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DoReMi Steering Wheel: Proposal for a Driving Assist System with Sound Display Depending on the Rotation Angle of Steering Wheel

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Abstract

It is difficult for novice drivers to improve their driving skills by themselves. One of the difficulties for novice drivers is the technique for driving on curves, such as the timing and amount of steering. Therefore, in this study, we propose a method to sensitively estimate the amount and timing of steering by using a sine wave of a musical scale corresponding to the steering angle. We called this method the "*DoReMi Steering Wheel*." We also implemented a prototype system on a driving simulator and conducted experiments to check the usefulness of our system. The results showed no significant difference in the number of steering corrections between the *DoReMi Steering Wheel* and the standard steering wheel. Still, there was a significant difference in the subjective evaluation of the ease of driving on curves, suggesting that the *DoReMi Steering Wheel* may support driving.

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Keywords: DoReMi Steering Wheel; Driving Assistance; Steering Wheel Operation; Curve Driving; Driving Simulator;

1. Introduction

More than one million people obtain a driver's license every year in Japan [1], indicating that many novice drivers have just acquired a driver's license. When we conducted a Web survey for 2,000 drivers using *Yahoo! Crowdsourcing*, 23% answered that they were not good at driving, and 52% responded that steering was difficult. This suggests that people who are not good at driving often have problems with steering.

Driving on a curve is difficult for novice drivers because the information from sight and arm sensation decides how to turn the steering wheel. In order to drive on a curve well, they need to gain experience, such as driving on

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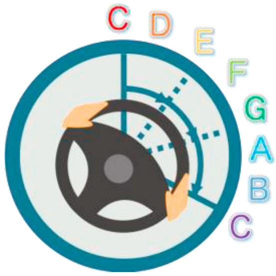

Fig. 1. DoReMi Steering Wheel.

many kinds of curves. However, novice drivers do not have much experience, so they cannot get a feel for driving on a curve. The objective of this work is to solve this problem.

One of the methods to solve this problem is to ask a driver's family to ride along and get their advice. However, it is not easy for the driver's family to make time to teach. In addition, novice drivers sometimes do not receive good advice from their families. If a driver and his/her family are incompatible, they will frustrate each other. Also, some people do not like to have their mistakes pointed out by others.

One way a system can assist with driving on a curve is by providing visual information such as the rotation angle of the steering wheel, using Augmented Reality technologies. However, it is not safe to watch for additional visual information near the steering wheel while driving. Parush [2] found that audio prompts can support the overall performance of visual tasks better than visual prompts. Murofushi et al. [3] showed that it is practical to teach the form of a continuous high-speed movement such as a hammer throw, which is generally considered difficult to correct, by attaching acceleration, angular velocity, and tension sensors to the hammer thrower's head and presenting the sensor values. Therefore, we have realized a system that enables novice drivers to quickly grasp the steering angle value from auditory information.

In order to enable novice drivers to grasp the value of the steering angle sensitively, we propose a method that involves playing the sounds Do-Re-Mi-Fa-So-La-Si-Do (C-D-E-F-G-A-B-C, in the musical scale) depending on the steering angle (see Fig.1). We call our system the "*DoReMi Steering Wheel*." We believe that our system can assist in driving on a curve because the user experiences not only vision and arm sensations through the steering wheel but also sound. We developed the *DoReMi Steering Wheel* on our driving simulator system in this work. We also conducted an experiment with it to test its effect, and analyzed the results separately for frequent and infrequent drivers.

2. Related Work

Lorna et al. [4] focused on the problem that visually impaired people have difficulty interpreting the shape of graphs. Therefore, in a graph with two sets of data, they proposed a method in which one set of data is represented by the sound of a piano and the other by a trumpet. After listening to the sound, participants were able to reproduce the shape of the graph with high accuracy when they drew a picture of the shape of the graph. By making sounds depending on the graph, they succeeded in conveying information about the shape of the graph. Bruce et al. [5] suggested the "Audio Abacus," an application for blind people, which allows them to understand a value sensitively using a musical scale. Users can determine the digits of a phonetized number with little practice. Our study focuses on the auralization of values as in these studies, and assists with driving on a curve by mapping a steering angle to a musical scale.

Abboud et al. [6] proposed a method, "EyeMusic", which uses musical tones generated from natural musical instruments to comfortably convey visual information to the visually impaired. The pixel's color determines the device, and the coordinates depend on the pitch. Thus, the visually impaired can intuitively understand shape and color information. Bologna et al. [7] proposed a method, "SeeColOr" which rapidly translates the colors of the environment into the tones of the instrument. It makes it easier for the visually impaired person to recognize the environment. As a result, they are able to walk along winding roads. Similarly, there has been some research on auditory feedback using music scales, which has been effective. We expect that our system enables drivers to grasp the steering wheel operation by making them hear the music scale of sound.

Many studies assist driving with hearing feedback. Hoc et al. [8] conducted an experiment to determine which senses are most effective in warning of a car crash. The results showed that the fastest time to react was when auditory and tactile warning signals occurred. Onimaru et al. [9] developed a driving simulator to improve the perception of the left-right position of a car in real-time. It has a system that gives feedback on a vehicle's position using differences in sound pressure at both ears. Driving performance improved without increasing load when used in combination with visual assistance. Thus, there is research on various assistance methods using auditory feedback in driving. This study aims to provide driving assistance, and especially to improve the driver's steering wheel operation in curves.

3. DoReMi Steering Wheel

3.1. Proposed method

The objective of our study is to help novice drivers to master driving on a curve easily. Visual information is essential while driving, so we aim to assist with auditory information. As for support by auditory information, it is possible to directly map the volume and frequency to the steering angle, and present the dynamically changing volume and frequency. This method can be used to grasp relative values, but it is challenging to grasp absolute values. In addition, it is not easy to understand the relative differences.

Therefore, changes in analog sound could be uncomfortable. We thought it would be better to present auditory information somewhat discretely to grasp the steering angle sensitively. We also thought it would be better to know the absolute value of the current rotation angle and the amount of rotation until the steering wheel is fully turned. We propose the *DoReMi Steering Wheel* that plays sine waves of a musical scale according to the steering angle.

Fig. 1 shows an image of the *DoReMi Steering Wheel* system. When the driver turns the steering wheel, the system plays a sine wave according to the angle of the steering wheel. Table 1 shows the mapping of the musical scale. The steering angle is 0 degrees when the driver keeps the steering wheel straight. The scales are evenly distributed so that a 'Do' is sounded when the absolute value of the steering angle is 0 degrees, and a "Do" one octave higher is expressed when the rise is 90 degrees.

By using the *DoReMi Steering Wheel*, we expect that users will be able to recognize a curve that they have already driven once on a scale of how far they need to turn the steering wheel. In addition, steering stability is necessary for driving on a curve well. The increase or decrease of the amount of steering wheel operation is not suitable for driving and will make the ride uncomfortable because steering correction depends on the amount of steering wheel operation. If we use the *DoReMi Steering Wheel*, we can recognize the steering corrections. This is because when the steering wheel is adjusted, the scale changes. Finally, we might be able to drive on a curve stably.

Table 1. Correspondence between scale and steering angle.

Musical scale（Frequency[Hz]）	Steering angle
C（261.6）	0.00 ~ 12.86
D（293.7）	12.86 ~ 25.66
E（329.6）	25.66 ~ 38.52
F（349.2）	38.52 ~ 51.38
G（392.0）	51.38 ~ 64.24
A（440.0）	64.24 ~ 77.10
B（493.9）	77.10 ~ 90.00
C（523.2）	90.00 ~ 102.86

3.2. Implementation

We improved the driving simulator [10] used for applying the *DoReMi Steering Wheel* using Unity. The system communicates and operates between the HMD (Head Mounted Display) used by the driver and a laptop PC that manages the experiment. Drivers can hear the sound of the *DoReMi Steering Wheel* through the HMD's loudspeakers. We adjusted the volume so that drivers could listen to both the engine noise and the sound of the *DoReMi Steering Wheel*. We used an Oculus Quest2 as the HMD, Fanatec's ClubSport Wheel Base V2.5 as the steering controller, Fanatec's Podium Lenkrad Classic 2 as the steering wheel, and Fanatec's ClubSport Pedals V3 as the pedals. We also used Next Level Racing's NLR-S010 as the driving seat.

Since the steering wheel controller cannot be directly connected to the Oculus Quest2, data from the steering wheel controller is acquired by a notebook PC, and then driving information is sent to the HMD via network communication. Fig. 2 shows the screen for participants, and Fig. 3 shows the screen for the experiment manager. The experiment manager can choose whether or not to use the *DoReMi Steering Wheel* on a laptop PC without operating the HMD. Fig. 4 shows a snapshot of using our system.

3.3. Usage

When participants wear the HMD, they can see a pseudo-visual image (Fig. 2). They can drive the car in this state and see speed information on the screen on the right rear of the steering wheel. Guardrails and trees are shown on both sides of the road. These scenery shifts to give the participant a more natural sense of speed. To avoid any sense of discomfort in driving, the steering wheel on the screen rotates in tandem with the steering wheel's rotation

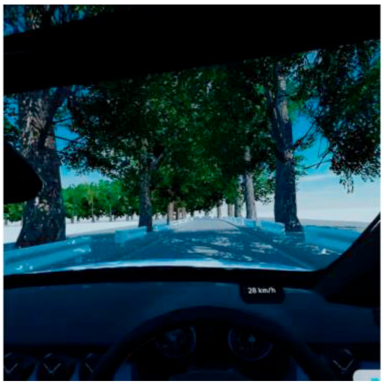

Fig. 2. A screenshot of our system.

Fig. 3. Screen for the experiment manager.

Fig. 4. A snapshot of using our system.

held in the participant's hands.

Fig. 3 shows a screen snapshot of the system for the experiment manager. The experiment manager inputs experimental conditions such as road width, curve angle, curve radius value, total course length, and the road in this system. In addition, for the collection of operation data in the experiment, time, speed, the position where the car passed, the amount that the accelerator pedal was pressed, and the amount of steering wheel rotation were acquired approximately 33 times per second from the start point to the goal point. The system stores the data on multiple curves in one trial for each participant using CSV format.

4. Experiment

To test the hypothesis that "the number of steering corrections per trial decreases more when drivers use the "*DoReMi Steering Wheel*" than when they do not use it," we experimented to examine whether there was a difference in smoothness and speed when learning to drive curves.

4.1. Experimental Settings

The driving method varies greatly depending on external factors such as weather, time of day, and pedestrian traffic. To produce data on the influence of only one of these factors, it is always necessary to conduct the experiment in a controlled environment with no external factors and keep the difficulty level the same for all participants. In addition, although it is preferable to conduct experiments using actual vehicles to approximate the natural environment, the driving environment may change depending on the weather and other road conditions on that day. Therefore, we used the driving simulator implemented in section 3 and conducted experiments in this study.

The experiment involved a 200m long road consisting of a 50m straight line, a 100m curve, and a 50m straight line. There were two types of curves, right and left turns, and the radius of the curves was 64 m, and the angle was 90 degrees so that the length of the curves was 100m. Fig. 5 shows the structure of the courses for this experiment. We prepared a public one-way road in the daytime with those conditions. We chose one-way streets to eliminate factors such as straying from the centerline.

In the experiment, we measured 20 consecutive trials of each type of curve to record the process of learning to drive a turn well. In addition, to account for familiarity with the experiment and the original unskillfulness of the participants depending on the direction of the curve, we experimented with the participants divided into four groups (Table 2).

Here, 'novice drivers' generally refers to drivers who have had their driver's license for less than one year, but there are cases where drivers have been driving for more than one year and are not accustomed to driving. Therefore, in this experiment, we defined "frequent drivers" as those who usually drive at least once a week and "infrequent drivers" as those who drive less frequently. We classified each group so that the number of infrequent and frequent drivers would be equal.

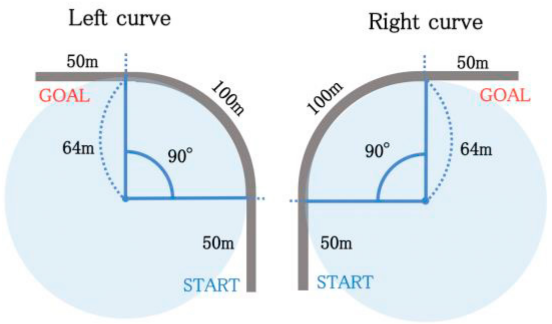

Fig. 5. The structure of the course.

Table 2. Four groups for the experiment (curve direction and steering wheel type).

	First half	Second half
GroupA	Right・DoReMi	Left・Standard
GroupB	Left・Standard	Right・DoReMi
GroupC	Left・DoReMi	Left・Standard
GroupD	Right・Standard	Right・DoReMi

4.2. Experimental Procedures

In the first part of the experiment, we explained the flow of the investigation and important points to the participants. Then, we asked participants to practice driving two times on each curve to familiarize themselves with the simulator before the main experiment.

The participants drove two types of curves every 20 trials for 40 tests. They took a break of 10 minutes at the end of the first 20 trials to prevent fatigue from changing the condition of the participants. Each trial began with a countdown (see Fig. 6). If the driving car touched the guardrails on either roadside, the system recorded the driving as an error. When that happened, they drove the curve which was recorded as an error at the end of the trial, and measured it again.

To minimize the effect of the sudden sound on the curve driving, the Do-Re-Mi sound was started 10m before the curve began (at 40m from the beginning of driving). In some cases, fear of collision prevents normal operation. Therefore, we asked the participants to reach a speed of 30 km/h or higher not to drive too slowly so the participants would drive in a usual manner. In the preliminary explanation, we did not inform them that they should drive with minor steering corrections or that these would be counted.

The experiment took approximately 45 minutes per participant, from the preliminary explanation to the end of the measurement. The number of participants was 26 (22 males and four females) who had a driver's license. We excluded two participants from the analysis because they had many collisions with the guardrail that could not be analyzed correctly. Finally, we used 24 participants' driving (20 males and four females) for analysis. Here, there were nine frequent drivers and 15 infrequent drivers.

5. Experimental Results

This experiment hypothesized that the number of steering corrections per trial would decrease more when drivers used the *DoReMi Steering Wheel* than when they did not use our system. Here, as an index for evaluating curve driving, we focus on the steering corrections and the amount of steering wheel operation correction to evaluate steering stability, which is one element of good curve driving.

5.1. Analysis of Driving Behaviors

There are various methods for assessing steering correction. In this case, we decided to count the point where the number sign of the derivative of the steering wheel angle per time reversed from the start of driving as the steering correction. Therefore, even in the smoothest curves, the number of steering corrections is counted at least once when the steering wheel is turned to return to the straight line, and then the steering wheel begins to turn back. We included only the data of the first 20 trials in the analysis to allow for habituation.

Fig. 7 shows the average number of steering corrections for all participants, infrequent and frequent drivers, respectively, over 200 m. We grouped the 20 trials into four to account for the minor blurring between tests.

Fig. 6. Countdown screen.

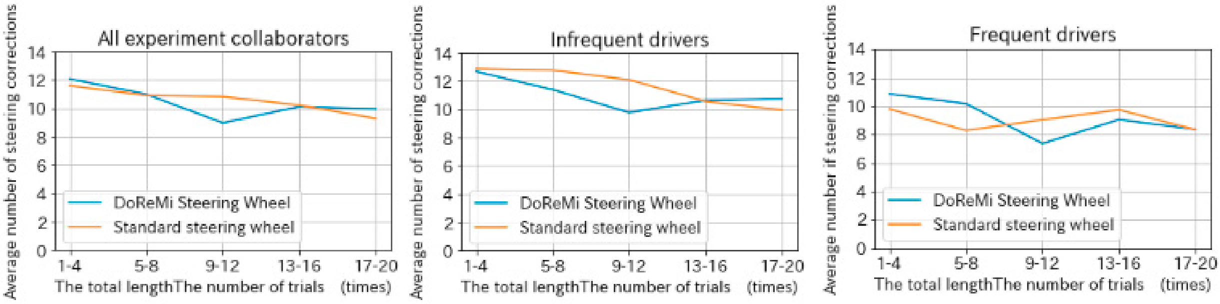

Fig. 7. The average number of steering corrections over the total length
(left) all experiment participants, (middle) infrequent drivers, (right) frequent drivers.

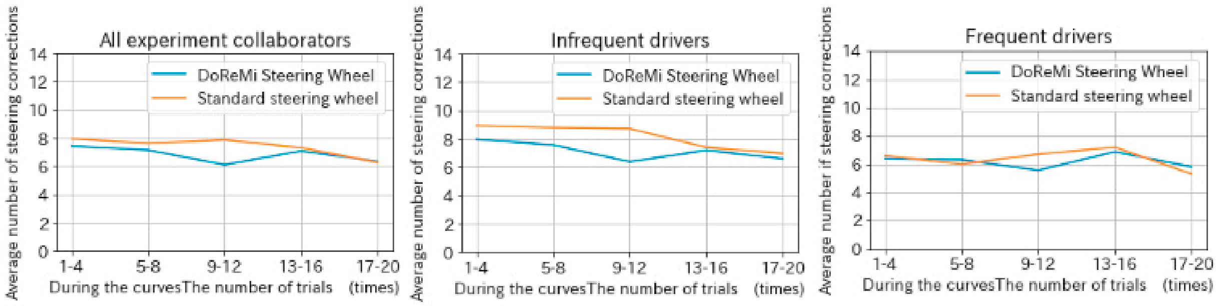

Fig. 8. The average number of steering corrections during the curves
(left) all experiment participants, (middle) infrequent drivers, (right) frequent drivers.

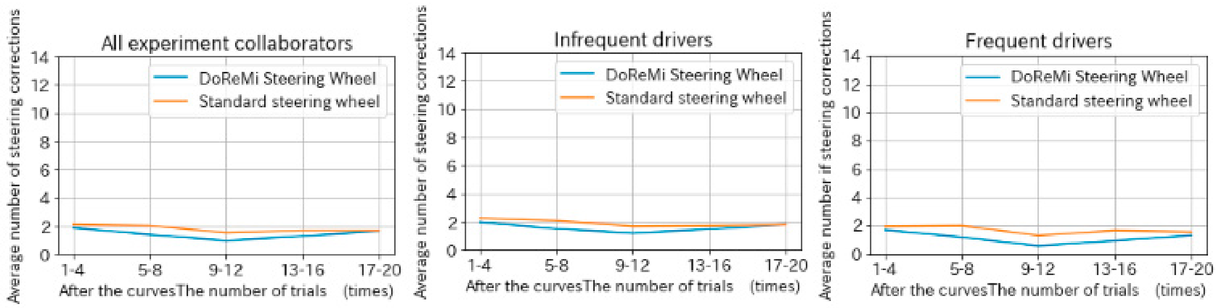

Fig. 9. The average number of steering corrections after the curves
(left) all experiment participants, (middle) infrequent drivers, (right) frequent drivers.

These figures show that the *DoReMi Steering Wheel* group made fewer steering corrections for all participants in the experiment than the standard steering wheel group in the 9-12 trial period. The number of steering corrections for the infrequent drivers was smaller for the *DoReMi Steering Wheel* group than for the standard steering wheel group from trials 1-4 to 9-12. On the other hand, the frequent drivers showed minor steering corrections in the standard steering wheel group in trials 1-8 but more minor in the *DoReMi Steering Wheel* group in trials 9-12. Conversely, the number of steering corrections was lower when using the standard steering wheel in the 1-8 and 5-8 trials.

Figs. 8 and 9 show the analysis results are limited to during and after the curve, because steering corrections occur primarily during and after curves. Fig. 8 shows that the number of steering corrections for all experimenters during curves was lower for the *DoReMi Steering Wheel* group in trials 9-12 than for the standard steering wheel group. The *DoReMi Steering Wheel* group had fewer steering corrections in the 1-12 trials than the standard steering wheel group among the infrequent drivers. However, there was no difference among the frequent drivers. Fig. 9 shows that the number of steering corrections for all experimenters after a curve was lower for the *DoReMi Steering*

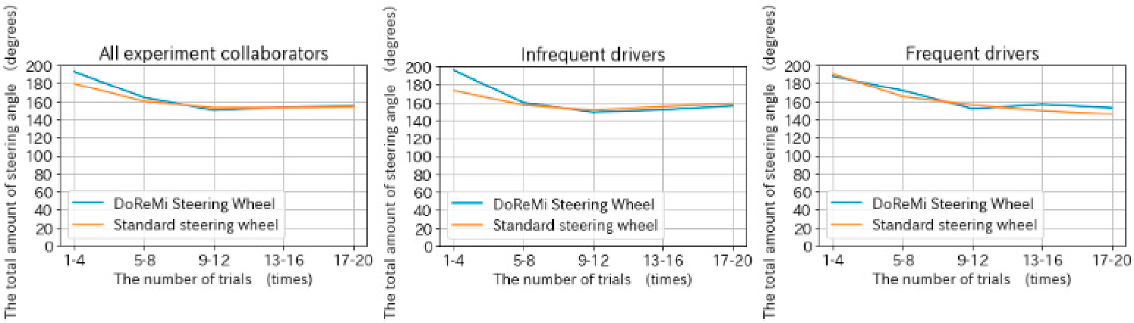

Fig. 10. Average steering wheel operating value over a total length of 200 m
(left) all experiment participants,(middle) low-frequency drivers,(right) high-frequency drivers.

Wheel group than for the standard steering wheel group. This result was similar for both infrequent and frequent drivers. We conducted a two-factor mixed analysis of variance (Factor 1: with/without *DoReMi Steering Wheel*, Factor 2: trial order (20 trials)) for the *DoReMi Steering Wheel* group and the standard steering wheel group. There was no significant difference in the number of steering corrections with and without the *DoReMi Steering Wheel*.

Fig.10 compares the average steering wheel operating value per trial with and without using the *DoReMi Steering Wheel*. We analyzed only the data from the first 20 trials to allow for habituation. We also calculated the average of the four trials and plotted to account for a minor blurring between trials. The experimental results showed that the amount of steering wheel operation did not change significantly depending on whether or not the participants used the *DoReMi Steering Wheel*. Among the infrequent drivers, the steering wheel operation for trials 1-4 was higher in the *DoReMi Steering Wheel* group.

Fig.11 shows the mean speeds and standard deviations for all participants, infrequent drivers, and frequent drivers with and without the *DoReMi Steering Wheel*. First, the pace of the *DoReMi Steering Wheel* group was slower for all participants. The *DoReMi Steering Wheel* group was slower than the standard steering wheel group among the infrequent drivers. Conversely, among the frequent drivers, the *DoReMi Steering Wheel* group was faster. Among the frequent drivers, the standard deviation of the *DoReMi Steering Wheel* group was 8.01, while that of the standard steering wheel group was 6.66. From this, it can be said that those who used the *DoReMi Steering Wheel* tended to result in more erratic driving in each trial.

5.2. Subjective evaluation

We asked participants to answer a questionnaire after the experiment. The questionnaire included a five-point scale (the higher the value, the easier it was to drive) for ease of turning curves and so on. The contents of the questionnaires were the same with and without the *DoReMi Steering Wheel*. Fig. 12 shows the average rating for ease of turning. In this figure, the *DoReMi Steering Wheel* was better in evaluation. We conducted a one-factor mixed analysis of variance (factor: with/without the *DoReMi Steering Wheel*) with a significance level of 5%. There was a significant difference in the ease of driving curves between the *DoReMi Steering Wheel* and the standard steering wheel.

The feedback on what the participants were conscious of while using the *DoReMi Steering Wheel* included "I found a reference for the scale and tried to operate the steering wheel so that it would reach that scale," "I tried to keep the scale steady during the curve and to play "Do" at the end of the curve," "I was conscious of keeping the rhythm of the scale change constant from trial to trial," "My attention was more focused on turning the steering wheel and less conscious of the trajectory than usual," and "My attention was more on matching the pitch than on driving." Feedback on situations in which they would like to use the *DoReMi Steering Wheel* indicated: driving school, long curves, parking, mountain roads, narrow roads, and places where it is difficult to see what would happen if there was an assist system. On the other hand, several respondents stated that they did not want to use the system in a practical
vehicle because they depended on the sound.

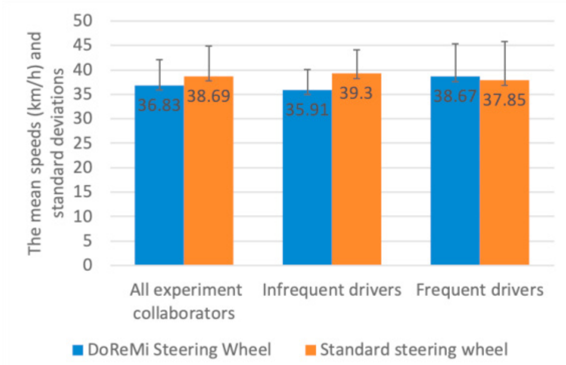

Fig. 11. The mean speeds (km/h) and standard deviations.

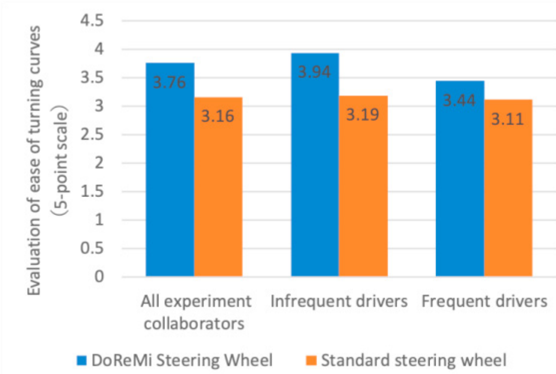

Fig. 12. Evaluation of ease of turning curves (5-point scale).

We received feedback about the differences between this experimental system and an actual vehicle. These included the difficulty in applying the engine brake, the steering wheel not automatically returning to its original position, the weak sensitivity of the brakes, and the less realistic feeling of being unable to feel a centrifugal force.

6. Discussion

The study obtained in section 5.1 showed no significant difference in the number of steering corrections between the group with and without the *DoReMi Steering Wheel*. There was no difference in the driving style, and this may have been because the participants had not yet become familiar with the *DoReMi Steering Wheel* in trials 1-4. The number of steering corrections tended to decrease for trials 9-12 but increased for trials 17-20. This was probably because they became bored during the experiment. The experiment was to drive the same course repeatedly to see how they improved, but it was easy to be bored. It was necessary to take a break, devise an approach, etc. Therefore, we will consider the appropriate number of trials and experiments again.

In addition, there was no difference in the amount of steering wheel operation with the use of the *DoReMi Steering Wheel*. The increase in steering wheel operation among the infrequent drivers in trials 1-4 was because they were not yet familiar with the sound and were confused. However, there was no such tendency among the frequent drivers. It is thought that the sound of the *DoReMi Steering Wheel* does not affect their steering wheel operation. There was a possibility that understanding the pitch that corresponds to good curve driving would cause drivers to increase the steering wheel operation to match the pitch, but this did not happen.

The average speed of the infrequent drivers in the *DoReMi Steering Wheel* group was slower than the standard steering wheel group. This result may be because the drivers focused on the steering wheel operation by using the *DoReMi Steering Wheel* and reducing the speed. The average speed of the frequent drivers was faster in the *DoReMi Steering Wheel* group than in the standard steering wheel group. In other words, the frequent drivers tended to drive well on curves only through steering wheel operation. On the other hand, the *DoReMi Steering Wheel* group was found to drive more erratically on each trial than the standard steering wheel group. The reason for this is unknown, but we suspect the effect of sound was a factor.

According to the subjective evaluation, infrequent and frequent drivers found that it was easier to turn curves using the *DoReMi Steering Wheel.* From the responses concerning what they were conscious of while using the *DoReMi Steering Wheel*, even participants who did not decrease the number of steering corrections also felt the system made it easier to drive. This may be because the analysis based on the number of steering corrections was inappropriate. We will analyze this more.

On the other hand, it is possible that it is difficult to focus on the driving action due to concentrating on the sound when using the *DoReMi Steering Wheel*. We plan to design sounds that do not decrease concentration. In addition, we have problems common to driving simulators, particularly engine braking and brake sensitivity. We will examine by improving the system and re-experimenting. We plan to conduct experiments on actual vehicles to examine their usefulness in the future.

In this work, we set the range of tones for one octave to the range where the handle rotates 90 degrees. In the future, we will consider setting that according to the angle of the curve to be turned so that the driver needs to just simply turn the steering wheel until a high "do" is heard each time on the actual road. By doing so, we expect to be able to support driving in places where the driver does not know the degree of the curve, or on sharp curves, such as mountain roads.

We are planning to enable our system to be used at driving schools. For first-time drivers, it is not easy to learn how much to turn the wheel. Therefore, we expect that telling them the approximate scale will reduce their worries. We should examine appropriate situations and designs for using the *DoReMi Steering Wheel* in practical use.

7. Conclusion

In this study, we proposed the *DoReMi Steering Wheel* that plays sine waves in pitch according to the steering angle in curves to help novice drivers master driving on a turn easily. We implemented the *DoReMi Steering Wheel* on a driving simulator. We hypothesized that “the number of steering corrections per trial decreases more when drivers use the *DoReMi Steering Wheel* than when they do not use it.” Then, we experimented with driving the same curve for 20 consecutive trials.

The experimental results showed that infrequent drivers tended to reduce the number of steering corrections in trials 5-12 when using the *DoReMi Steering Wheel* compared to when using the standard steering wheel. However, there was no significant difference in the number of steering corrections between the *DoReMi Steering Wheel* and the standard steering wheel. The steering wheel operation with and without the *DoReMi Steering Wheel* also did not change. On the other hand, in the subjective evaluation, both infrequent and frequent drivers felt that it was easier to drive on curves when using the *DoReMi Steering Wheel*, and significant differences were also confirmed. It is possible that they could not make the turns well because they were not used to the *DoReMi Steering Wheel* itself and became bored with using it continuously.

We plan to redesign the experiment to make it more appropriate. In addition, we also plan to improve the driving simulator so that we can conduct experiments in a more realistic environment. Moreover, we would like to find the best timing to start using the *DoReMi Steering Wheel* for each driver. We plan to examine the system on an actual vehicle in the future.

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