An Investigation of Driver Behavior on Urban General Road and in Tunnel Areas

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Abstract: The objective of this study is to examine experience-related differences in microscope driving behavior as drivers performed six separate maneuvers, namely 1) driving on general urban roads, 2) approaching a tunnel portal, 3) driving through a tunnel’s threshold zone, 4) driving in the interior tunnel zone, 5) driving in the zone ahead the tunnel exit and 6) driving after the tunnel exit. An on-road experiment was conducted with 20 drivers in two groups. The first group was made up of new licensed drivers, and the second group contained the more experienced drivers. The study consisted of one between-subject (experience) and five within-subject variables (drive environment type). The drivers’ behavior was measured through Mean Glance Duration, AOI Attention Ration, Horizontal Eye Activity, Vertical Eye Activity, Percentage of Eyelid Closure, and Heart Rate Variability. With respect to the relevant psychological measures, the results show that in general more attention is focused on the far left-hand side of the road and the near front road when driving through tunnel areas when compared with driving on general roads. In addition, the psychological measurements indicate that tunnel’s dark narrow environment causes anxiety on driving for lower heart rate variation coefficient (RRCV). New licensed drivers were more severely affected by the tunnel environment than the experienced drivers.

1. Introduction

Road safety involves the quality of the road and is defined by the level of accidents on that road. However, road safety is also reflected by the degree of safety displayed by the traffic participants in terms of road traffic accidents and their consequences. Road safety can also be understood to be the result of the safe interaction of traffic participants, between themselves and the environment. Therefore, when assessing road traffic safety, we need to take into account the psychophysical capabilities of the drivers [1].

A proper road tunnel could solve the problem of environment damage, land resources preserving, and air pollution reducing, tunnels have been an alternative solution to satisfy the roadway construction. On the other hand, urban tunnel safety poses a new question in terms of the corresponding traffic system. The last decade has seen more improvements than ever before introduced in terms of driver safety. In spite of these improvements, a significant number of traffic accidents still occur all over the world. Most of those accidents are caused by human mistakes while driving, such as typing text messages, speaking on a mobile phone, eating or drinking, etc. [2]. These actions distract drivers and lead to crashes. What’s more, the driving environment can also result in
critical accidents, due to that environment’s psychosocial effects on drivers. The environments of general urban roads and tunnels are very different. Urban tunnels have long been considered the bottleneck sections of urban traffic systems, due to those tunnels’ dramatic and sudden changes to the driving environment. As the virtual throat of the traffic network, the risk of crashes in tunnels is lower than the risk on an open road network, but the consequences of a tunnel crash are often severe [3-5]. Most research efforts to date have been allocated to accident analysis. Both in Norway [6] and in Austria [7], it has been found that slightly fewer crashes occur in tunnels than on normal roads, but the fatality rate is substantially higher in tunnel crashes. Nussbaumer [5] mentions that, according to police reports, the main reasons for tunnel crashes are a lack of vigilance (caused by fatigue, distraction, inattention) and behavioral aspects (e.g. driving at a safe distance from other vehicles, remaining in your lane, overtaking). Constant high levels and constant low levels of activation can both be detrimental to driving. For example, performance breaks down when the driver’s workload becomes too high [8-10], whereas long periods of monotonous driving can lead to boredom and fatigue [11-12]. The PIARC Technical Committee reported that a tunnel's dark, narrow environment may cause driver anxiety, uncertainty, and even fear of hitting another vehicle or tunnel walls, and of other dangerous circumstances such as fire or a tunnel collapse. The transition zones in tunnels are especially considered to be the most dangerous areas, due to their rapidly changing environments. When a vehicle approaches a tunnel entrance, the driver normally decelerates, in order to adapt to the dim light. This condition is called “black hole phenomena”. After entering a tunnel, the driver will decelerate to a speed that is slower than one the driver would normally travel at on an open road. However, when driving away from the tunnel, vehicles frequently accelerate quite rapidly. These significant speed fluctuations have a deleterious impact on traffic safety [13].

We also find that the characteristic eye movements change with the corresponding driving environment. These changes, in turn, have some relationship with the crash rate. According to McDowell and Rockwell [14], a driver’s mean fixation duration when driving on roads with high crash rates is longer than when driving on roads which experience fewer or no crashes. In addition, Wierwille [15] was able to establish a relationship model between fixation time and crash rate. Furuichi and Kadoma[16] measured driving load by fixation duration and fixation number. These studies all conclude that drivers’ eye movements can accurately reflect driving pressures and the effects on road safety. Even psychologists conclude that higher levels of visual stress will probably lead to more traffic accidents.

S. Bassan[17] summarized the differences between tunnels and open roads from the aspect of structural design, cost, traffic installations, and driver perception reaction time. Jian Sheng Yeung [18] concluded that traffic in tunnel expressways can be safer than the conventional open expressways from a microscopic behavioral perspective. Yeung’s findings suggest that microscopic behavioral studies can serve as reliable traffic safety assessments. However, an urban traffic system is more complicated than a freeway. As such, this paper aims to acquire the microscopic quantitative differences in driver behavior when driving along an urban tunnel area, in contrast to driving on a general road.

2. Data Collection
A field experiment was conducted in the Xi’an men Tunnel and on the Longpanzhong Road. Xi’an men Tunnel is a typical urban tunnel located in Nanjing, Jiangsu Province, in China. The tunnel is 1.65km long and designed in a straight line and with a smoothly longitudinal slope of 1.36% (in the driving direction of our test). The tunnel is open only to automobiles. A 20-metre reinforced concrete arched awning is located at each entrance and exit. The tunnel is equipped with two rows of fluorescent lights; after the awnings, additional pressure sodium lamps are installed in the transition section. The tunnel’s posted speed limit is 60 km/h. Longpanzhong Road, which is an open road above the Xi’an men Tunnel, was chosen as the contrasting element. The experiment scenario is shown in figure 1.
Ten new licensed drivers and 10 experienced drivers were recruited for the experiment. All participants had a valid driver license. Based on the requirements to obtain those licenses, a visual acuity of at least 20/40 (corrected if necessary) in at least one eye was assumed. The ratio of male to female participants was approximately 50/50. In the new licensed driver group, the average reported female age was 30 years, and all were within the age range of 24-34 years. The average male was 31 years old, and all were within the age range of 23-35 years. In the experienced group, the average female age was reportedly 33 years old, and all were within the age range of 24-36 years. The average experienced male was 34 years old, and all were within the age range of 23-37 years. Although the number of participants is not large enough to fully represent the entire population of the subject area, the experiment’s results still help us to understand drivers’ behavior at urban open road and tunnel sections.

In this study, the field test was conducted on workdays, in good weather and during free hours (10 to 11 a.m., and 3 to 4:30 p.m.), using a D-Lab driving analysis system (made in Ergoneers Company, in Germany). D-lab is a powerful tool used for synchronous data capture and analysis for behavior studies. D-lab has four modules which satisfy our test: 1) the eye tracking system (Dikablis), 2) video system, 3) physiology monitor and analyze system and 4) TCP/IP data record and analyze system (DataStream).

During the experiment, participants were to wear eye tracking glasses and three electrode sheets, allowing us to collect eye movement information and ECG data. In order to become used to the equipment and vehicle, drivers completed a five-minute practice drive. They were instructed to proceed along the general road. Participants were not given any idea of the purpose of this study. They were asked to drive as usual, so as not to affect the experiment’s results. Following the practice drive, the participants completed three separate drives. Each journey had the same series of road tasks, with drivers travelling on an open road, into a tunnel entrance and exit zone and driving through the tunnel’s interior zone. Thus, each participant provided 12 behavior samples, and the total sample size was 240. During the test, all participants were exposed to virtually the same natural lighting conditions, which was approximately 30,000Lux. While the participants were driving, the video module recorded the driving speed and the scenario outside the car. We could then select the data relating only to free travel status. Simultaneously, the physiology monitors and analyze system recorded drivers’ physiological features (ECG). The driving scenario and eye tracking analysis system is shown in figure 2.
According to this paper’s objectives, the entire experiment’s driving duration was chosen and divided into the six main task roads, which include 1) an urban general road zone (OP), 2) access zone ahead tunnel portal (AZ), 3) threshold zone after tunnel portal (TZ), 4) tunnel interior zone (IZ), 5) zone ahead exit and 6) after tunnel exit (EZ1/EZ2) for each participant. The task roads are shown in fig.3. In addition, the task roads were defined in the D-Lab software. Traffic conditions may influence driving behavior. For that reason, the experiment chose only free traffic condition for the detailed analysis.

This was a mixed design, with one between-subject variable (experienced and new licensed drivers) and six within-subject variables (six different road tasks: OP, AZ, TZ, IZ, EZ1, and EZ2).

To validate our results, a post-participation survey was conducted after the participants completed the experiments. On the survey, participants answered questions regarding: whether the testing
equipment affected their driving behavior and how they felt about driving along the tunnel (i.e., did they feel uncomfortable wearing the glasses and whether their responses to the tunnel environment were similar to what they would have done on an open road.). The survey results showed that 98 percent of these drivers thought the equipment had no effect on their driving. Almost all drove as they normally would. Virtually every driver felt nervous while decelerating when approaching the tunnel and coping with the black hole phenomenon, and then accelerating when leaving the tunnel. However, no participant mentioned any influence of the white hole phenomenon on their driving.

3. Results and Conclusion

3.1 Dependent Variables
Psychophysical measurements reflecting the drivers’ microscopic driving behavior during the tasks were collected using the D-lab analysis system. In psychological terms, eye movement measures include a glance, saccade, pupil diameter, fixation range and percentage of eye closure. According to Shan Boa’s study on visual scanning at median-divided highway intersections in rural areas [19], visual scanning is classified into seven possible area of interest, (AOI) relative to a straight ahead position while driving. In this study, visual scanning was divided into six AOIs, as shown in figure 4. Those six are (1) left rear view mirror (head movement greater than 45° to the left, LRM), (2) far left hand side (head movement less than or equal to 45° to the left, FLS), (3) far ahead (FA), (4) near front (NF), (5) right side (including right rear view mirror, head movement to the right, RS) and (6) dashboard (DB). These scanning AOIs were then used to examine the perception and randomness of visual scanning as described in the next section. As pupil diameter is known to respond to many other variables other than luminance levels, including stress, interest, etc., the following psychological measures were used in this study:

- Mean Glance Duration (MGD/s)
- AOI Attention Ration (AAR/%)
- Horizontal Eye Activity (HEA/pixel)
- Vertical Eye Activity (VEA/pixel)
- Percentage of Eyelid Closure (PEC/%)

Analysis of variance (ANOVAs) techniques in SAS 9.1 using PROC MIXED were used to analyze the MGD and AAR, checking each AOI, while HEA, VEA and PEC were analyzed if they were different on every task road.

3.2 Psychological measurements results
Experience-related differences are examined based on the above dependent variables of an executed driving route, to distinguish if any significance differences exist between driving on the general road zone, approach to ahead of and after the tunnel portal, driving in the tunnel’s interior zone, and driving away before and after exiting the tunnel. Our goal was to identify the road tasks that appear to be the most problematic for the two specific (new licensed and experienced) groups. All results are reported at a significance level of 0.05.
Table 1 Summary results of Mean Glance Duration (MGD/s)

|        | Left rear view mirror Mean (S.D.) | Far hand side Mean (S.D.) | Far ahead Mean (S.D.) | Near front Mean (S.D.) | Right side Mean (S.D.) | Dashboard Mean (S.D.) |
|--------|----------------------------------|---------------------------|----------------------|------------------------|------------------------|----------------------|
|        |                                  | Mean (S.D.)                | Mean (S.D.)          | Mean (S.D.)            | Mean (S.D.)            | Mean (S.D.)          |
| **OP** |                                  |                            |                      |                        |                        |                      |
| Y      | 0.165(0.17)                      | 0.207(0.06)                | 0.673(0.18)          | 0.299(0.09)            | 0.581(0.15)            | 0.044(0.02)          |
| E      | 0.455(0.07)                      | 0.394(0.0)                 | 0.540(0.09)          | 0.286(0.05)            | 0.336(0.10)            | 0.28(0.06)           |
| **AZ** |                                  |                            |                      |                        |                        |                      |
| Y      | 0.294(0.11)                      | 0.152(0.14)                | 0.725(0.45)          | 0                      | 0.624(0.44)            | 0                    |
| E      | 0.099(0.06)                      | 0.366(0.08)                | 0.599(0.18)          | 0.215(0.19)            | 0.061(0.05)            | 0                    |
| **TZ** |                                  |                            |                      |                        |                        |                      |
| Y      | 0.050(0.09)                      | 0.257(0.14)                | 0.706(0.41)          | 0.163(0.14)            | 0.264(0.06)            | 0                    |
| E      | 0.096(0.08)                      | 0.431(0.12)                | 0.307(0.06)          | 0.595(0.16)            | 0.375(0.31)            | 0                    |
| **IZ** |                                  |                            |                      |                        |                        |                      |
| Y      | 0.113(0.10)                      | 0.483(0.17)                | 0.555(0.15)          | 0.314(0.23)            | 0.262(0.33)            | 0.047(0.01)          |
| E      | 0.035(0.05)                      | 0.264(0.02)                | 0.347(0.15)          | 0.222(0.19)            | 0.34(0.14)             | 0.136(0.01)          |
| **EZ1**|                                  |                            |                      |                        |                        |                      |
| Y      | 0.35(0.05)                       | 0.264(0.02)                | 0.347(0.15)          | 0.222(0.19)            | 0.341(0.14)            | 0.136(0.01)          |
| E      | 0.326(0.06)                      | 0.373(0.20)                | 0.300(0.10)          | 0.311(0.06)            | 0.216(0.19)            | 0.083(0.02)          |
| **ANOV**P/Eta² |                  |                            |                      |                        |                        |                      |
| Y      | 0.011(0.67)                      | 0.015/0.65                 | 0.308/0.36           | 0.013/0.66             | 0.558/0.255            | 0.216/0.435          |
| E      | 0/0.85                           | 0.024/0.62                 | 0.072/0.53           | 0.017/0.64             | 0.028/0.61             | 0.163/0.45           |

Y: new licensed drivers; E: experienced drivers; the ANOVA: α = 0.05

Table 2 Summary results of AOI Attention Ration (AAR/%)

|        | Left rear view mirror Mean (S.D.) | Far hand side Mean (S.D.) | Far ahead Mean (S.D.) | Near front Mean (S.D.) | Right side Mean (S.D.) | Dashboard Mean (S.D.) |
|--------|----------------------------------|---------------------------|----------------------|------------------------|------------------------|----------------------|
|        |                                  | Mean (S.D.)                | Mean (S.D.)          | Mean (S.D.)            | Mean (S.D.)            | Mean (S.D.)          |
| **OP** |                                  |                            |                      |                        |                        |                      |
| Y      | 2.711(0.38)                      | 3.216(1.13)                | 45.0(5.31)           | 1.126(0.62)            | 22.843(7.85)           | 0                    |
| E      | 3.97(0.76)                       | 10.87(0.55)                | 39.94(2.78)          | 8.19(0.97)             | 12.53(0.96)            | 1.29(0.56)           |
| **AZ** |                                  |                            |                      |                        |                        |                      |
| Y      | 3.54(0.71)                       | 2.596(0.17)                | 35.15(6.83)          | 0                      | 36.45(12.71)           | 0                    |
| E      | 0.32(0.06)                       | 24.96(5.08)                | 31.97(2.97)          | 5.38(2.74)             | 0.80(0.35)             | 0                    |
| **TZ** |                                  |                            |                      |                        |                        |                      |
| Y      | 0.247(0.43)                      | 12.89(0.51)                | 44.627(6.88)         | 4.73(0.46)             | 9.848(11.14)           | 0                    |
| E      | 1.02(0.83)                       | 8.13(2.39)                 | 20.19(5.96)          | 18.29(4.52)            | 0                      | 0.516(0.23)          |
| **IZ** |                                  |                            |                      |                        |                        |                      |
| Y      | 0.73(0.08)                       | 18.61(0.37)                | 7.12(0.48)           | 27.85(0.67)            | 3.92(0.57)             | 0                    |
| E      | 1.02(0.76)                       | 23.31(3.60)                | 0.27(0.12)           | 41.60(5.13)            | 1.56(0.77)             | 1.74(0.95)           |
| **EZ1**|                                  |                            |                      |                        |                        |                      |
| Y      | 1.67(0.82)                       | 11.69(0.67)                | 19.11(0.54)          | 14.18(2.76)            | 5.53(0.86)             | 0.254(0.04)          |
| E      | 0                                | 24.31(5.78)                | 3.19(0.78)           | 24.95(4.82)            | 0.963(0.66)            | 0                    |
| **EZ2**|                                  |                            |                      |                        |                        |                      |
| Y      | 5.58(0.61)                       | 15.34(1.43)                | 14.10(2.21)          | 9.59(0.27)             | 13.25(0.94)            | 1.07(0.48)           |
| E      | 5.57(1.61)                       | 21.82(2.97)                | 9.47(3.91)           | 11.48(3.87)            | 2.35(0.91)             | 0.56(0.07)           |
### Table 3 Summary results of fixation range and eyelid closure

|          | Horizontal Eye Activity (HEA/pixel) Mean (S.D.) | Vertical Eye Activity (VEA/pixel) Mean (S.D.) | Percentage of Eyelid Closure (PEC/%) Mean (S.D.) |
|----------|-------------------------------------------------|---------------------------------------------|-----------------------------------------------|
| OP       |                                                 |                                             |                                               |
| Y        | 496.28(56.04)                                   | 124.87(40.53)                               | 22.48(8.23)                                   |
| E        | 373.52(57.99)                                   | 165.52(34.191)                              | 18.85(3.29)                                   |
| AZ       |                                                 |                                             |                                               |
| Y        | 485.52(28.35)                                   | 107.88(3.01)                                | 5.80(4.85)                                    |
| E        | 510.65(32.20)                                   | 117.22(14.57)                               | 8.90(5.67)                                    |
| TZ       |                                                 |                                             |                                               |
| Y        | 229.56(46.07)                                   | 64.29(30.04)                                | 4.34(2.53)                                    |
| E        | 477.87(52.39)                                   | 155.37(5.67)                                | 6.18(1.67)                                    |
| IZ       |                                                 |                                             |                                               |
| Y        | 368.09(14.64)                                   | 89.91(5.48)                                 | 10.27(3.01)                                   |
| E        | 426.63(16.04)                                   | 89.42(11.09)                                | 5.94(0.85)                                    |
| EZ1      |                                                 |                                             |                                               |
| Y        | 511.33(62.25)                                   | 175.64(13.08)                               | 10.04(2.93)                                   |
| E        | 417.61(121.82)                                  | 148.21(19.21)                               | 9.71(2.32)                                    |
| EZ2      |                                                 |                                             |                                               |
| Y        | 799.28(113.78)                                  | 115.64(11.02)                               | 13.72(3.05)                                   |
| E        | 555.28(86.70)                                   | 141.82(35.46)                               | 9.21(6.13)                                    |

| ANOVA P/Eta² | Y 0.011/0.67 0.015/0.65 0.308/0.36 0.013/0.66 0.558/0.255 0.216/0.435 | E 0.0/0.85 0.024/0.62 0.072/0.53 0.017/0.64 0.028/0.61 0.163/0.45 |

Y: new licensed drivers; E: experienced drivers; the ANOVA: \( \alpha = 0.05 \)

The Mean Glance Duration time which drivers spent checking each AOI is shown in Table 1. the parentheses represent the S.D. of observed values (this method is also adopted in table 2 and table 3). With respect to checking the left rear view mirror, a significant interaction between road tasks was observed for both groups (new licensed group and experienced group). The drivers’ glance duration is longer when conducting open road tasks than when those same drivers are in tunnel areas. The duration of the glance is shortest in IZ. Differences between road tasks were also observed in checking AOI on the far left-hand side and near the front of the vehicle, with drivers taking longer glances in IZ zones and EZ1. It is especially worth noting that in the experienced group, a significant difference was also shown when checking the right side. The experienced group had longer glance duration when driving in the OP zone.

The AOI Attention Ration (AAR/%) of the new licensed group and experienced group of drivers is shown in Table 2. With respect to checking the left rear view mirror, a significant interaction between road tasks was observed. Both groups of participants devoted more attention to this AOI when driving along the open road and approaching and leaving the tunnel (AZ and EZ2). In the experienced group, a significant difference was also shown in the amount of time spent checking the far left hand side, far ahead and the right side. With regard to the AOI of the far left-hand side (FLS), experienced drivers devote more attention when driving along the AZ, IZ and EZ. However, the attention devoted to far
ahead and the right side was in direct contrast with FLS. With respect to the near front of the vehicle, more attention was spent on this AOI when driving in the tunnel area, including the TZ, IZ, and EZ1, for both groups.

Table 3 shows the objects’ experimental results of the participants’ fixation range and eyelid closure ration. The ANOVA results indicate that the experienced group had significant differences in the measurements of Vertical Eye Activity (VEA/pixel) and Percentage of Eyelid Closure (PEC/%) for the six different task roads. Except for these two measurements, new licensed drivers were also influenced by road tasks in terms of the Horizontal Eye Activity (HEA/pixel) measure. As shown in Table 3, in the horizontal fixation range, new licensed drivers checked less in the TZ and IZ zones. In addition, both new licensed and experienced drivers’ vertical fixation range became lower in AZ and IZ. Meanwhile, the percentage of eyelid closures became smaller when driving in the tunnel area.

### 3.3 Physiological measurements results

Table 4 shows the summary of experimental results of the heart rate variable. As shown in figure 5, RRCV fluctuates more in new licensed drivers than in the experienced group. The RRCV also decreases for both groups when driving through the tunnel portal and exit.

| Road task | New licensed driver (Y) | Experienced driver (E) |
|-----------|------------------------|------------------------|
| N | Mean | S.D. | RRCV | N | Mean | S.D. | RRCV |
| OP | 198 | 0.81 | 0.039 | 0.048 | 177 | 1.15 | 0.063 | 0.055 |
| AZ | 168 | 0.9 | 0.017 | 0.019 | 169 | 0.95 | 0.018 | 0.019 |
| TZ | 178 | 1.38 | 0.022 | 0.016 | 189 | 3.58 | 0.059 | 0.016 |
| IZ | 188 | 0.89 | 0.021 | 0.024 | 162 | 1.17 | 0.047 | 0.040 |
| EZ1 | 178 | 1.04 | 0.019 | 0.018 | 154 | 1.23 | 0.039 | 0.032 |
| EZ2 | 180 | 0.77 | 0.014 | 0.018 | 189 | 1.3 | 0.041 | 0.032 |

**Figure 5 Heart rate variable on six road tasks**

### 4. Discussion

The objective of this study is to examine experience-related differences in microscope driving behavior on urban general roads and in urban tunnel areas. Driving safely along the road and in tunnels depends on a driver’s ability to visually detect and monitor traffic signs and potential conflicts, as well as the driver’s ability to adapt to different traffic environments. Selective attention refers to a driver directing their gaze towards objects of interest and concerns within the driving environment [20]. Therefore, differences in visual selection may reflect different driver strategies. Heart Rate Variability (HRV) is more commonly used as the physiological measure in human research, with higher HRV reflecting more tension or stress of driver. In this study, visual differences were assessed
using five psychophysical measures, including 1) Mean Glance Duration (MGD/s), 2) AOI Attention Ratio (AAR%), 3) Horizontal Eye Activity (HEA/pixel), 4) Vertical Eye Activity (VEA/pixel) and 5) Percentage of Eyelid Closure (PEC%). These measurements indicate that drivers look at different areas of interest (AOI), and the drivers’ HRV measurement indicates the physiological tension associated with the driving environment. Our results confirm the hypothesis that differences do exist between the two groups of participants (experienced and new licensed drivers) in terms of where they look, for how long and how they feel.

When driving in a tunnel’s interior area, drivers scanned toward the left rear view mirror for a significantly shorter period of time, while a significantly longer duration was spent viewing the far left-hand side and near front, compared to when those same participants are driving on general roads. This could be explained by the fact that lane changing is forbidden in tunnels. The traffic flow in a tunnel could be more stable than the flow on an open road, so shorter glances at the left rear view mirror might be enough for drivers to judge the traffic conditions behind them. Since the luminance levels in a tunnel are significantly lower than on open roads, drivers need to pay more attention to the far left hand side and near front environment to ensure safe driving. What’s more, experienced drivers spend longer checking the right side along an open road than new licensed drivers, which indicates that new licensed drivers are more inclined to ignore the traffic conditions on the right side of the vehicle because drivers sit on the left side of the car. Therefore, this study suggests that candidate drivers should be trained to pay more attention to the right side before getting a driving license.

In a study by Harbluk et al. [21], drivers were observed to make significantly reduced inspection glances during intersection negotiations when performing a difficult secondary task (as compared to when they are driving alone). Consistent with this study, drivers’ visual scanning perception towards the left rear view mirror AOI tends to be less, and the fixation range in vertical tends to be slighter during demanding situations. In the same study, in addition to the luminance change, the tunnel portal and exit were comprised of more complicated geometric features with vertical curves. However, drivers decreased the percentage of eyelid closure when driving along the tunnel as compensation for these complex geometric features, especially during the EZ2, IZ and EZ1 zones. Because of the limited environment in a tunnel area, a driver’s scanning range is smaller than when on an open road, and a higher percentage of AOI attention is paid to the near front. No road task differences were observed with regard to the horizontal eye activity of experienced drivers, but a significance difference existed with new licensed drivers. This further demonstrates the effects of the environment on new licensed drivers, who need more training in safe driving view patterns.

As discussed earlier, HRV can reflect a driving motion in physiological terms, in that a lower RRCV indicates higher tension. Driving along a tunnel’s dark, narrow environment may cause anxiety, uncertainty, and even fear (of hitting another vehicle or tunnel walls, or of other dangerous circumstances such as fire or a tunnel collapse) [22-23]. This study found that urban tunnel portals and the exit environments are more dangerous, with a lower RRCV than when driving in the tunnel’s interior area. This phenomenon is also likely to be more severe for new licensed drivers than for the experienced group. This finding is consistent with previous studies, which found that crash rates are higher in tunnel entrance zones (zones of AZ and TZ), while the crash rates are lower as drivers continue inside the tunnel [24]. However, some studies have also concluded that the number of crashes is higher in the tunnel’s interior zone, which is the principal zone, as it covers a longer distance. However, this factor was not significant in the view of the RRCV in this study, because the test tunnel was not long enough for the internal driving to become a more serious factor.

This present study was conducted in urban areas under free traffic conditions, and the results may not reflect the road task differences in highway or suburban areas, or it may not follow in all traffic conditions because of the differences in driving environments. Therefore, additional studies with different sites and types of urban tunnels, with a variety of traffic flow and various geometric characteristics should be performed to strengthen and generalize these results.
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