WILEY | Hindawi

Research Article

Effect of High-Altitude Environment on Driving Safety: A Study on Drivers' Mental Workload, Situation Awareness, and Driving Behaviour

Xinyan Wang,[1] Wu Bo [1,2] Weihua Yang,[1] Suping Cui,[1] and Pengzi Chu[3]

[1]*School of Engineering, Tibet University, Lhasa 850000, China*
[2]*School of Transportation, Southeast University, Nanjing 211189, China*
[3]*The Key Laboratory of Road and Traffic Engineering, Ministry of Education, Tongji University, Shanghai 201804, China*

Correspondence should be addressed to Wu Bo; thinfog@seu.edu.cn

This study aims to analyze the effect of high-altitude environment on drivers' mental workload (MW), situation awareness (SA), and driving behaviour (DB), and to explore the relationship among those driving performances. Based on a survey, the data of 356 lowlanders engaging in driving activities at Tibetan Plateau (high-altitude group) and 341 lowlanders engaging in driving activities at low altitudes (low-altitude group) were compared and analyzed. The results suggest that the differences between the two groups are noteworthy. Mental workload of high-altitude group is significantly higher than that of low-altitude group, and their situation awareness is lower significantly. The possibility of risky driving behaviours for high-altitude group, especially aggressive violations, is higher. For the high-altitude group, the increase of mental workload can lead to an increase on aggressive violations, and the situation understanding plays a full mediating effect between mental workload and aggressive violations. Measures aiming at the improvement of situation awareness and the reduction of mental workload can effectively reduce the driving risk from high-altitude environment for lowlanders.

1. Introduction

Road traffic injury is now the leading cause of death, particularly for persons aged 5–29 years [1]. Road safety is an important public health concern around the world, and safe mobility has been considered as a human right [2]. Scholars have long been committed to the reduction of traffic accidents.

Tibetan Plateau is an oxygen-deprived region with an average altitude of more than 4 000 m above sea level [3], which is the first step of China's terrain [4]. Physical activity at high altitude for lowlanders can induce acute mountain sickness (AMS) [5, 6], and even diseases, such as hypertension [7]. The status of traffic safety in the region also needs to be improved. According to the statistics of the National Bureau of Statistics of China, for Tibet, there were 363 traffic accidents, 124 death tolls, and 2.43 million yuan's

property damage caused by traffic accidents in 2018. However, the region's permanent population at the end of the year was only 3.44 million, indicating the road safety condition was also not optimistic. However, there are many floating populations from low altitudes taking driving activity, a kind of physical work, in Tibet.

From an intuitive perspective, the high-altitude environment plays a negative impact on driving activities. But, there are few studies focused on the suitability of driving activities for drivers at high altitude. Previous studies had confirmed that the physical work capacity of low-altitude residents (i.e., lowlanders) was significantly reduced at high altitudes [8]. An experiment on the Qinghai-Tibet plateau showed that the higher the altitude, the more fatigue the driver [9]. When driving at high altitude, the mental workload of drivers would heighten with the increase of altitude, together with the increase of fatigue, reaction time,

and emotional stress [10]. On the other hand, the conclusions obtained from short-term stress reaction had not considered the long-term adaptability of human sufficiently, and the results may not be applicable to the safety features of drivers at high altitude for a long time. Based on this, in order to discuss the safety status for floating drivers, the study explored the performance and influencing factors based on questionnaire data. Indicators selected included mental workload, situation awareness, and driving behaviour.

Mental workload, situation awareness, and driving behaviour are important factors influencing driver safety. For driver, mental workload can be defined as the proportion of information processing capability used to perform a driving task [11]. Mental workload that is too high or too low is not conducive to driving safety [12, 13]. As an assessment index to analyze drivers' performance, situation awareness is a very important precondition to drive safely in a complex and dynamic environment. It can be described as the ability to accurately perceive the traffic environment for drivers and to adapt their interaction with distracting activities [14, 15]. Drivers with higher situation awareness can find more hazards in a driving task [16]. For driving behaviour, it is widely analyzed for the possibility of being involved in a traffic accident and can be regarded as a series of driver's behaviours while driving [17–19].

Being able to measure with questionnaires is one other reason to choose these indicators (i.e., mental workload, situation awareness, and driving behaviour) in the study. For example, the driver behaviour questionnaire (DBQ) proposed by Reason [18] has been widely extended and applied to survey drivers' self-reported driving behaviours [20, 21]. The Situation Awareness Global Assessment Technique (SAGAT) [22] and the Situation Awareness Rating Technique (SART) [23] have been widely used for the measurement of situation awareness [24–26]. The Subjective Work Assessment Technique (SWAT) and the National Aeronautics and Space Administration-Task Load Index (NASA-TLX) are popular measuring tools of mental workload [27–31].

This study focuses on different performances between drivers at high altitudes from low altitudes and drivers at low altitudes. Specifically, the study is organized as follows: some analyses are implemented in Section 2 (study 1) for the differences of drivers' mental workload, situation awareness, and driving behaviour. In Section 3 (study 2), the relationships among the three factors are analyzed based on the structural equation modeling (SEM). Then, Section 4 and Section 5 are the discussion and the conclusion of the study, respectively.

2. Study 1: Differences on Driving Performances

Considering the undesired influences of high-altitude environment on human's physiological condition [6, 8, 10], the study aims at determining if there are adverse effects of high-altitude environment on driving safety to drivers from low altitudes.

2.1. Methodology

2.1.1. Design. In fact, factors affecting driver's safety are varied, and a proper assumption need to be set before statistical analysis. For this, the study first assumed that there was no significant difference in their normal driving tasks between the drivers at high altitudes from low altitudes (high-altitude group) and drivers at low altitudes (low-altitude group). Driving tasks involved of these two groups are their common driving activities, and the standards of traffic management, traffic design, and traffic regulations are highly consistent in the two areas. Therefore, the assumption that driving activities of these two groups are similar is reasonable.

For the differences of the two groups on driving performances, a survey on driving performances was carried out from three angles: mental workload, situation awareness, and driving behaviour, and the analysis of variance (ANOVA) was used to the comparison. Meanwhile, there are three hypotheses need to be tested:

> H1: mental workload of high-altitude group is significantly higher than that of the low-altitude group
>
> H2: situation awareness of high-altitude group is significantly lower than that of the low-altitude group
>
> H3: undesired driving behaviour of high-altitude group is significantly more frequent than that of the low-altitude group

2.1.2. Materials and Procedure. The subjective workload assessment technique (SWAT) with equal weight was chosen as the measuring tool, which has a desired sensitivity [31, 32]. During the preparation of the questionnaire, three questions of SWAT [27] were modified to suit driving task (e.g., "how high is your stress usually when driving on Tibetan Plateau?"), and a preresearch had been implemented to reduce the difficulty of understanding. Answers to those questions were designed to utilize a three-point scale. The SWAT contains three dimensions: time load (TL), mental effort load (EL), and psychological stress load (SL). The score of mental workload (MW) in the study was calculated by the following formula [32]:

$$MW = \frac{TL + EL + SL}{3}. \tag{1}$$

For situation awareness, the situation awareness global assessment technique (SAGAT) and the situation awareness rating technique (SART) are popular measuring tools for situation awareness [24–26]. SAGAT was commonly used in the process of an experiment [33], and SART was often used for post hoc evaluation [34]. Clearly, SART is more suitable for the study.

During the preparation of the questionnaire, the questions of 10-D SART [23] were modified to suit the driving task (e.g., "how high is your alertness usually when driving on Tibetan Plateau?"), and a preresearch had been completed to improve readability. Answers to these questions were designed to utilize a ten-point scale. The 10-D SART

contains ten questions which could be further grouped into three overall dimensions named 3D-SART: (a) attention demand (AD); (b) attention supply (AS); and (c) situation understanding (SU). Specifically, attention demand is a combination of the instability of situation, the complexity of situation, and the variability of situation; attention supply is a combination of the arousal of situation, the concentration of attention, the division of attention, and the spare mental capacity; situation understanding is the combination of the quantity of information, the quality of information, and the degree of familiarity. By using a group score, the score of SA was calculated by the following formula [24]:

$$SA = SU - (AD - AS), \quad (2)$$

where SU is the situation understanding, AD is the attention demand, and AS is the attention supply.

In terms of measuring tool of driving behaviour, the driver behaviour questionnaire (DBQ) is an instrument applied widely to examine the self-reported driving behaviour [18, 20, 21]. The DBQ with three-factor structure (e.g., errors, lapses, and violations) or four-factor structure (e.g., errors, lapses, ordinary violations, and aggressive violations) has been broadly implemented in many studies [35–37]. In the study, a DBQ considering errors, lapses, ordinary violations, and aggressive violations and including 23 items was carried out to gather data. All the items were derived or revised from literatures of af Wåhlberg et al. [38], Bener et al. [39], Liu and Chen [3], Reason et al. [18], Hezaveh et al. [40], and Maslać et al. [41]. Every question has five options by using a five-point scale ranging from never (1) to nearly all the time (5). Meanwhile, Chinese statements of the referenced items were translated and back translated to minimize the difficulty of understanding on the premise of ensuring the original meaning.

A five-month survey was carried out to obtain questionnaire data, and the survey was conducted in the form of electronic questionnaire and distributed by social media such as email, QQ, and WeChat. Participants were invited to participate in the survey with a certain charge. And, 1295 copies of questionnaire were obtained. 356 participants were lowlanders from low altitudes, that is, provinces in the third step of China's terrain with an average altitude of less than 500 m above sea level [4], and the lowlanders had engaged in driving task on Tibetan Plateau (high-altitude group). Other 939 participants were also from these low altitudes.

The platform of electronic questionnaire can automatically identify the city where the participant was located and judge whether it was a valid object according to holding a valid driver license or not, the identified city, and the filled place where the households are registered. Only valid participants can complete the questionnaire. The lowlanders of 939 participants conducted the self-reports of mental workload, situation awareness, and driving behaviour according to their experience, and the high-altitude group reported their experience of driving at high altitude according to the content of questionnaire. On the other hand, to reduce the difference between these two groups on demographic characteristics, the collection of high-altitude

group's data was finished first. And, to meet the characteristics of the high-altitude group, a total of 939 copies were collected, of which 341 copies were selected randomly as a control group (low-altitude group).

The analytical approach involved in the study contains reliability analysis, validity analysis, and differential analysis. Cronbach's alpha, factor load matrix, the statistic of Kaiser–Meyer–Olkin (KMO) test, and Bartlett's spherical test were used to further identify reliability or validity [42]. As is mentioned above, for the comparison on mental workload, situation awareness and driving behaviour between high-altitude group and low-altitude group, the analysis of variance (ANOVA), which has been used widely for the differential analysis on driver performances was selected [40, 43].

2.2. Results. The summary of those 697 participants is given in Table 1. The results of analysis of variance (ANOVA) indicate that there is no significant difference between the two groups on traits of gender, age, years of driving experience, and driving distance. That is to say, the control group is effective. Then, the analysis in the study is based on these data.

The reliability analysis showed that Cronbach's alpha of the subjective workload assessment technique (SWAT) was 0.641. Typically, Cronbach's alpha greater than 0.7 is ideal [42], and the value is lower than that. The result may be the cause that the set option of SWAT is a three-point scale, and SWAT only contains three dimensions. Based on this, the result had been accepted in the study and SWAT could be utilized as a tool for drivers to measure mental workload.

Further, the results of analysis of variance indicate that the p value for time workload (TL) was 0.141 ($F (1, 695) = 3.549$, $p > 0.05$), the p values for mental effort load (EL) equaled 0.000 ($F (1, 695) = 44.149$, $p < 0.01$), psychological stress load (SL) equaled 0.000 ($F (1, 695) = 24.587$, $p < 0.01$), and mental workload (MW) 0.000 ($F (1, 695) = 35.207$, $p < 0.01$). Therefore, there are strong evidences of difference between drivers of the high-altitude group and drivers of the low-altitude group on EL, SL, and MW, and those indicators of the high-altitude group are higher than those of the low-altitude group (Figure 1). The hypothesis of H1 is valid and acceptable.

Table 2 shows the reliability of the situation awareness rating technique (SART) in different dimensions and the statistics of 10 items. The results show that Cronbach's alpha of SART and its three dimensions are all greater than 0.7, and the reliability is ideal.

The difference test results showed that the p values of attention demand (AD), attention supply (AS), and situation understanding (SU) equaled 0.004 ($F (1, 695) = 8.235$, $p < 0.01$), 0.000 ($F (1, 695) = 13.104$, $p < 0.01$), and 0.000 ($F (1, 695) = 64.697$, $p < 0.01$), respectively. And, the p value of SA was 0.000 ($F (1, 695) = 15.880$, $p < 0.01$). Thus, there are strong evidences of difference between drivers of the high-altitude group and drivers of the low-altitude group on attention demand, attention supply, situation understanding, and situation awareness, with lower on attention supply,

TABLE 1: Sample information.

Categorical variable (F (1, 695), p value)	Category	High-altitude group ($N = 356$)	Low-altitude group ($N = 341$)
Gender (1.469, 0.226)	Female	74	84
	Male	282	257
Age (0.060, 0.807)	Up to 30 years	240	235
	Above 30 years	116	106
Years of driving experience (0.800, 0.372)	Up to 5 years	272	281
	Above 5 years	84	60
Driving distance (3.504, 0.062)	Up to 50,000 km	257	255
	Above 50,000 km	99	86
Years of driving experience on Tibetan Plateau	Up to 1 years	201	—
	Above 1 years	155	—
Driving distance on Tibetan Plateau	Up to 10,000 km	206	—
	Above 10,000 km	150	—

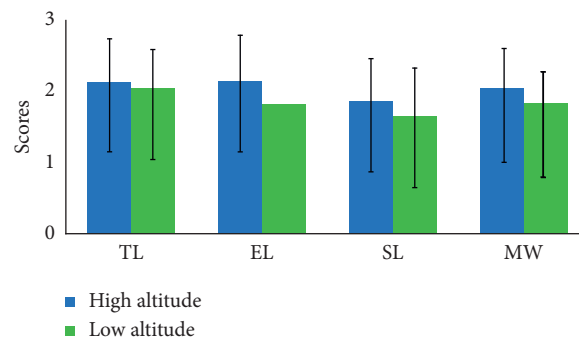

FIGURE 1: Scores of mental workload.

TABLE 2: Results of internal consistency and statistics.

Dimensions (Cronbach's alpha)		Items (notation)	High-altitude group Mean (std. D)	Low-altitude group Mean (std. D)
SA (0.856)	AD (0.869)	Instability of situation (s11)	6.247 (2.102)	5.589 (1.981)
		Complexity of situation (s12)	6.169 (2.225)	5.868 (1.947)
		Variability of situation (s13)	6.225 (2.206)	5.997 (1.903)
	AS (0.806)	Arousal of situation (s21)	6.534 (2.071)	7.114 (1.807)
		Division of attention (s22)	6.301 (2.026)	7.399 (1.797)
		Spare mental capacity (s23)	6.284 (1.978)	6.557 (1.698)
		Concentration of attention (s24)	6.927 (1.768)	6.328 (1.843
	SU (0.771)	Information quantity (s31)	5.596 (2.404)	6.689 (1.658)
		Information quality (s32)	6.239 (1.839)	6.645 (1.742)
		Familiarity (s33)	6.208 (1.996)	6.786 (1.806)

situation understanding, and situation awareness but higher on attention demand of the high-altitude group (Figure 2). And, the hypothesis of H2 is also acceptable.

Results of reliability analysis in Table 3 show that the values of Cronbach's alpha are greater than 0.7, which indicate the internal consistency of the driver behaviour questionnaire (DBQ) is ideal. For the validity, because each item comes from researches related to driving behaviour in the past, the content validity is ideal. In terms of structural validity verified by factor analysis, four components were retained with eigenvalues greater than 1, and the rotating component matrix is shown in Table 4. Due to the existence

of cross-loading of ov_2 (increase speed to pass a yellow light) and ov_5 (disregard the speed limit of the roads), with 0.654 and 0.654 to ordinary violations but 0.401 and 0.411 to aggressive violations, these two items were removed. As shown in Table 3, before and after ov_2 and ov_5 was deleted, the values of Cronbach's alpha and KMO statistics and results of Bartlett's spherical test are in the ideal range. The cumulative proportion of variance contribution of these four factors increase from 59.150 to 60.300 and from 48.261 to 50.876 to ordinary violations.

Results of analysis of variance showed that the p values of ordinary violations (OV), errors (ER), aggressive
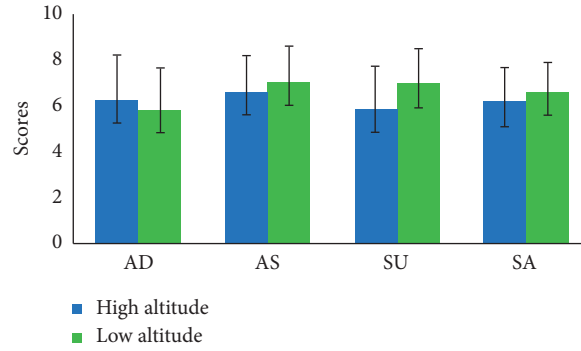
FIGURE 2: Scores of situation awareness.

TABLE 3: Results of internal consistency and validity of factors.

Category	Cronbach's alpha	KMO statistic	Bartlett's spherical test	Cumulative (%)
Ordinary violations (OV)	0.731 (0.811)[a]	0.744 (0.839)[a]	0.000 (0.000)[a]	50.876 (48.261)[a]
Errors (ER)	0.864	0.862	0.000	64.717
Aggressive violations (AV)	0.821	0.824	0.000	59.127
Lapses (LA)	0.845	0.856	0.000	61.694
Driving behaviours (DB)	0.917 (0.921)[a]	0.927 (0.927)[a]	0.000 (0.000)[a]	60.300 (59.150)[a]

[a]Result before ov_2 and ov_5 was deleted.

TABLE 4: Factor loading and statistics.

Category	Brief items	High-altitude Mean (SD)	Low-altitude Mean (SD)	Factor loading
Ordinary violations (OV)				
ov_1	Ignore the red light and pass through an intersection	1.447 (0.794)	1.420 (0.643)	0.701
ov_2[a]	Increase speed to pass a yellow light	2.101 (1.119)	1.971 (0.781)	0.654 (0.401)
ov_3	Drive the wrong lane in the opposite direction	1.320 (0.699)	1.325 (0.533)	0.736
ov_4	Take more passengers than allowed	1.253 (0.674)	1.299 (0.561)	0.648
ov_5[a]	Disregard the speed limit of the roads	1.843 (1.068)	1.736 (0.787)	0.654 (0.411)
ov_6	Forget to wear seat belt	1.694 (1.074)	1.472 (0.731)	0.534
ov_7	Use the cellular phone while driving	1.975 (1.041)	1.823 (0.863)	0.479
Errors (ER)				
er_1	Fail to notice when a traffic-signal turns green	2.039 (0.972)	2.009 (0.705)	0.675
er_2	Misjudge an overtaking gap	1.879 (0.981)	1.942 (0.753)	0.787
er_3	Hit a cyclist nearly when turning right	1.767 (0.958)	1.806 (0.755)	0.658
er_4	Brake inappropriately to stop	1.826 (0.972)	1.959 (0.795)	0.789
er_5	Insufficient attention to vehicle or pedestrian ahead	1.803 (0.962)	1.832 (0.720)	0.620
Aggressive violations (AV)				
av_1	Drive too close to impel the car in front to go faster	1.927 (1.018)	1.710 (0.733)	0.557
av_2	Feel angered by another driver's behaviour	2.360 (1.106)	1.925 (0.883)	0.744
av_3	Become impatient with a slow driver and pass on the right	2.421 (1.156)	2.238 (0.922)	0.670
av_4	Race away from traffic lights to beat the driver next to you	1.801 (0.980)	1.545 (0.702)	0.58
av_5	Be annoyed and sound the horn	1.896 (1.017)	1.725 (0.787)	0.592
Lapses (LA)				
la_1	Intend to A, but driving on route to B	2.410 (0.982)	2.493 (0.789)	0.696
la_2	Turn on the wrong device of the vehicle	1.935 (1.006)	1.919 (0.770)	0.710
la_3	Forget where the car parked	1.924 (1.014)	2.006 (0.892)	0.732
la_4	Feel unsure about the lane when approaching an intersection	2.017 (1.045)	1.954 (0.868)	0.724
la_5	Forget to open lights timely when the night has come	2.110 (1.049)	1.870 (0.805)	0.688

[a]Variable was dropped from the measurement due to cross-loading, with 0.401 and 0.411 to aggressive violations, respectively.

violations (AV), and lapses (LA) equaled 0.076 (F (1, 695) = 3.148, $p > 0.05$), 0.432 (F (1, 695) = 0.619, $p > 0.05$), 0.000 (F (1, 695) = 23.147, $p < 0.01$), and 0.198 (F (1, 695) = 1.662, $p > 0.05$), respectively. And, the p value of the total score of driving behaviours (DB) was 0.030 (F (1, 695) = 4.741, $p < 0.05$). Hence, there are strong evidences of difference

between the high-altitude group and the low-altitude group on driving behaviours, with more undesired risky driving behaviour for the high-altitude group. Meanwhile, according to the results, the difference is mainly caused by the behaviour of aggressive violations with smaller p values similarly and simultaneously (Figure 3). The results partly support the hypothesis of H3.

3. Study 2: Factors Affecting Drivers' Aggressive Violations

Considering the significant difference on aggressive violations between the two groups, the causes of the phenomenon are worth exploring. Do the level of mental workload and situation or situation awareness affect the frequency of aggressive violations for high-altitude group? And, is there a progressive relationship between the three dimensions of situation awareness? The analysis may lead to some implications for the management of aggressive violations for the group.

3.1. Methodology

3.1.1. Design. Aiming at the relationships between the factors of mental workload, situation awareness, and aggressive violations for the high-altitude group, the sample of high-altitude group was applied to statistical analysis based on the method of structural equation modeling (SEM). For the verification, the following six hypotheses need to be further tested (Figure 4):

> H41: attention demand has a significant positive impact on attention supply
>
> H42: attention supply has a significant positive impact on situation understanding
>
> H43: attention demand has a significant positive impact on mental workload
>
> H44: mental workload has a significant negative impact on situation understanding
>
> H45: situation understanding has a significant negative impact on aggressive violations
>
> H46: mental workload has a significant positive impact on aggressive violations

3.1.2. Statistical Analysis. In order to verify the roadmap or model above, a structural equation model was established to develop a path analysis using maximum likelihood for the multidimensional relationships between drivers' aggressive violations, mental workload, attention demand, attention supply, and situation understanding. While the structural equation model was developed, the goodness-of-fit of the model was assessed according to CMIN/DF, absolute index (including GFI, AGFI, and RMSEA), incremental index (including NFI and CFI), and parsimony index (including PGFI and PNFI), following the recommendations of several literatures [17, 44, 45]. The recommended threshold of CMIN/DF was less than 0.3, of GFI, AGFI, NFI, and CFI
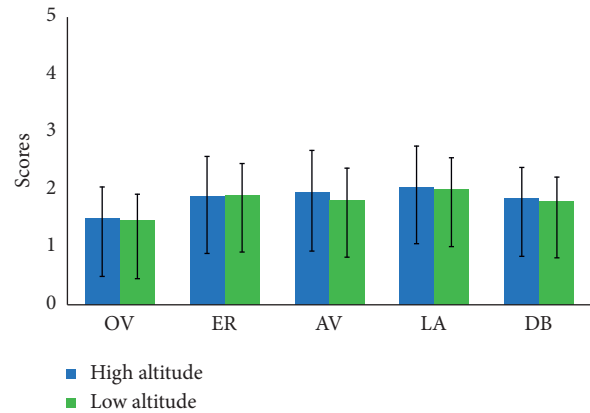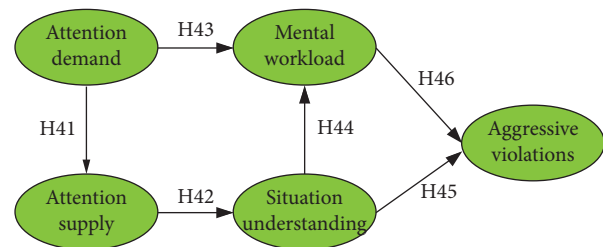

Figure 3: Scores of driving behaviour.

Figure 4: Hypothesis roadmap.

more than 0.9, of RMSEA less than 0.08 or 0.05, and of PGFI and PNFI more than 0.5 [17, 44, 46]. In the study, to acquire a better goodness-of-fit, the original model was modified according to the modification indices (MIs) [17, 47].

As for sampling of SEM, several recommendations suggested that sample size should be at least 10–15 times the number of observed variables [45, 48]. In this study, data from high-altitude group were used, and the sample size was 19.778 times the number of observed variables (356 samples/ 18 observed variables). The analysis tool involved in the study was AMOS 21.0 version.

3.2. Results. The original model followed the conception of Figure 4 and had been revised to improve the goodness-of-fit by correlating the error terms of e12 and e33, e22 and e33, and ea2 and ea4 because of larger modification indices (MIs). Regression weights between latent variables and observed variables and covariances and correlations between error terms and variances of the modified model (Figure 5) were all significant. In terms of goodness-of-fit, the results exported by AMOS were that chi-squared equaled 247.147, degree of freedom 126, CMIN/DF 1.961, GFI 0.904, AGFI 0.870, RMSEA 0.052, NFI 0.901, CFI 0.948, PGFI 0.745, and PNFI 0.742. Thus, only AGFI is lower than the recommended thresholds, and the model fits the data well.

Meanwhile, results of the path analysis (Table 5) supported some hypotheses. For the three dimensions of situation awareness, hypothesis H41 and hypothesis H42 were valid ($p < 0.001$). The increase of the attention
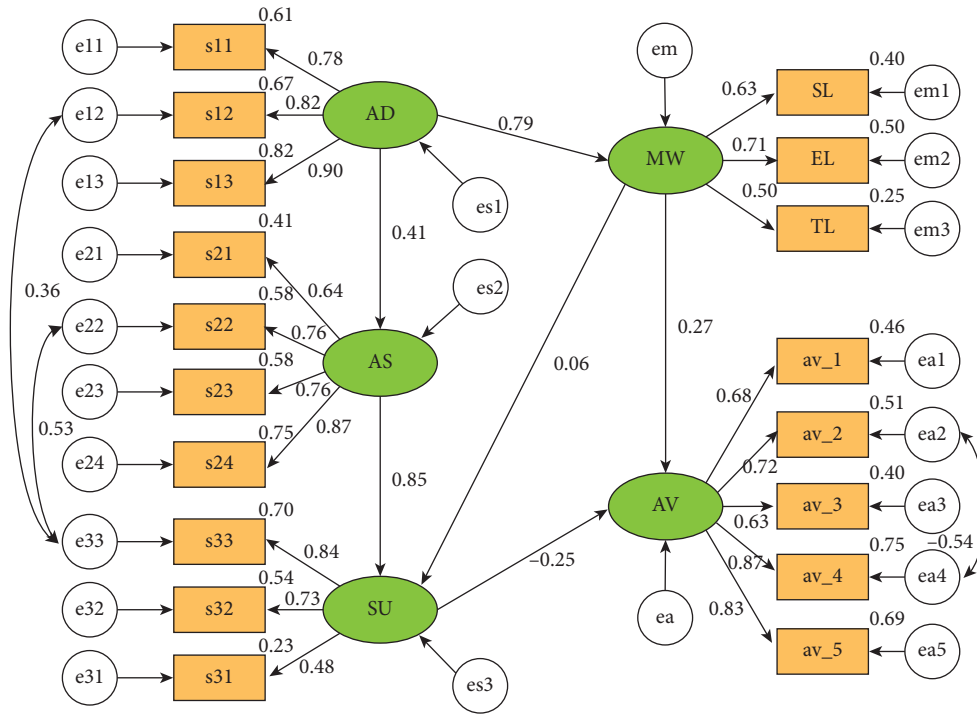
FIGURE 5: Estimated results with standardized estimates. Note: AD = attention demand; AS = attention supply; SU = situation understanding; MW = mental workload; AV = aggressive violations.

TABLE 5: Result of the path analysis.

Hypotheses and constructs	R. W.	Std. R. W.	S. E.	C. R.	p value	Result
H41: AS ⟵ AD	0.322	0.412	0.068	4.756	***	Supported
H42: SU ⟵ AS	0.620	0.846	0.112	5.54	***	Supported
H43: MW ⟵ AD	0.123	0.786	0.023	5.429	***	Supported
H44: SU ⟵ MW	0.214	0.058	0.261	0.819	0.413	Not supported
H45: AV ⟵ SU	−0.190	−0.249	0.079	−2.421	0.015	Supported
H46: AV ⟵ MW	0.753	0.268	0.307	2.454	0.014	Supported

R. W.: regression weight; Std. R. W.: standardized regression weight; S. E.: standard error; C. R.: critical ratio. *** $p < 0.001$

demand could spur the increase of driver's attention supply, and the increase of the attention supply led to an increase of the level of situation understanding. The result showed a progressive relationship among attention demand, attention supply, and situation understanding, and the intermediary role of the attention supply was also valid. In addition, the increase of the attention demand could increase driver's mental workload ($p < 0.001$), but the increase of the mental workload did not mean an increase in the level of the situation understanding ($p > 0.05$). For the group, the increase of the mental workload could increase their aggressive violations ($p < 0.05$), and the increase of the level of the situation understanding could reduce the frequency of aggressive violations ($p < 0.05$). Thus, the situation understanding played a full mediating role between the mental workload and the aggressive violations. Moreover, the mental workload also played a mediating role between the attention demand and aggressive violations.

4. Discussion

The results of study 1 and study 2 support some hypotheses, including that the high-altitude group has more driving behaviors of aggressive violations, greater mental workload, and lower situation awareness than of the lower altitude group. And, aggressive violations are positively correlated with the mental workload and negatively correlated with the situation understanding. Some discussions of these results are as follows.

Due to a higher mental effort load and psychological stress load, the mental workload of the high-altitude group is significantly higher than that of the low-altitude group. As mentioned above, many studies have confirmed that the physical work capacity of low-altitude residents is significantly reduced at high altitudes [8]. Drivers are more prone to fatigue with the increase of altitude [9]. The raise of altitude not only leads to an increase in mental workload but also affects the driver's reaction time and their mood [10]. In

the study, the mental effort load and the psychological stress load of high-altitude group were higher than of the low-altitude group with a similar time load, which might be related to the altitude of position where drivers were located. The sample of the high-altitude group came from the Tibetan Plateau, where the average altitude is more than 4 000 m. High-altitude environment with low-pressure and oxygen-deprived climate are more likely to cause fatigue or negative emotions [10, 49], which is the same for lowlanders to driving in spite of them have a certain experience in the environment, and the phenomenon may not change significantly over time. Considering the lack of oxygen and its bad effect on drivers' emotion, the provision of oxygen and the playing calm music may help to improve their driving performances [10, 49, 50].

Driving behaviour has long been discussed as an important object of researches in traffic safety [17, 18, 40, 41]. Results of the study show that there are differences on driving behaviour between these two groups. The undesired risky driving behaviour of the high-altitude group is more than that of low-altitude group, which mainly caused by the behaviors of aggressive violations. Combined with the connotation of aggressive violations and the effects of high altitude on human cognition, psychology, and behaviour, especially the irritability and hostility induced by anoxic environments [17, 40, 47, 49, 51], there is a considerable correlation between risky driving behaviours and high-altitude environment, especially the behaviors of aggressive violations. Considering the increase of mental workload and the impact of mental workload on aggressive violations, lowlanders may develop an undesirable change of driving habits because of driving in the environment for a long time.

Combined with the intermediary role of the attention supply, the progressive relationship among the attention demand, the attention supply, and the situation understanding further contribute to explain the hierarchy of the different level of situation awareness [15, 52, 53]. For other correlations in Figure 5, the direct positive relationship between the attention demand and the mental workload means that the increase of the attention demand in driving activities at high altitudes further increase drivers' mental workload. And, the increase of the mental workload can increase the frequency of aggressive violations, while the increase of the level of the situation understanding can help to reduce the likelihood. Therefore, it is beneficial to appropriately reduce drivers' mental workload at high altitudes. At the same time, improving driver's understanding of the traffic condition and training their situation awareness for driving at high altitudes are also helpful for reducing the bad effect of the high-altitude environment on driving performances.

5. Conclusion

Based on a survey by the subjective workload assessment technique (SWAT), the situation awareness rating technique (SART), and the driver behaviour questionnaire (DBQ), the effect of high-altitude environment on driving performances was analyzed, and the relationships among mental workload, situation awareness, and aggressive violations were explored. For drivers from low-altitudes, the high-altitude environment can lead to greater mental workload, worse situation awareness, and more risky driving behaviors, especially aggressive violations. Meanwhile, the mental workload and the situation understanding can affect the frequency of aggressive violations. According to the above results, there are the three suggestions for lowlanders driving at high altitude:

(1) It is recommended to understand the traffic environment before engaging in driving task at high altitude, including possible dangers and personal psychological and physical feelings. The beneficial effect of the situation understanding on driving behaviours in the study can support the recommendation. At the same time, the traffic management department can consider making some propaganda on the suggestion.

(2) The drivers should reduce risky driving behaviours consciously and judge their driving ability correctly for the decision whether it is necessary to reduce driving activities or the work intensity.

(3) It may be an effective mean of releasing oxygen in the car or playing calm music while driving. The supply of oxygen can increase the oxygen content in the car, and a gentle music can make people feel calm and perform better in driving task.

Furthermore, the study only discussed the bad effect of the high-altitude environment by comparing the differences between the high-altitude group and the low-altitude group based on self-reported data. Future studies can focus on the gap for a larger region or the gap between local drivers and nonlocal drivers, as well as the refined traffic design and traffic management, and the evaluation of suitability for lowlanders driving at high altitudes.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

Acknowledgments

References

[1] WHO, *Global Status Report on Road Safety 2018*, WHO, Geneva, Switzerland, 2018.

[2] J. Broughton, B. Johnson, I. Knight et al., *Road Safety Strategy beyond 2010: A Scoping Study*, Road Safety Research Report, Department for Transport, England, 2009.

[3] X. Liu and B Chen, "Climatic warming in the Tibetan Plateau during recent decades," *International Journal of Climatology*, vol. 20, no. 14, pp. 1729–1742, 2000.

[4] X.-H Zhang, Z.-L Wang, F.-H Hou, J.-Y Yang, and X.-W Guo, "Terrain evolution of China seas and land since the Indo-China movement and characteristics of the stepped landform," *Chinese Journal of Geophysics*, vol. 58, no. 1, pp. 54–68, 2014.

[5] T. Y. Wu, S. Q. Ding, S. L Zhang et al., "Altitude illness in Qinghai-Tibet railroad passengers," *High Altitude Medicine & Biology*, vol. 11, no. 3, pp. 189–198, 2010.

[6] T. Wu, S. Ding, J. Liu, J. Jia, Z. Chai, and R. Dai, "Who are more at risk for acute mountain sickness: a prospective study in Qinghai-Tibet railroad construction workers on Mt. Tanggula," *Chinese Medical Journal*, vol. 125, pp. 1393–1400, 2012.

[7] T.-Y. Wu, S. Q Ding, J. L Liu et al., "Who should not go high: chronic disease and work at altitude during construction of the Qinghai-Tibet railroad," *High Altitude Medicine & Biology*, vol. 8, no. 2, pp. 88–107, 2007.

[8] S. Saksena, S. C. Manchanda, and S. B. Roy, "Reduced physical work capacity at high altitude—a role for left ventricular dysfunction," *International Journal of Cardiology*, vol. 1, no. 2, pp. 197–204, 1981.

[9] J. Liu, X. Ma, Z. Zhang, Z. Guo, and B. Liu, "Fatigue characteristics of driver in Qinghai-Tibet Plateau based on electrocardiogram analysis," *Journal of Traffic and Transportation Engineering*, vol. 16, pp. 151–158, 2016.

[10] J.-b Hu and Y. Yang, "Driver factor characteristics of traffic safety on the low traffic volume Qinghai-Tibet highway in China," in *Proceedings of the International Conference on Optoelectronics and Image Processing*, Haikou, China, November 2010.

[11] K. A. Brookhuis and D. De Waard, "The use of psychophysiology to assess driver status," *Ergonomics*, vol. 36, no. 9, pp. 1099–1110, 1993.

[12] K. A. Brookhuis and D. de Waard, "Monitoring drivers' mental workload in driving simulators using physiological measures," *Accident Analysis & Prevention*, vol. 42, no. 3, pp. 898–903, 2010.

[13] F. P. d. Silva, "Mental workload, task demand and driving performance: what relation?" *Procedia - Social and Behavioral Sciences*, vol. 162, pp. 310–319, 2014.

[14] M. Jeon, B. N. Walker, and T. M. Gable, "The effects of social interactions with in-vehicle agents on a driver's anger level, driving performance, situation awareness, and perceived workload," *Applied Ergonomics*, vol. 50, pp. 185–199, 2015.

[15] N. Schömig and B. Metz, "Three levels of situation awareness in driving with secondary tasks," *Safety Science*, vol. 56, pp. 44–51, 2013.

[16] G. Underwood, A. Ngai, and J. Underwood, "Driving experience and situation awareness in hazard detection," *Safety Science*, vol. 56, pp. 29–35, 2013.

[17] M. Mohamed and N. F. Bromfield, "Attitudes, driving behavior, and accident involvement among young male drivers in Saudi Arabia," *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 47, pp. 59–71, 2017.

[18] J. Reason, A. Manstead, S. Stradling, J. Baxter, and K. Campbell, "Errors and violations on the roads: a real distinction?" *Ergonomics*, vol. 33, no. 10-11, pp. 1315–1332, 1990.

[19] R. Rowe, G. D. Roman, F. P. McKenna, E. Barker, and D. Poulter, "Measuring errors and violations on the road: a bifactor modeling approach to the driver behavior questionnaire," *Accident Analysis & Prevention*, vol. 74, pp. 118–125, 2015.

[20] J. C. F. de Winter, F. A. Dreger, W. Huang et al., "The relationship between the driver behavior questionnaire, sensation seeking scale, and recorded crashes: a brief comment on Martinussen et al. (2017) and new data from SHRP2," *Accident Analysis & Prevention*, vol. 118, pp. 54–56, 2018.

[21] N. Zhao, B. Mehler, B. Reimer, L. A. D'Ambrosio, A. Mehler, and J. F. Coughlin, "An investigation of the relationship between the driving behavior questionnaire and objective measures of highway driving behavior," *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 15, no. 6, pp. 676–685, 2012.

[22] M. R. Endsley, *SAGAT: A Methodology for the Measurement of Situation Awareness*, Northrop Corporation, Hawthorne, CA, USA, 1987.

[23] R. M. Taylor, "Situational awareness rating technique (SART): development of a tool for aircrew systems design," in *Proceedings of the AGARD AMP Symposium on Situational Awareness in Aerospace Operations*, CP478, Copenhagen, Denmark, 1989.

[24] B. Bashiri and D. D. Mann, "Automation and the situation awareness of drivers in agricultural semi-autonomous vehicles," *Biosystems Engineering*, vol. 124, pp. 8–15, 2014.

[25] D. Kaber, S. Jin, M. Zahabi, and C. Pankok, "The effect of driver cognitive abilities and distractions on situation awareness and performance under hazard conditions," *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 42, pp. 177–194, 2016.

[26] K. L. Young, P. M. Salmon, and M. Cornelissen, "Missing links? The effects of distraction on driver situation awareness," *Safety Science*, vol. 56, pp. 36–43, 2013.

[27] G. B. Reid and T. E. Nygren, "The subjective workload assessment technique: a scaling procedure for measuring mental workload," *Advances in Psychology*, Elsevier, vol. 52, pp. 185–218, , Amsterdam, Netherlands, 1998.

[28] S. G. Hart and L. E. Staveland, "Development of NASA-TLX (task load index): results of empirical and theoretical research," *Advances in Psychology*, Elsevier, vol. 52, no. 6, , pp. 139–183, Amsterdam, Netherlands, 1988.

[29] D. D. Heikoop, J. C. F. de Winter, B. V. Arem, and N. A. Stantona, "Effects of platooning on signal-detection performance, workload, and stress: a driving simulator study," *Applied Ergonomics*, vol. 60, pp. 116–127, 2016.

[30] J. C. F. de Winter, R. Happee, M. H. Martens, and N. A. Stanton, "Effects of adaptive cruise control and highly automated driving on workload and situation awareness: a review of the empirical evidence," *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 27, pp. 196–217, 2014.

[31] M. Hjälmdahl, S. Krupenia, and B. Thorslund, "Driver behaviour and driver experience of partial and fully automated truck platooning—a simulator study," *European Transport Research Review*, vol. 9, no. 1, p. 8, 2017.

[32] A. Luximon and R. S. Goonetilleke, "Simplified subjective workload assessment technique," *Ergonomics*, vol. 44, no. 3, pp. 229–243, 2001.

[33] A. M. Soliman and E. K. Mathna, "Metacognitive strategy training improves driving situation awareness," *Social Behavior and Personality: An International Journal*, vol. 37, no. 9, pp. 1161–1170, 2009.

[34] S. Liu, X. Wanyan, and D. Zhuang, "Modeling the situation awareness by the analysis of cognitive process," *Bio-Medical Materials and Engineering*, vol. 24, no. 6, pp. 2311–2318, 2014.

[35] T. Lajunen, D. Parker, and H. Summala, "The Manchester driver behaviour questionnaire: a cross-cultural study," *Accident Analysis & Prevention*, vol. 36, no. 2, pp. 231–238, 2004.

[36] L. M. Martinussen, L. Hakamies-Blomqvist, M. Møller, T. Özkan, and T. Lajunen, "Age, gender, mileage and the DBQ: the validity of the driver behavior questionnaire in different driver groups," *Accident Analysis & Prevention*, vol. 52, pp. 228–236, 2013.

[37] A. N. Stephens and M. Fitzharris, "Validation of the driver behaviour questionnaire in a representative sample of drivers in Australia," *Accident Analysis & Prevention*, vol. 86, pp. 186–198, 2016.

[38] A. af Wåhlberg, L. Dorn, and T. Kline, "The Manchester driver behaviour questionnaire as a predictor of road traffic accidents," *Theoretical Issues in Ergonomics Science*, vol. 12, no. 1, pp. 66–86, 2011.

[39] A. Bener, M. G. A. Al Maadid, T. Özkan, A. E. Al-Bast, K. N. Diyab, and T. Lajunen, "The impact of four-wheel drive on risky driver behaviours and road traffic accidents," *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 11, no. 5, pp. 324–333, 2008.

[40] A. M. Hezaveh, T. Nordfjærn, A. R. Mamdoohi, and Ö. Şimşekoğlu, "Predictors of self-reported crashes among Iranian drivers: exploratory analysis of an extended driver behavior questionnaire," *PROMET–Traffic and Transportation*, vol. 30, no. 1, pp. 35–43, 2018.

[41] M. Maslać, B. Antić, D. Pešić, and N. Milutinović, "Behaviours of professional drivers: validation of the DBQ for drivers who transport dangerous goods in Serbia," *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 50, pp. 80–88, 2017.

[42] S. Sun and Z. Duan, "Modeling passengers' loyalty to public transit in a two-dimensional framework: a case study in Xiamen, China," *Transportation Research Part A: Policy and Practice*, vol. 124, pp. 295–309, 2019.

[43] C.-q. Xie and D. Parker, "A social psychological approach to driving violations in two Chinese cities," *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 5, no. 4, pp. 293–308, 2002.

[44] K. A. Bollen, *Structural Equations with Latent Variables*, Wiley, New York, NY, USA, 2014.

[45] J. F. Hair, W. C. Black, and B. J. Babin, *Multivariate Data Analysis: A Global Perspective*, Pearson Education, Upper Saddle River, NJ, USA, 7 edition, 2010.

[46] J. K. Layer, W. Karwowski, and A. Furr, "The effect of cognitive demands and perceived quality of work life on human performance in manufacturing environments," *International Journal of Industrial Ergonomics*, vol. 39, no. 2, pp. 413–421, 2009.

[47] T. Ram and K. Chand, "Effect of drivers' risk perception and perception of driving tasks on road safety attitude," *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 42, pp. 162–176, 2016.

[48] J. S. Tanaka, ""How big is big enough?": sample size and goodness of fit in structural equation models with latent variables," *Child Development*, vol. 58, no. 1, pp. 134–146, 1987.

[49] M. S. Bahrke and B. Shukitt-Hale, "Effects of altitude on mood, behaviour and cognitive functioning," *Sports Medicine*, vol. 16, no. 2, pp. 97–125, 1993.

[50] T. Zimasa, S. Jamson, and B. Henson, "Are happy drivers safer drivers? evidence from hazard response times and eye tracking data," *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 46, pp. 14–23, 2017.

[51] A. L. Barach and J. Kagan, "Disorders of mental functioning produced by varying the oxygen tension of the atmosphere," *Psychosomatic Medicine*, vol. 2, no. 1, pp. 53–67, 1940.

[52] B. Sætrevik, "Developing a context-general self-report approach to measure three-level situation awareness," *International Maritime Health*, vol. 64, no. 2, pp. 66–71, 2013.

[53] C. R. Aragon, S. S. Poon, G. S. Aldering, R. C. Thomas, and R. Quimby, "Using visual analytics to maintain situation awareness in astrophysics," in *Proceedings of 2008 IEEE Symposium on Visual Analytics Science and Technology*, Columbus, OH, USA, October 2008.