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Structural Equation Modeling for Quantifying Riding Performance of Motorcycle Rider using Real-time Measurable Indexes

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Abstract: Motorcycle riders' fatality is four times that of four-wheeled vehicle drivers. Previous studies have shown the effect of the Advanced Rider Assistance System (ARAS) is different depending on the user's driving style. To realize personally optimized ARAS, it needs to keep track of riding performance and emotional state. Most studies define one index as driving performance to control the onset timing of ARAS. In this study, we designed a structural equation model to identify the driving behavior indexes that are directly related to the risk of traffic accidents from the emotional state and driving behavior. We investigated the driving behaviors of 23 test subjects using a riding simulator by inducing various emotional states in different conditions of driving scenery, traffic volume, and music. As a result, this model suggests that arousal level, valence level, carelessness, lateral instability, steering instability, and driving style are related to riding performance.

Keywords: Emotional state, Riding performance, Structural equation modeling

1. INTRODUCTION

According to the database of traffic accidents investigated by the Institute for Traffic Accident Research and Data Analysis (ITARDA), the number of four-wheeled vehicle driver accidents is decreasing, but the number of motorcycle rider accidents is not decreasing in Japan [1]. The number of serious injuries and fatalities of four-wheeled vehicle drivers is flat, but the number of serious injuries of motorcycle riders is increasing [2]. One of the reasons for the decline in fatalities and serious injuries of four-wheeled vehicle drivers is the practical use of the Advanced Driver Assistance System (ADAS) is increasing [3]. Furthermore, the fatalities of motorcycle riders are more than four times that of four-wheeled vehicle drivers [1]. Four-wheeled vehicle drivers are protected by the car body when an accident occurs, but motorcycle riders have nothing to protect their bodies.

For these reasons, it is important to prevent traffic accidents before they occur for motorcycle riders. One of the ADAS is a brake system to collision avoidance, but due to the poor stability of motorcycles, applying braking control to motorcycles is not realistic. There are some Advanced Rider Assistance Systems (ARAS) under development or in practical use [4]. There are for example, Motorcycle Antilock Braking System (ABS), Motorcycle Stability Control (MSC), and Forward Collision Warning (FCW). ABS is a safety anti-skid braking system to prevent locking wheels during braking to increase the

stability of vehicles. MSC is a system that improves a vehicle's stability by detecting and reducing skidding. FCW is a system that assists riders by warning the collision possibility in advance. Almost all of them are the type of systems that use fixed operating thresholds to control the onset timing which are calculated from such as the relative distance and the relative velocity between own vehicle and the other vehicle. However, it was reported that the effect on the rider's driving behaviors from ARAS is different depending on their driving style in the previous research [5]. It suggests that ARAS should have different driving support method depending on the driving style of riders.

We think that it is necessary to monitor the riding performance of riders in real-time to realize personally optimized ARAS. The personalized ARAS keeps track of riding performance in real-time and works when the riders' riding performance is low. In the previous studies, one index such as brake reaction time, change of vehicle velocity, time to lane crossing, and other is defined to quantify the driving performance [6, 7]. Of course, these indexes have a high relationship with the actual driving performance or riding performance. However, these indexes may not be directly related to the risk of traffic accidents. Therefore, we think that it is necessary to investigate the driving behaviors that are directly related to the risk of traffic accidents. The final goal of this study is to estimate the riding performance in the event of an accident from the driving behavior in advance during driving and design an ARAS to prevent traffic accidents.

Therefore, we set the following two goals in this study.

- 1) Clarifying the relationship between the human emotional state and driving behaviors.
- 2) Designing a model to estimate the riding performance using real-time measurable indexes.

2. RIDING SIMULATOR EXPERIMENT

2.1 Riding simulator

In this study, we used a Riding Simulator (RS) shown in Figure 1 developed by Misaki-design and the authors. The simulator consists of a motorcycle chassis, an electric fan, and two PCs: one is to calculate the vehicle maneuver and the other one is to present the graphics of driving scenery to riders. The driving airflow was generated to riders according to the driving speed using an electric fan to enhance the reality of driving. The inputs are accel opening degree, brake gripping amount, steering angle, the rolling angle of RS, and the left lever operation. The RS's steering handle has two levers on each side. The right lever is the brake lever and the left lever is the clutch lever used to investigate the reaction time of test subjects. The graphics are presented on the Head Mounted Display (HMD). The RS can generate rolling motion according to the input of the steering angle and the RS's angle of roll direction. The maximum rolling angle of the RS is ± 15 degrees.

2.2 Experimental procedure

The test subjects are 23 male college students who have a motorcycle driving license, and the mean age is 21.63 ± 1.71 . The average temperature during the experiment of all the experiments was $24.2^\circ\text{C} \pm 1.06$, and the average humidity is $42.7\% \pm 11.3$. Before we started the experiments, we got informed consent which is confirmed by the ethics committee of Kagawa University Faculty of Engineering and Design.

The experiment flow of this study is divided into three parts: practice, rest, and driving session. First, test subjects practiced the operation of RS for about 15 minutes to get used to driving the RS. Test subjects had sufficient rest time after they became accustomed to the drive of RS. The

Figure 1: Riding simulator used in experiments

driving session started after taking three minutes to break by closing the test subjects' eyes on the RS. After three minutes break, the main driving session was started.

The driving course was designed with a 20 km long one-lane road and with intersections every 1 km and a 50 m radius curve every 5 km. Two types of experimental courses were set to induce high and low arousal condition as shown in Figure 2. The three risk events were designed for each experimental course as risk event #I and #II. Risk event #I is a risk event that does not lead to a collision with the other vehicle, and risk event #II is a risk event that leads to a collision shown in Figure 3. All risk events were assumed the head-on collision accident at the intersection when a subject vehicle is driving a priority road. It is because the most common traffic accident is a head-on collision at intersections for motorcycle riders [2]. The other vehicle velocity was set road velocity limit + 10 km/h (70 km/h) at the risk event #II. Such conditions of risk events were set based on guidelines for the Advanced Safety Vehicle (ASV) in Japan [8].

As the main-task, the test subjects were instructed to drive to the destination while avoiding a collision when risky situations occurred. As the sub-task, subjects were instructed to maintain the vehicle velocity at 60 km/h and keep driving in the center of the lane as much as possible. When a risk event #I occurs, test subjects are required to react to the other vehicle using the clutch lever. When risk event #II occurs, test subjects are required to avoid a

Figure 2: Experimental courses and the timings of risk event #I and #II of high and low arousal condition

Figure 3: Risk event #II between the subject vehicle and the other vehicle at an intersection

collision by using the brake lever. After every risk event, the test subjects are required to answer questionnaires named Revised Emotions Measurement (REM) to investigate their emotional state which is explained in Section 2.4.2.

2.3 Emotion induction

The human emotional state was defined by Russell, et al. (1980) as a two-continuous dimensional space such as arousal and valence dimension as shown in Figure 4 [9]. Besides, it was also reported that human performance has a u-shaped relationship between arousal and valence levels, respectively. In other words, there is a relationship between emotional state and human performance as shown in Figure 5 [10]. Therefore, it is possible to investigate the different riding performances of riders by inducing the riders to various emotional states.

The arousal level was induced by driving scenery and traffic volume [11,12]. The sceneries of high and low arousal conditions are shown in Figure 6. For the high and low arousal condition, we set the scenery of the

downtown area and heavy traffic volume, and the scenery of the countryside and low traffic volume, respectively. The valence level was induced by using music [13]. We selected annoying sounds and light music to control the test subjects' valence level. We have tried to induce test subjects to various emotional states, but some of them were not induced. Neutral arousal or not high/low arousal means that not alarmed, not angry, not sleepy, or not droopy. Neutral valence or not negative/positive valence means that not miserable, not sad, not happy, or not pleased. We classify these uninduced test subjects as neutral arousal/valence levels by using the results of REM.

2.4 Experimental index

In this study, the riding performance was investigated by test subjects' driving behaviors, emotional state, and driving style. The driving behaviors and emotional state were investigated while driving on the RS. The questionnaire in terms of driving style was investigated before the experiment starts. Besides, interviews about the details of the emotional state, the music, and the scenery were conducted after experiments.

2.4.1 Driving behavior

We investigated as many driving behavior data as possible to clarify which index involved in riders' riding performance. Table 1 below shows the indexes that confirmed a high correlation with riding performance through correlation analysis. TTC_{min} and RT were investigated when risk events occur, and the other indexes are investigated while the test subjects are driving. These indexes are investigated at 100 Hz in the experiment.

Figure 4: Russell's circumplex model

Figure 5: U-shaped relationship between emotional state and human performance

Figure 6: Driving scene of the test subjects while driving of high and low arousal condition

Table 1: Experimental indexes of driving behavior

Index	Description
TTC_{min}	Time to collision between the subject vehicle and the other vehicle
RT	The reaction time from the other vehicle appears
v_{sd}	The standard deviation of velocity
a_{sd}	The standard deviation of acceleration
v_{max}	The maximum velocity
v_{min}	The minimum velocity
DC_{avg}	The average of the lateral distance from the center of the lane
$Lane_{1.0}$	The time while the subject vehicle is out of the virtual lane whose width is 1.0 m
DC_{sd}	The standard deviation of the lateral distance from the center of the lane
HE_{sd}	The standard deviation of heading angle error which is the difference between lane and motorcycle body angle
TLC_{avg}	The average of the time to lane crossing
$Steer_{sd}$	The standard deviation of steering angle

TTC_{min} is the minimum value of the time to collision calculated by dividing the minimum relative distance by the relative velocity between the subject vehicle and the other vehicle. The longer TTC_{min} means safer than shorter TTC_{min} because there is enough time before a collision with the other vehicle.

RT is the time from when the other vehicle appears until the test subject notices it and reacts using the clutch lever. In the previous study, RT was used as the index to quantify the crash avoidance [14].

v_{sd} is the standard deviation of the subject vehicle velocity. The smaller v_{sd} means the more stable velocity. In the previous study, experiments using a driving simulator to verify how performance is affected by talking on cell phones while driving [14] and an experiment using an actual four-wheeled vehicle to evaluate driving skill [15], v_{sd} was used as an index for speed control.

a_{sd} is the standard deviation of acceleration. The smaller a_{sd} means the more stable speed control. In the previous study, a_{sd} was used as an index of speed control [14] and used to detect drowsiness and distraction [16].

v_{max} is the maximum and v_{min} is the minimum velocity of the subject vehicle. In the previous study, the relationship between the driving characteristic and the driving skill was clarified based on the result of multiple regression analysis including v_{max} , v_{min} , and subjective evaluation result by passengers [15].

DC_{avg} is the average and DC_{sd} is the standard deviation of the distance from the center of the lane. The smaller DC means driving more along the road, and the more stable lateral control. In some previous studies, it was reported that if the driver is under influence of alcohol, drug, or fatigue the lateral deviation of a drowsy driver is also increasing [17].

$Lane_{1.0}$ is the time when the subject vehicle is out of the virtual lane whose width is 1.0 m from the center of the lane. The smaller $Lane_{1.0}$ means the test subjects drive within 0.5 m of the center of the lane. In the previous study, $Lane_{1.0}$ is used for driver drowsiness detection [17].

HE_{sd} is the standard deviation of heading angle error which is the difference between lane and motorcycle body angle. The smaller HE_{sd} means driving more along with the road shape and it was used for driver drowsiness detection [17]. The lateral deviation of drowsy drivers shows larger HE_{sd} than that of alert drivers. The driver makes steering control correctly to the road shape prediction when the drivers are alert, but the driver's performance to predict the road shape is low in the case of a drowsy driver.

TLC_{avg} is the average of the time to lane crossing. TLC is calculated by dividing the distance to the lane considering the angle of the subject vehicle by the driving velocity.

The distance to the lane considering the angle of the subject vehicle is shown in Figure 7. The larger TLC means driving more along the road. In the previous research, TLC_{avg} is used drowsiness detection [17].

Figure 7: Distance to the lane considering the angle of the subject vehicle

$Steer_{sd}$ is the standard deviation of the steering angle. The smaller $Steer_{sd}$ means the more stable steering control. $Steer_{sd}$ was used as an index of keeping lane position [14] and for driver drowsiness detection [17].

2.4.2 Questionnaire

We analyzed the riding characteristics using the Riding Style Questionnaire (RSQ) which revised the Driving Style Questionnaire (DSQ) to investigate the driving style of test subjects [18]. RSQ has 18 questions about driving style with four scales in Japanese. By asking this questionnaire, we can understand the characteristics of test subjects in terms of confidence in driving skills, impatient driving tendency, preparation for the signal, unstable driving tendency, negative driving tendency, careful driving tendency, motorcycle as status, and anxiety tendency.

We also surveyed the test subject's emotional state using Revised Emotions Measurement (REM) [19] which is a revised version of Self-Assessment Manikin (SAM) [20] to estimate the emotional state of test subjects. SAM is an image-type emotional scale, consists of five images with different facial expressions and postures in each dimension of arousal and valence with nine scales. Figure 8 shows REM which is a revised version of SAM for Japanese people who are familiar with illustrations such as anime. Regarding valence level, 1 is the most positive valence and 9 is the most negative valence. Regarding arousal level, 1 is the highest arousal and 9 is the lowest arousal. Test subjects are required to answer the REM after each risk event occurred. The questionnaire was presented on the HMD of RS, and the test subjects answered the score verbally while driving.

Figure 8: Revised Emotions Measurement used in this study

3. EXPERIMENTAL RESULTS

3.1 Data preparation

The investigated indexes are sorted on three scales by arousal and valence level based on the results of REM. For arousal level, the result of REM 1 to 3 means high arousal, 4 to 6 means neutral arousal, and 7 to 9 means low arousal. For the valence level, the result of REM 1 to 3 means positive valence, 4 to 6 means neutral valence, and 7 to 9 means negative valence. The data by each emotional state is shown in Table 2. The numbers indicate the frequency of data for each index, and the numbers in parentheses are the number of TTC_{min} data. We induced emotional state of test subjects like higher and lower arousal, more negative and more positive valence to obtain as much emotional state data as possible, but the number of neutral data was largest. There are two possible reasons. The first reason is the effects of the stimuli method to induce emotions. In the previous studies, some studies used movie clips to induce the emotional state of test subject [7]. However, it was difficult to control the test subjects' emotional state using these movie clips while driving with an RS. Alternatively, we used light music and sounds to control emotional states. The control method using sounds is also a good method [13], the effect of inducing the emotional states may weak. Therefore, some test subjects had difficulties to induce emotional states. The second reason is the difficulty of driving tasks. The test subjects needed to drive in the center of the lane keeping the certain velocity. The test subjects needed to concentrate on driving rather than daily normal driving. Therefore, there is a possibility of the test subjects were less affected by the scenery, traffic volume, and music.

Table 2: Number of data for each emotional state

Arousal Valence	Negative	Neutral	Positive	Total
High	13 (8)	26 (9)	21 (11)	41 (17)
Neutral	7 (3)	71 (33)	5 (1)	83 (37)
Low	4 (2)	29 (12)	8 (3)	60 (28)
Total	25 (14)	125 (53)	34 (15)	184 (82)

3.2 TTC_{min}

Figure 9 shows the results of TTC_{min} in different arousal and valence levels. The figure contains outliers, but we analyzed without these outliers. As shown in the figure, data in the range outside the range which is smaller than 25th percentile minus 1.5 time the interquartile and larger

Figure 9: Results of TTC_{min} by arousal and valence level

than 75th percentile plus 1.5 times the interquartile was treated as outliers. There are some outliers in the figure. The possible reason is habituation. All test subjects run the same course for four times and there are three same risk events in each driving for unified experimental condition. Some test subjects may have noticed the experimental condition.

According to the results of one-way ANOVA test, there are significant differences of arousal level ($F(2, 77) = 8.531$, $p = 0.000$) and valence level ($F(2, 78) = 5.394$, $p = 0.006$). Multiple comparisons using the Games-Howell test were performed and shows that there is a significant difference between low and high arousal ($p = 0.005$), between neutral and high arousal ($p = 0.013$), and between negative and neutral valence ($p = 0.000$). The tendency was confirmed that TTC_{min} is longer when the arousal level is lower and TTC_{min} is shorter when the arousal level is higher. Also, the tendency was confirmed that TTC_{min} is shorter when the valence level is more negative or more positive. The longer TTC_{min} means safer than the shorter TTC_{min} . From these results, the lower arousal state is safer than the higher arousal state. It is different from the hypothesis of high performance in neutral arousal. The reason for this result is discussed in Section 5.1. The shorter TTC_{min} was caused by dangerous deceleration behavior due to drowsiness. The neutral valence state is safer than the negative/positive valence state. It was confirmed that the data variance was small in the case of high arousal state and the mean TTC_{min} was the shortest. It suggests that TTC_{min} of most of all test subjects was short when they are in a high arousal state. For valence state, it was confirmed that the data variance was small in the case of negative valence state and the mean TTC_{min} was the shortest. It suggests that TTC_{min} of all test subjects was short when they are negative valence state.

3.3 RT

Figure 10 shows the results of RT in different arousal and valence levels. There are no significant differences of arousal ($F(2, 178) = 0.486$, $p = 0.616$) and valence level ($F(2, 177) = 2.558$, $p = 0.080$). Considering the results of TTC_{min} , it suggests that different emotional states make different braking operations because only TTC_{min} were different according to emotional states. It is considered that the deceleration of the brake to avoid a collision was quick in high arousal and negative valence state.

Figure 10: Results of RT by arousal and valence level

4. STRUCTURAL EQUATION MODELING

In this study, we investigated which indexes are significantly related to riding performance. We clarified the relationship between indexes that can be measured in real-time and the indexes that can be quantified when a traffic accident occurs. That is because the goal of this study is to use those indexes to estimate the riding performance in real-time and design an ARAS to prevent traffic accidents. To achieve this goal of this study, Structural Equation Modeling (SEM) analysis was performed. The most important reason for choosing SEM is that it is possible

to create latent variables which are related to the riding performance that is easy to understand the rider's driving condition. Furthermore, it may be possible to be applied as major state variables to the design of ARAS.

The model in this study was designed using SEM to investigate indexes related to the risk of traffic accidents in Figure 11. All standardized parameters are shown, and the validity of all paths was confirmed. Carelessness, Lateral Instability, Steering Instability, and Riding Performance were set as independent variables. The latent variables were designed to be easy for riders to understand when applied to ARAS.

v_{sd} ($\beta = 0.904$), a_{sd} ($\beta = 0.853$; $p = 0.000$), v_{max} ($\beta = 0.403$; $p = 0.000$), and v_{min} ($\beta = -0.423$; $p = 0.000$) are the outcome variables of Carelessness. We defined as Carelessness since these indexes are related to speed control. The high value of the former three indexes and the low value of v_{min} lead to higher carelessness of riders. DC_{sd} ($\beta = 0.424$), DC_{avg} ($\beta = 0.870$; $p = 0.000$), and $Lane_{1,0}$ ($\beta = 0.871$; $p = 0.000$) are the outcome variables of Lateral Instability. We defined as Lateral Instability since these indexes are involved in lateral position of the vehicle. The high value of these indexes leads to higher instability of the lateral direction. $Steer_{sd}$ ($\beta = 0.325$), HE_{sd} ($\beta = 0.651$; $p = 0.003$), DC_{sd} ($\beta = 0.508$; $p = 0.007$), and TLC_{avg} ($\beta = -0.625$; $p = 0.006$) are the outcome variables of Steering Instability. We defined as Steering Instability since these indexes are related to the instability, especially in the steering control. The high value of the former three indexes and the low value of TLC_{avg} lead to higher instability of the steering control. Also, the validity of these latent variables was verified by confirmatory factor analysis. As a result, the significances of these latent variables were almost confirmed.

Figure 11: Structural equation model to estimate the riding performance of motorcycle riders from driving behaviors, driving style, and emotional state in real-time

The results of validating factor analysis is shown in Table 3. Fornell and Lacker (1981) [21] recommended a Composite Reliability (CR) value of 0.60 or more, and an Average Variance Extracted (AVE) greater than 0.50. Hair (2010) [22] said that SFLs should be 0.50 or more. However, the results do not meet the all conditions. We have to use real-time measurable indexes because we estimate riding performance while driving. From the way to choose indexes used in the model and the validity of latent variables, there may be some other factors that contribute to riding performance. We limited the factors because we modeled from an engineering perspective rather than a scientific one.

Table 3: Results of confirmatory factor analysis

Constructs	Items	Standardized Factor Loading (SFL)	Composite Reliability (CR)	Average Variance Extracted (AVE)
Carelessness	1. v_{sd}	0.904	0.588	0.471
	2. a_{sd}	0.853		
	3. v_{max}	0.403		
	4. v_{min}	-0.423		
Lateral Instability	1. DC_{sd}	0.424	0.783	0.566
	2. DC_{avg}	0.870		
	3. $Lane_{1.0}$	0.871		
Steering Instability	1. $Steersd$	0.325	0.207	0.295
	2. TLC_{avg}	-0.625		
	3. HE_{sd}	0.651		
	4. DC_{sd}	0.508		

Arousal and *Valence* are the results of REM. *Passivity*, *Thorough*, *Unstable*, and *Anxiety* are the results of RSQ. In the model, *Passivity* ($\beta = 0.218$; $p = 0.022$) and *Valence* ($\beta = 0.155$; $p = 0.047$) have a direct positive effect and *Thorough* ($\beta = -0.375$; $p = 0.000$) and *Unstable* ($\beta = -0.335$; $p = 0.001$) have a direct negative effect on Carelessness. In other words, riders who are passivity, not thorough, and not unstable are likely to be carelessness more than other riders. *Arousal* ($\beta = 0.426$; $p = 0.000$) has a direct positive effect and *Anxiety* ($\beta = -0.275$; $p = 0.014$) has a direct negative effect on Lateral Instability. It means that high arousal level and riders who are not anxiety are easy to be instable in lateral position control. *Passivity* ($\beta = 0.273$; $p = 0.028$) has a direct positive effect and *Anxiety* ($\beta = -0.431$; $p = 0.008$) and *Unstable* ($\beta = -0.430$; $p = 0.008$) have a direct negative effect on Steering Instability. In other words, riders who are passivity, not anxiety, and not unstable are likely to be instability in steering control.

TTC_{min} ($\beta = 0.890$) and RT ($\beta = -0.387$; $p = 0.007$) are the outcome variables of Riding Performance. TTC_{min} is the minimum value of the time to collision between the subject vehicle and the other vehicle, and it is possible to

determine if there is a collision. RT is used to define driving performance in some papers [6].

In the model, Carelessness ($\beta = 0.667$; $p = 0.000$) has a direct positive effect and Steering Instability ($\beta = -0.808$; $p = 0.006$) and Arousal ($\beta = -0.378$; $p = 0.000$) have a direct negative effect on Riding Performance. Carelessness and Steering Instability are calculated from driving behavior, and Arousal is emotional state. It means that means that driving behavior and arousal level have a great effect on Riding Performance.

5. DISCUSSION

5.1 Driving behavior and questionnaire

We examined the relationship among each index to investigate the difference in driving behaviors due to changes in an emotional state, and it was confirmed the tendency that TTC_{min} is different depending on the emotional state even the RT is the same level. Certainly, there is a correlation ($r = -0.340$, $p = 0.002$) between TTC_{min} and RT , but there is no significant difference in RT depending on the emotional state. Moreover, the tendencies were confirmed that lower arousal induced longer TTC_{min} , and higher arousal induced shorter TTC_{min} . It is different from the hypothesis of high performance in neutral arousal. Samuel, et al. (2019) examined whether motorcycle rider emotional state is contingent on the environment and behavior [23]. It was reported that 18 motorcycle riders drove motorcycles on the real road and they provided a verbal commentary of emotional state. As a result, it is confirmed that riders' emotional state changes from low to high arousal, and between negative and positive valence. It means that it is easy for motorcycle riders to be higher arousal. It is also confirmed that the valence level is important for motorcycle riders.

The results of interviews on whether their emotional state was influenced by suggested sounds or not showed the following tendencies. Sixty percentage of test subjects whose results of REM show low arousal during the experiments answered they felt drowsy. The reason why TTC_{min} was long even though the test subjects felt drowsy is the deceleration was too high. Multiple comparisons using the Bonferroni test were performed for the result of deceleration, and it was confirmed that the deceleration in low arousal was significantly larger than neutral arousal ($p = 0.022$). Therefore, it was confirmed that the deceleration behavior in the case the test subjects felt drowsiness was dangerous. Thirty-five percentage of test subjects whose results of REM show neutral arousal answered they felt nothing. Thirty-two percentage of the

others whose results of REM shows neutral answered they were distracted. It was confirmed that their riding performance deteriorated because they could not concentrate on driving because of the distraction.

Forty-eight percentage of test subjects whose results of REM showing negative valence answered they were distracted. It was confirmed that their riding performance deteriorated because they felt discomfort due to the music, traffic volume, or drowsiness and they could not concentrate on driving. Thirty-two percentage of test subjects whose results of REM show positive valence answered they felt drowsy. It was confirmed that their riding performance deteriorated because the music made them feel drowsy or too relaxed. However, the tendencies that neutral valence induced longer TTC_{min} and negative or positive arousal induced shorter TTC_{min} are the same as the hypothesis.

5.2 Structural equation modeling

To achieve the second goal of this study, designing a model to estimate the riding performance using real-time measurable indexes, we investigated the relationship between indexes of driving behavior, driving style, and emotional state using structural equation modeling. The result of this study supports the fact that driving behavior, driving style, and emotional state are directly and indirectly related to riding performance. The experimental conditions of this study are relatively limited for subjects and reproduced traffic accident, but some of the findings of this study will be useful for the future study dealing with motorcycle safety. For example, the fact that the driving style that can be measured from a questionnaire has effects on the driving behavior and the fact that the emotional state also has effect on the driving behavior and riding performance.

The proposed model can be applied to the driving support function of ARAS such as feedbacks of the riding performance to the rider in real-time to support riders understand his/her driving state. The concept of ARAS using the result of SEM to feedback the riding performance to the riders is shown in Figure 12.

Since the indexes used in the SEM can be measured while driving, it can be used in the design of real practical usage of ARAS. We used a questionnaire to investigate emotional state while driving, but it is difficult while driving in the real world. For the practical use, biological signals are effective [24-26]. Galvanic skin response (GSR) and photoplethysmography (PPG) are easy to measure in real-time while driving. They can be used to estimate arousal and valence level of riders.

Figure 12: The concept of ARAS using the result of SEM to feedback the riding performance to riders

The most realistic way to use the proposed model as ARAS is by using smartphones. Smartphones have many sensors such as acceleration, gyro sensors, and GPS. Moreover, the smartphone has a display to present riders' state as an ARAS. There are several ways to calculate riding performance to introduce this model into ARAS, for example, by calculating using machine learning [27], or by offering predictors that do not depend on an assumed prior distribution for parameters [28]. There are possibilities to calculate the latent variables using these ways in our model.

6. LIMITATIONS

Since this study was conducted in the experiments using an RS, it needs to verify the reality of driving in the RS driving environment. All test subjects were able to drive the RS after the practice of driving, but some test subjects had difficulty in driving the RS before the practice driving. This means that the RS maneuver may differ from the actual motorcycle's maneuver in the real world. In particular, it is considered that the subject's braking operation differs from the actual driving in the experimental state. The RS constructed in this study has a motion device, but it does not make test subjects turnover like in the real world. Therefore, there is a possibility that the test subjects were braking differently compared to the actual motorcycles.

Some studies have verified the reality of the simulator experiment compared to the real driving test. Lee, et al. (2003) performed logistic regression analysis to determine the criteria that influence the outcome of self-reported crashes using a driving simulator [29]. This study indicated those individuals at inflated risk of vehicle crashes could be identified using a driving simulator. Bella (2008) performed comparative and statistical analysis to validate

the driving simulator's usefulness as a tool for speed research [30]. It was concluded that the driving simulator should be used for driving speed behavior research. Auberlet, et al. (2012) performed experiments using the driving simulator and actual vehicle to verify the risk on rural crest vertical curves focusing on the lateral position of drivers in relation [31]. The results showed the usefulness of the driving simulator in the road design process. From these studies, it is clarified the possibility to identify individuals at inflated risk of vehicle crashes, driving behavior research, and road design process using a driving simulator. Therefore, it was confirmed the usefulness of the driving simulator experiments.

7. CONCLUSIONS

- 1) Clarifying the relationship between the human emotional state and driving behaviors.

From the results of TTC_{min} , lower arousal level leads riders to longer TTC_{min} , and higher arousal level leads riders to shorter TTC_{min} . It means that there is enough time before a collision in lower arousal. However, the drowsy rider's deceleration to avoid a collision was too fast and dangerous rather than the other riders. Therefore, TTC_{min} is short in the state of low arousal, but it is not indicated that they are safe because of the too much deceleration. In the neutral valence, TTC_{min} is longer than in the negative and positive valence. From the results of RT, there was no significant difference according to the emotional states.

- 2) Designing a model to estimate the riding performance using real-time measurable indexes.

We designed a structural equation model to predict riding performance. The riding performance means the performance leads to avoid traffic accidents in this study. The results show the possibility to predict the riding performance using some indexes measured in real-time.

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