights in low illumination, I drive reasonably by observing the movement of pedestrians and other vehicles	3.39	1.00
SN22	Without streetlights in low illumination, I notice the dynamics of the roadside	3.28	1.07
SN23	Without streetlights in low illumination, I overtake cars safely and reasonably	3.32	1.08
SN24	Without streetlights in low illumination, I judge the safe speed according to different road conditions	3.31	1.03
SN25	Without streetlights in low illumination, I pay attention to the movement around my vehicle	3.29	1.05
SN26	Without streetlights in low illumination, I quickly detect the risky actions of other drivers	3.17	1.16
SN27	Without streetlights in low illumination, I quickly identify pedestrians ahead crossing the road	3.30	1.07

TABLE 5: Sample characteristics ( $n = 243$ ).

Variable category	Description	Frequency	Percentage (%)
Gender	Male	182	74.9
	Female	61	25.1
Age (years)	<26	40	16.5
	26–34	127	52.3
	35–44	58	23.9
	45–55	18	7.40
Educational background	Junior high school and below	7	2.8
	High school diploma	16	6.5
	Technical training	54	22.2
	Undergraduate degree	141	58.0
	Postgraduate degree and above	25	10.2
Average amount of nighttime driving per week measured in days	<3	152	62.6
	3–5	68	27.9
	>5	23	9.5
Average night driving time per week (hours)	<1	51	21.0
	1–3	173	71.2
	>3	19	7.8
Driving experience (years)	<3	72	29.6
	3–5	83	34.2
	>5	88	36.2

0.977 for the DSI items with and without streetlights, respectively, indicating that the overall structure of the questionnaire had high reliability. Factor 4 was technical driving skills ( $\alpha = 0.958/0.958$ ) and was composed of 10 items that explained 71.34% and 67.41% of the variance with and without streetlights, respectively. Factor 5, risk perception ( $\alpha = 0.974/0.971$ ), consisted of 12 items that explained 5.06% and 8.57% of the variance with and without streetlights, respectively. Table 7 displays the factor loadings for the DSI items regarding the presence or absence of streetlights in low illumination conditions.

Pearson's correlation analysis was used to measure the correlation between the subscales and the total scale. The total scale of the DSI was positively correlated with risk perception ( $r = 0.975/0.957$ ,  $p < 0.01$ ,  $n = 243$ ) and technical driving skills ( $r = 0.965/0.937$ ,  $p < 0.01$ ,  $n = 243$ ) with and without streetlights. Among the 2 dimensions of the DSI, risk perception ( $r = 0.882/0.796$ ,  $p < 0.01$ ,  $n = 243$ ) was positively related to technical driving skills with and without streetlights. The results showed that there was a significant correlation between the subscales (with and without streetlights) and the total scale, indicating that the revised scale had good content validity.

**3.2. Differences in Driving Errors, Lapses, and Risk Perception between Low Illumination Conditions with and without Streetlights.** The paired  $t$ -test method was applied to evaluate the differences between the with and without streetlight conditions for the three factors (errors, lapses, and risk perception) established based on principal factor analysis. The results indicated that errors ( $t(242) = -3.16$ ,  $p = 0.02$ ), lapses ( $t(242) = -5.15$ ,  $p < 0.01$ ), and risk perception ( $t(242) = -7.16$ ,  $p < 0.01$ ) were significantly different between the with and without streetlight conditions. Since no

differences were found for the violation and technical driving skill factors in the presurvey, these two factors were not analyzed.

**3.3. Effects of Driver Characteristics on Driving Behavior and Driving Skills.** Pearson's correlation test was applied to evaluate the effects of driver characteristics, including gender, age, driving experience, and annual distance traveled, on driving behavior and driving skill. In particular, the effect of the presence of streetlights under low illumination conditions was considered. The results of Pearson's correlation test are presented in Table 8. The results indicated that driver age, driving experience, involvement in a traffic violation, and involvement in a crash were significantly correlated with the propensity for risky driving behavior, driving skill and risk perception under low illumination conditions. In particular, increases in driver age and driving experience were correlated with a lower propensity for risky driving behavior, better driving skills, and higher risk perception under low illumination conditions. However, no evidence was found for a significant correlation between age and risk perception when streetlights were present. In addition, drivers who had incurred more driving offense points were found to have lower risk perception and poorer driving skills under low illumination conditions than those who had accumulated fewer driving offense points. Additionally, the presence of driver myopia was correlated with lower risk perception and poorer driving skills under low illumination conditions. However, no evidence was found for differences in driver characteristics and correlations between the with and without streetlight conditions.

The effects of driver characteristics on driving behavior and risk perception were evaluated. In addition, differences in the DBQ and DSI between age groups (i.e., age 20–25,

TABLE 6: Factor structure of the DBQ items.

	DBQ items (38 items)	Factor loading
Factor 1: violation $\alpha = 0.866/0.866$		
Q3	In low illumination, speed up and cross at lights that will turn yellow	0.764/0.767
Q4	In low illumination, do not give way to pedestrians who have already walked at a zebra crossing without traffic lights	0.621/0.653
Q5	In low illumination, disregard the speed limit on a residential road	0.760/0.688
Q6	In low illumination, use a mobile phone when driving	0.628/0.627
Q7	In low illumination, race nearby vehicles away from traffic lights and try to overtake them	0.738/0.723
Q8	In low illumination, honk the horn to show annoyance with another driver	0.773/0.715
Q9	In low illumination, have an aversion to a particular class of road user and indicate your hostility by whatever means you can	0.702/0.754
Factor 2: lapse $\alpha = 0.855/0.878$		
Q12	In low illumination, forget where you left your car in a car park	0.683/0.524
QY16/ QN16	With and without streetlights in low illumination, hit something when reversing that you had not previously seen	0.750/0.521
QY18/ QN18	With and without streetlights in low illumination, misread the signs and exit from a roundabout on the wrong road so that you get into the wrong lane	0.736/0.555
QY19/ QN19	With and without streetlights in low illumination, miss "give way" signs and narrowly avoid colliding with traffic that has the right of way	0.611/0.430
QY22/ QN22	With and without streetlights in low illumination, fail to notice pedestrians crossing when turning onto a branch road from a main road	0.496/0.492
QY27/ QN27	With and without streetlights in low illumination, realize that you have no clear recollection of the road along which you have just been traveling	0.663/0.795
QY28/ QN28	With and without streetlights in low illumination, get into the wrong lane at a roundabout or when approaching a road function	0.674/0.768
Factor 3: error $\alpha = 0.902/0.905$		
QY17/ QN17	With and without streetlights in low illumination, misjudge your gap in a car park and nearly (or actually) hit an adjoining vehicle	0.572/0.544
QY20/ QN20	With and without streetlights in low illumination, on turning right, nearly hit a cyclist who is traveling on the right	0.528/0.727
QY21/ QN21	With and without streetlights in low illumination, underestimate the speed of an oncoming vehicle when overtaking	0.572/0.637
QY24/ QN24	With and without streetlights in low illumination, fail to check your rear-view mirror before pulling out, changing lanes, etc.	0.684/0.604
QY26/ QN26	With and without streetlights in low illumination, attempt to overtake someone that you had not noticed signaling a left turn	0.703/0.806
QY29/ QN29	With and without streetlights in low illumination, in a queue of vehicles turning right onto a main road, pay such close attention to the traffic approaching from the main road that you nearly hit the car in front	0.804/0.723
QY30/ QN30	With and without streetlights in low illumination, misjudge your gap with a nearby vehicle and narrowly miss collision	0.756/0.677
QY31/ QN31	With and without streetlights in low illumination, stay in a motorway lane that you know will be closed ahead until the last minute before forcing your way into the other lane	0.685/0.651
QY32/ QN32	With and without streetlights in low illumination, turn left onto a main road into the path of an oncoming vehicle that you had not seen or whose speed you had misjudged	0.679/0.729

26–34, 35–45, and 45–55 years) were examined using one-way ANOVA. The results of the ANOVA are shown in Table 9. The results indicated that the differences across age groups in errors, lapses, violations, and risk perception in the presence of streetlights were remarkable. In general, the propensity for risky driving behavior decreased as age increased, while the level of risk perception increased as age increased. In particular, drivers aged 45–55 years attained the lowest scores for errors, lapses, and violations but highest scores for risk perception and technical driving skill. These results suggested that the driving performance of drivers aged 45–55 years was superior to that of drivers in other age groups.

*3.4. Prediction of Risky Driving Behavior.* Pearson's correlation analysis was used to measure the correlation between the DSI and DBQ factors. Risk perception was negatively correlated with errors ( $r = -0.291/-0.245$ ,  $P < 0.01$ ,  $n = 243$ ), lapses ( $r = -0.246/-0.249$ ,  $P < 0.01$ ,  $n = 243$ ), and violations ( $r = -0.013/-0.013$ ,  $P > 0.05$ ,  $n = 243$ ) with and without streetlights. Likewise, technical driving skills were negatively correlated with errors ( $r = -0.247/-0.206$ ,  $P < 0.01$ ,  $n = 243$ ), lapses ( $r = -0.193/-0.246$ ,  $P < 0.01$ ,  $n = 243$ ), and violations ( $r = -0.001/-0.001$ ,  $P > 0.05$ ,  $n = 243$ ) with and without streetlights.

Possible factors contributing to driver errors, lapses, and violations were examined using the multiple linear



TABLE 7: Factor structure of the DSI items.

DSI items (35 items)		Factor loading
Factor 4: technical driving skills, $\alpha = 0.958/0.958$		
S1	In low illumination, I drive fluidly	0.863/0.799
S2	In low illumination, I drive steadily on a slippery road	0.855/0.808
S4	In low illumination, I can park my car safely and correctly on the ramp	0.784/0.789
S5	In low illumination, I drive safely and steadily	0.703/0.800
S6	In low illumination, I drive a car smoothly at night, such as slow acceleration and deceleration	0.649/0.825
S8	In low illumination, I have mastered the methods and techniques of the emergency turn	0.645/0.723
S9	In low illumination, I have mastered braking quickly and controlling the car	0.644/0.716
S10	In low illumination, I complete the necessary driving actions in an emergency	0.650/0.748
S11	In low illumination, I skillfully use various electronic navigation equipment in the car	0.594/0.765
SY19/ SN19	With and without streetlights in low illumination, I change lanes reasonably in heavy traffic	0.604/0.761
Factor 5: risk perception, $\alpha = 0.974/0.971$		
S3	In low illumination, I observe the surrounding traffic before driving	0.791/0.777
SY13/ SN13	With and without streetlights in low illumination, I always safely avoid an emergency	0.694/0.642
SY14/ SN14	With and without streetlights in low illumination, I detect potential traffic risks	0.768/0.669
SY15/ SN15	With and without streetlights in low illumination, when driving in a strange environment, I detect its potential risks	0.686/0.641
SY16/ SN16	With and without streetlights in low illumination, I keep sufficient following distance	0.820/0.525
SY18/ SN18	With and without streetlights in low illumination, I react quickly to an emergency while driving	0.835/0.817
SY20/ SN20	With and without streetlights in low illumination, I make a decision quickly when I encounter a choice	0.810/0.799
SY22/ SN22	With and without streetlights in low illumination, I notice the dynamics of the roadside	0.845/0.795
SY24/ SN24	With and without streetlights in low illumination, I judge the safe speed according to different road conditions	0.815/0.834
SY25/ SN25	With and without streetlights in low illumination, I pay attention to the movement around my vehicle	0.794/0.873
SY26/ SN26	With and without streetlights in low illumination, I quickly detect the risky actions of other drivers	0.671/0.835
SY27/ SN27	With and without streetlights in low illumination, I quickly identify pedestrians ahead crossing the road	0.724/0.876

TABLE 8: Correlations between driver characteristics and the DBQ and DSI factors.

Variables	Error	Lapse	Violation	Risk perception	Technical driving skill
	With/without streetlight	With/without streetlight	With/without streetlight	With/without streetlight	With/without streetlight
Age	-0.181**/-0.169**	-0.126*/-0.183**	-0.131*/-0.131*	0.125/0.155*	0.140*/0.140*
Driving experience	-0.235**/-0.210**	-0.180**/-0.248**	0.073/0.073	0.210**/0.189**	0.210**/0.210**
Myopia	0.069/0.039	0.085/0.030	0.060/0.060	-0.140*/-0.128*	-0.156*/-0.156*
Annual distance traveled	-0.125/-0.127*	-0.152*/-0.127*	-0.032/-0.032	0.064/0.063	0.133*/0.133*
Crash involvement	0.163*/0.221**	0.143*/0.146*	0.183**/0.183**	-0.014/-0.060	0.030/0.030
Penalty points	0.150*/0.096	0.111/0.120	0.081/0.081	-0.248**/-0.261**	-0.189**/-0.189**
Night driving self-assessment	0.051/-0.026	0.147*/0.052	-0.037/-0.037	-0.263**/-0.289**	-0.268**/-0.268**
Driving self-assessment	0.170**/0.139*	0.215**/0.246**	-0.188**/-0.188**	-0.364**/-0.376**	-0.399**/-0.399**

\* $p < 0.05$  and \*\* $p < 0.01$ .

regression approach. Specifically, the independent variables were classified into two layers. In the first layer, factors including age, driving experience, education level, and annual distance traveled were considered. In the

second layer, factors including crash involvement, risk perception, and technical driving skills were considered. The results of the stepwise regression models are shown in Table 10.

TABLE 9: Differences according to age for the DBQ and DSI factors.

	Age 20–25	Age 26–34	Age 35–44	Age 45–55	F-statistic
	With/without streetlight Mean (S.D.)	With/without streetlight Mean (S.D.)	With/without streetlight Mean (S.D.)	With/Without streetlight Mean (S.D.)	
Error	1.52 (0.56)/1.64 (0.68)	1.55 (0.50)/1.61 (0.57)	1.42 (0.40)/1.45 (0.48)	1.22 (0.27)/1.28 (0.37)	2.958*/2.896*
Lapse	1.64 (0.60)/1.81 (0.76)	1.65 (0.48)/1.80 (0.60)	1.66 (0.46)/1.70 (0.56)	1.29 (0.27)/1.35 (0.41)	3.105*/3.164*
Violation	1.69 (0.62)/1.69 (0.63)	1.80 (0.63)/1.80 (0.62)	1.60 (0.49)/1.60 (0.49)	1.45 (0.56)/1.45 (0.56)	2.761*/2.761*
Risk perception	3.33 (0.91)/3.07 (0.84)	3.57 (0.93)/3.28 (0.95)	3.46 (0.81)/3.15 (0.86)	4.03 (0.82)/3.92 (0.95)	2.769*/3.943*
Technical driving skill	3.25 (0.90)/3.25 (0.90)	3.53 (1.00)/3.53 (1.00)	3.47 (0.79)/3.47 (0.79)	3.93 (0.77)/3.93 (0.77)	2.401/2.401

\* $p < 0.05$  and \*\* $p < 0.01$ .

TABLE 10: Results of multiple linear regression analyses.

Variable	Error		Lapse		Violation	
	With/without streetlight		With/without streetlight		With/without streetlight	
	$\beta$	$\Delta R^2$	$\beta$	$\Delta R^2$	$\beta$	$\Delta R^2$
Layer 1		0.102**/0.083**		0.051**/0.078**		0.076**/0.076**
Age	-0.052/-0.040		-0.017/-0.012		-0.332**/-0.332**	
Driving experience	-0.116/-0.087		-0.081/-0.163*		0.329**/0.329**	
Education	0.194**/0.168**		0.017/0.091		0.110/0.110	
Annual distance traveled	-0.048/-0.059		-0.107/-0.053		-0.039/-0.039	
Layer 2		0.078*/0.091**		0.061*/0.102**		0.042**/0.042**
Crash involvement	0.151*/0.198**		0.134**/0.223**		0.206**/0.206**	
Risk perception	-0.242**/-0.299**		-0.214*/ -0.326**			

\* $p < 0.05$  and \*\* $p < 0.01$ .

As shown in Table 10, in the presence of streetlights under low illumination conditions, factors in the first layer accounted for 10.2%, 5.1%, and 7.6% of the variation in errors, lapses, and violations, respectively. Age and driving experience were significant predictors of violations. The mean frequency of commission of traffic violations increased as driver experience increased [41]. For the second layer, crash involvement and risk perception played vital roles in the propensity for errors and lapses, but risk perception was not found to predict violations.

Under the low illumination condition without the presence of streetlights, factors in the first layer accounted for 8.3%, 7.8%, and 7.6% of the variations in errors, lapses, and violations, respectively. Age and driving experience were significant predictors of violations, indicating that traffic violations increased as age and driving experience increased. However, crash involvement and risk perception explained more of the variance in errors and lapses than street lighting.

#### 4. Discussion

This study aimed to examine the relationships between driver demographics, such as age, driving experience, and crash involvement, and risk perception and propensity for risky driving behavior under low illumination conditions using the DBQ and DSI. The results suggested that the adapted versions of the DBQ and DSI have clear factorial structures, items with high factorial weight, and good internal consistency. In particular, the effect of the presence of

streetlights was considered. The results indicated that differences in the associations between possible factors, risk perception, and propensity for risky driving behavior in the presence and absence of streetlights were significant. Keall et al. [42] showed that roads with nighttime illumination are less risky at night than they are during the day relative to roads without illumination. This implies that the design, planning, and installation of streetlights play an important role in road safety at night.

In particular, involvement in driving offenses and visual impairment were correlated with risk perception and driving skills under low illumination conditions. This finding indicates that the design of driver assistance systems and warning systems could enhance the safety awareness of drivers at night [43, 44].

Driver aggressiveness and risky driving behavior are major concerns for road safety [45]. In this study, factors including driver age and driving experience were found to be correlated with driver error and the propensity to commit violations under low illumination conditions. Increases in driver age and driving experience were found to be correlated with increases in driving skill and risk perception. This result is consistent with the findings of previous studies; in particular, Tränkle et al. [46] reported that young male drivers have a lower capability for judging hazardous conditions on roads. Additionally, Shi et al. [47] suggested that an increase in driving experience is correlated with a reduction in driving errors and lapses. Furthermore, the presence of streetlights was found to affect the association

between age and risk perception, which highlights the importance of the design and planning of streetlights in this study.

Regarding propensity for risky driving behavior, age was found to affect the associations between errors, lapses, violations, risk perception, and risky driving behavior. Overall, the propensity for risky driving behavior decreased with age [48], while risk perception increased with age. Specifically, drivers aged 45–55 years had the lowest propensity for errors, lapses, and violations. Additionally, drivers aged 45–55 years exhibited the highest levels of risk perception and technical driving skills among the age groups. Moreover, the frequencies of errors and lapses, regardless of driver age, were lower under low illumination conditions in the presence of streetlights than under low illumination conditions without streetlights. This could be because of variations in the driver's field of vision and differences related to the mental workload in low illumination conditions with and without streetlights. This notion is consistent with the findings of previous studies. In particular, Reason et al. [36] and Kontoyiannis et al. [49] suggested that increased age is correlated with a reduction in the propensity for traffic violations.

Under low illumination conditions, both risk perception skills and technical driving skills were found to be significantly correlated with errors and lapses. However, no evidence was found of an association among risk perception, driving skills, and violations. Although this finding was seemingly not consistent with that of previous studies [30, 50], it could be because of the intervention effect of low illumination and the presence of streetlights, which has often been ignored in empirical studies.

In future research, it would be beneficial to explore the effects of driver assistance systems on the relationships between driver characteristics, risk perception, safety attitude, and therefore propensity for risky behavior using driving simulator studies and attitudinal models.

## 5. Conclusions and Limitations

This study showed that both the DBQ and DSI are valuable instruments in traffic safety analysis in low illumination conditions and indicated that errors, lapses, and risk perception were significantly different between with and without streetlight conditions. Pearson's correlation test found that elderly and experienced drivers had a lower likelihood of risky driving behaviors when driving in low illumination conditions, and crash involvement was positively related to risky driving behaviors. Regarding the relationship between study variables and driving skills, the research suggested that age, driving experience, and annual distance were positively associated with driving skills, while myopia, penalty points, and driving self-assessment were negatively related to driving skills. The differences across age groups in errors, lapses, violations, and risk perception in the presence of streetlights were remarkable, and the driving performance of drivers aged 45–55 years was superior to that of drivers in other age groups. The multiple linear regression model predicted the frequency of risky driving behavior well,

and age, driving experience, education background, crash involvement, and risk perception were significant predictors.

This study has some limitations. For instance, the participants were mainly male drivers, and it would be worth exploring the effect of gender on risk perception and driving safety under low illumination conditions if the sample size could be increased in an extended study. Additionally, the models established in this study were based on drivers' self-reported data. The questionnaire relied on self-reported data and may therefore have been sensitive to several biases, such as overestimation of one's own skills. In an extended study, the results could be verified by obtaining empirical driving and safety data from crash databases, naturalistic driving data, and/or driving simulator experiments.

## Data Availability

No data were used to support this study.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

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