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TITLE:

Tactile Vibrating Toolkit and Driving Simulation Platform for Driving-Related Research

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KEYWORDS:

driving simulator, simulator, collision warning system, car-following task, tactile warning, simulation and vibrating toolkit

SUMMARY:

This protocol describes a driving simulation platform and a tactile vibrating toolkit for the investigation of driving-related research, especially in evaluating collision warning systems. An exemplar experiment demonstrating the effectiveness of tactile warnings is also presented.

ABSTRACT:

Collision warning system plays a key role in the prevention of driving distractions and drowsy driving. Previous studies have proven the advantages of tactile warnings in reducing driver's brake response time. At the same time, tactile warnings have been proved effective in take-over request (TOR) for partially autonomous vehicles.

How the performance of tactile warnings can be optimized is an ongoing hot research topic in this field. Thus, the presented low-cost driving simulation software and methods are introduced to attract more researchers to take part in the investigation. The presented protocol has been divided into five sections: 1) participants, 2) driving simulation software configuration, 3) driving

simulator preparation, 4) vibrating toolkit configuration and preparation, and 5) conducting the experiment.

In the exemplar study, participants wore the tactile vibrating toolkit and performed an established car-following task using the customized driving simulation software. The front vehicle braked intermittently, and vibrating warnings were delivered whenever the front vehicle was braking. Participants were instructed to respond as quickly as possible to the sudden brakes of the front vehicle. Driving dynamics, such as the brake response time and brake response rate, were recorded by the simulation software for data analysis.

The presented protocol offers insight into the exploration of the effectiveness of tactile warnings on different body locations. In addition to the car-following task that is demonstrated in the exemplar experiment, this protocol also provides an option to apply other paradigms to the driving simulation studies with simple modifications and basic programming skills. However, it is important to note that due to its affordable price, the driving simulation software and hardware introduced here may not be able to fully compete with other high-fidelity commercial driving simulators. Nevertheless, this protocol can act as an affordable and user-friendly alternative to the general high-fidelity commercial driving simulators.

INTRODUCTION:

According to the data revealed by the Global Health Estimates in 2016, traffic injury is the eighth cause of global deaths, leading to 1.4 million deaths worldwide[1]. In the year 2018, 39.2% of the traffic accidents were collisions with motor vehicles in transport, and 7.2% of which were rear-end collisions. A solution to increase vehicle and road safety is the development of an advanced driving assistance system (ADAS) to warn drivers with potential hazards. Data has shown that ADAS can greatly reduce the rate of rear-end collisions, and it is even more effective when equipped with an auto brake system[2]. In addition, with the development of autonomous vehicles, less human involvement will be required to control the vehicle, making a take-over request (TOR) warning system a necessity when the autonomous vehicle fails to regulate itself. The design of ADAS and TOR warning system is now an important piece of technology for drivers to avoid imminent accidents within a few seconds. The exemplar experiment used a vibrating toolkit along with a driving simulation platform to investigate which location would generate the best outcome when a vibrotactile warning system has been used as a potential ADAS and TOR warning system.

Categorized by perceptual channels, there are generally three types of warning systems, that is visual, auditory, and tactile. Each warning system has its own merits and limitations. When visual warning systems are in use, drivers can suffer from visual overload[3], impairing driving performances due to inattentional blindness[4,5]. Although an auditory warning system does not influence drivers' visual field, its effectiveness greatly depends on the surroundings such as background music and other noises in the driving environment[6,7]. Thus, situations that contain other external auditory information or significant noise may lead to inattentional deafness[8,9], reducing the effectiveness of an auditory warning system. In comparison, tactile warning systems do not compete with drivers' visual or auditory processing. By sending vibrotactile warnings to drivers, tactile warning systems overcome the limitations of visual and auditory warning systems.

Previous studies showed that tactile warnings can benefit drivers by shortening their brake response time. It was also found that tactile warning systems yield a more effective result over visual[10,11] and auditory[12–14] warning systems in certain situations. However, limited research has focused on investigating the optimal location for placing a tactile warning device. According to sensory cortex hypothesis[15] and sensory distance hypothesis[16], the exemplar study chose the finger, wrist, and temple areas as the experimental locations for placing a tactile warning device. With the introduced protocol, the frequency and delivering time of a vibrating warning, and intervals between vibrations of the vibrating toolkit, can be configured to fit the experimental requirements. This vibrating toolkit consisted of a master chip, a voltage regulator chip, a multiplexer, a USB to TTL converter, a MOS tube, and a Bluetooth module. The number of vibrating modules can also vary according to researchers' needs, with up to four modules vibrating at the same time. When implementing the vibrating toolkit in the driving-related experiments, it can be configured to fit the experimental settings as well as synchronized with driving performance data by revising the codes of the driving simulation.

While for researchers, conducting a driving experiment on a virtual platform is more feasible than in the real world due to the risk and cost involved. For instance, collecting performance indicators can be difficult, and it is hard to control the environmental factors involved when experiments are being conducted in the real-world. As a result, many studies have used fixed-base driving simulators running on PCs in recent years as an alternative to conduct on-road driving studies. After learning, developing, and researching for over 11 years in the driving research community, we established a driving simulation platform with a real car that consists of an open-source driving simulation software and a hardware kit, including a steering wheel and gearbox, three pedals, and an 80-inch projection screen with a resolution of 3840 x 2160.

There are two major advantages of using the presented driving simulation platform. One advantage of this platform is that it uses an open-source software. Using the user-friendly open-source platform, researchers can customize the simulation and vibrating toolkit for their unique research needs with basic programming and simple modifications. By revising the codes, researchers can create driving simulations that provide relative fidelity to the reality with plenty of options available on car types, road types, resistance of the steering wheel, lateral and longitudinal wind turbulence, time and brake event application program interfaces (APIs) for external software synchronization, and implementation of the behavioral paradigms such as car-following task and N-Back task. Although conducting driving-related research in a driving simulator cannot fully replicate driving in the real world, data collected through a driving simulator is reasonable and has been widely adopted by researchers[17,18].

Another advantage of the proposed driving simulator is its low cost. As mentioned previously, the introduced driving simulation software is an open-source software that is available to users free of charge. In addition to the software, the total cost of the whole hardware set up was approximately $3,000. In contrast, typical high-fidelity commercial driving simulators (fixed based) usually cost around $10,000 to $100,000. With its highly affordable price, this driving simulator can be a popular choice not only for academic research purposes, but also for conducting driving classes[19] and for demonstration of driving-related technologies[20,21].

The driving simulation software and vibrating toolkit in the proposed method have already been used in previous studies by our researchers[22–29]. This self-developed vibrating toolkit following the ISO standard[30] can be applied in different fields[31,32] by adjusting the vibration frequency and intensity. It is important to note that a newer version of the vibrating toolkit has been developed and is introduced in the following protocol. Instead of adjusting the vibration frequency using an adjustable voltage adapter, the newer version is equipped with five different vibration frequencies and can be easier adjusted using the codes provided in **Supplemental Coding File 1**. Moreover, the presented driving simulator provides researchers with a safe, inexpensive, and effective way to investigate various kinds of driving-related research. Thus, this protocol is suitable for research laboratories that have a limited budget and have a strong need to customize experimental driving environments.

PROTOCOL:

NOTE: All methods described here have been approved by the Institutional Review Board (IRB) of Tsinghua University and informed consent was obtained from all participants.

1. Participants

1.1 Conduct a power analysis to calculate the required number of participants for recruitment according to the experimental design to achieve statistical power.

1.2 Balance the gender of the participants during recruitment as much as possible.

1.3 Ensure that participants have a valid driving license and at least one year of driving experience.

1.4 Ensure that the participants have normal or corrected to normal vision using the vision chart.

1.5 Ensure that the participants did not consume alcohol or drugs that affect driving abilities within 24 h before the experiment[33].

2. Driving simulation software configuration

2.1. Enter the folder of the driving simulation software, followed by the **Runtime** folder and the **Config** folder. Then, open the “expconfig.txt” file (i.e., the file path should be “\torcs-1.3.3-Exp-2018-10-25\torcs-1.3.3\runtime\config\”).

2.2. Determine whether to apply any configuration or to proceed with the driving simulation using the default settings without any configuration fresh out of the box by referring to the experimental design. **Table 1** shows a detailed description of the default configurations of all the available options.

[Place **Table 1** here]

2.2.1. Proceed to Section 3 of the protocol if no changes are to be made.

2.3. Configure the settings on how to end the experiment based on the decided control variable of the experimental design.

2.3.1. Decide on whether to use clock time as a trigger to end the experiment with the "endExpByTime =" option using either True or False as the choice of options. Set this option to **False** to replicate the exemplar study.

2.3.2. Select whether to end the experiment with time traveled as a trigger with the "endExpAfterMinute =" option by inputting the number of minutes in the format with one decimal place. The time traveled can be decided entirely by the researchers. Input **12** to replicate the exemplar study.

2.3.3. Set on whether to end the experiment with distance traveled as a trigger with the "endExpByDist =" option using either True or False as the choice of options. Note that when both "endExpByTime =" and "endExpByDist =" options are set to True, the experiment will end with the condition which is met first. Set this option to **True** to replicate the exemplar study.

2.3.4. Use the "endExpAfterMeter =" option to set the distance traveled from the starting line in meters in the format with one decimal place. The distance traveled can be decided entirely by the researchers. Input **10000.0** to replicate the exemplar study.

2.4. Configure the wind settings for the simulated driving environment according to the wind speed[34,35] designed for the virtual environment and the cognitive load[36] to be initiated into the experiment.

2.4.1. Set on whether to enable frontal wind with random interval and duration with the "enableRandomFrontalWind =" option using either True or False as the choice of options. Set this option to **True** to replicate the exemplar study.

2.4.2. Define the minimum and maximum frontal wind interval with the "frontalWindIntervalMin =" and "frontalWindIntervalMax =" options by inputting the number of seconds in the format with one decimal place, respectively. Use the default setting (i.e., 3.0 and 13.0, respectively) to replicate the exemplar study.

2.4.3. Define the minimum and maximum frontal wind duration with the "frontalWindDurationMin =" and "frontalWindDurationMax =" options by inputting the number of seconds in the format with one decimal place, respectively. Use the default setting (i.e., 2.0 and 3.0, respectively) to replicate the exemplar study.

2.4.4. Define the minimum and maximum frontal wind force with the "frontalWindForceMin =" and "frontalWindForceMax =" options by indicating the amount of force in newton, respectively. Use the default setting (i.e., 500.0 and 1,000.0, respectively) to replicate the exemplar study.

2.4.5. Choose whether to enable lateral wind with random interval and duration with the "enableRandomLateralWind =" option using either True or False as the choice of options. Set to **True** to replicate the exemplar study.

2.4.6. Define the minimum and maximum lateral wind force interval with the "lateralWindIntervalMin =" and "lateralWindIntervalMax =" options by inputting the number of seconds in the format with one decimal place, respectively. Use the default setting (i.e., 3.0 and 8.0, respectively) to replicate the exemplar study.

2.4.7. Define the minimum and maximum lateral wind duration with the "lateralWindDurationMin =" and "lateralWindDurationMax =" options by inputting the number of seconds in the format with one decimal place, respectively. Use the default setting (i.e., 2.0 and 3.0, respectively) to replicate the exemplar study.

2.4.8. Define the minimum and maximum lateral wind force with the "lateralWindForceMin =" and "lateralWindForceMax =" options by indicating the amount of force in newton, respectively. Use the default setting (i.e., 1,000.0 and 2,000.0, respectively) to replicate the exemplar study.

2.5. Configure the settings for the simulated car-following task according to the experimental design and needs[35].

2.5.1. Set the constant speed of the lead vehicle in miles per hour with one decimal place using the "leadCarConstantSpeedMPH =" option. Input **40** to replicate the exemplar study.

2.5.2. Define the distance in meters with one decimal place between the lead vehicle and driver's vehicle to trigger the lead vehicle to start waiting for the driver's vehicle to catch up, or to resume driving, with the "leadDistToStartWaiting =" and " leadDistToStopWaiting =" options, respectively. Use the default setting (i.e., 100.0 and 80.0, respectively) to replicate the exemplar study.

2.5.3. Set the maximum and minimum random time interval of the lead vehicle brake events with the options "leadCarBrakeIntervalTimeMin =" and "leadCarBrakeIntervalTimeMax =" by inputting the number of seconds in the format with one decimal place (e.g., 30.0 and 60.0), respectively. Use the default setting (i.e., 30.0 and 60.0 respectively) to replicate the exemplar study.

2.5.4. Define the brake event duration with the "leadCarBrakeEventDuration =" option by entering the number of seconds in the format with one decimal place. Use the default setting (i.e., 5.0) to replicate the exemplar study.

2.6. Configure the settings for random short message notification sound according to the experimental design and needs.

2.6.1. Decide on whether to enable short message service (SMS) notification sounds play with random intervals with True or False as the choice of options for the “enableRandomSMSSound =” option. Set the option to False to replicate the exemplar study.

2.6.2. Define the minimum and maximum time interval from the onset of the first SMS notification to the onset of the second SMS notification using the “randSMSIntervalMin =” and “randSMSIntervalMax =” options, by indicating the number of seconds in the format with one decimal place (e.g., 5.0 and 10.0) respectively.

2.7. Configure the settings for the simulated N-back task[37] according to the experimental design and needs.

2.7.1. Set N-back number sounds to play with random intervals with True or False as the choice of options for the “enableRandomNbackSound =” option. Set the option to **False** to replicate the exemplar study.

2.7.2. Define the minimum and maximum time interval from the offset of the first sound to the onset of the second sound using the “randNbackIntervalMin =” and “randNbackIntervalMax =” options to indicate the number of seconds in the format with one decimal place (e.g., 5.0 and 10.0), respectively.

2.8. Configure the User Datagram Protocol (UDP) settings if a UDP data transfer is required for the experiment.

2.8.1. Decide on whether to enable the UDP for data transfer by allowing time stamp data synchronization to a specific local network IP address via the “enableUDPSendData =” option by using True or False as the choice of options. Enable this option to replicate the exemplar study.

2.8.2. Select whether to enable the UDP for data transfer to a specific IP address for an advertisement study via the “enableUDPSendDataAdStudy =” option using True or False as the choice of options. It is also be reminded that this option is conflicted with the “enableUDPSendData =” and both options cannot be set to True at the same time. Set the option to **False** to replicate the exemplar study.

2.8.3. Define the IP address for the UDP transfer by specifying each section of the IP address using “UDPTargetIPa1 =”, “UDPTargetIPa2 =”, “UDPTargetIPa3 =”, and “UDPTargetIPa4 =”.

2.8.4. Indicate the target port number under “UDPTargetPort =”.

2.8.5. Set the frequency for the data to be sent under "UDPcycleNumber =" with any integer greater than or equal to "1" cycle in which, each cycle is 20 ms.

2.9. Configure the UDP queuing network (QN) model[38] connection with reference to the experimental design and needs.

2.9.1. Set whether or not to enable the QN-Java model drive simulation in which, the UDP server and client are sharing the same computer, with the "enableUDPQNConnection =" option using True or False as the choice of options. Disable this option to replicate the exemplar study.

2.9.2. Indicate the number from the UDP QN port to the simulation port under the "UDPQNtoTORCSPort =" option.

2.9.3. Indicate the number from the simulation port to the UDP QN port under the "UDPTORCStoQNPort =" option.

2.10. Configure whether to connect to a website for braking signals according to the experimental design under the "leadCarBrakingByWebCommand =" option using True or False as the choice of options. Please note that when this option is set to True, the "endExpByTime =" and "endExpAfterMinute =" will stop working. Set the option to **False** to replicate the exemplar study.

2.11. Set whether to enable the simulated car-following task in training mode with the "enableCarFollowingTraining =" using True or False as the choice of options.

2.11.1. Define the interval from the last warning sound onset to the next warning sound onset of the training with the "carFollowingTrainingWarningInterval =" option by indicating the number of seconds with one decimal place (e.g., 2.0).

2.12. Save the file upon completing the configuration.

3. Driving simulator preparation

3.1. Connect the steering wheel and screen (80-inch LCD with a screen ratio of 16:9, a resolution of 3840 × 2160 pixels, and 60 Hz screen refresh frequency) to the computer. **Figure 1** shows the completed setup of the driving simulator.

[Place **Figure 1** here]

3.2. Set the screen resolution under **Options | Display**, to match the screen size upon starting the driving simulation software.

3.3. Enter the **Configure** page to select a player and follow the instructions provided by the software to calibrate the steering wheel, accelerator, and brake pedal. These include turning the steering wheel and pressing the accelerator and brake pedal as instructed.

4. Vibrating toolkit configuration and preparation

4.1. Connect the vibrating toolkit to the power supply. Each of the four modules has a dimension of 67 x 57 x 29 mm**. Figure 2** shows an image of the vibrating toolkit.

[Place **Figure 2** here]

4.2. Switch on the vibrating toolkit and connect the toolkit to the computer via Bluetooth.

4.3. Define the vibrating frequency to be used for the experiment upon completing a pilot skin sensitivity test or according to experimental needs.

4.4. Set the vibrating frequency to 70 Hz[39–41] using the codes provided as **Supplemental Coding File 1**. A total of five frequency levels (i.e., 14Hz, 28Hz, 42Hz, 56Hz, 70Hz) are currently available with each vibration stimulation that lasts for 0.5 s by default.

4.5. Use the codes provided as **Supplemental Coding File 1** to synchronize the brake events from the driving simulation software and vibrating toolkit. **Figure 3** shows a labeled screenshot of the codes to be revised as a reference.

[Place **Figure 3** here]

5. Conducting the experiment

5.1. Instruct the participants to read and sign the informed consent form that introduces the experimental process and declare that the study is to evaluate driving performance upon arrival at the laboratory.

5.2. Assist the participants to adjust the seat distance to the pedal and set the backrest to a comfortable position manually.

5.3. Teach the participants how to operate the simulator, including the steering wheel, brake pedal, and accelerator pedal.

5.4. Instruct the participants to drive as they would in the real world, following the car in front of them and keeping a two-second headway behind it. **Figure 4** shows the road map used for the driving simulation.

[Place **Figure 4** here]

5.5. Inform the participants to brake as soon as possible whenever the front vehicle brakes, even if the scenario does not require a brake response. The rear light of the front vehicle will turn on as per real-world driving to indicate a brake event.

5.6. Provide participants with a 5 min practice trial to learn to maintain a two-second headway distance behind the front vehicle. The practice trial includes a set of 5 random brakes.

5.6.1. During the practice trial, if the participant is less than 1.5 s behind the front vehicle, the driving simulation software will play a prompt with a female voice "too close, please slow down".

5.6.2. If the participant is between 2.25 to 2.5 s behind the front vehicle, the driving simulation software will play a prompt with a female voice "too far, please speed up".

5.6.3. Do not include data from the practice trial for the analysis.

5.7. Let the participants know that the study can be stopped without any penalty by notifying the experimenters at any time, if necessary.

5.8. Begin the formal experiment once the participants have completed the practice session and can maintain a stable following distance.

5.9. Start the formal experimental session, which consists of a total of four blocks (i.e., finger, wrist, temple, and no warning) with 13 random braking events in each block, resulting in a total of 52 experimental trials. The order of conditions is counterbalanced with the Latin square design. No voice prompt is provided in the formal trial.

5.10. Assist the participants to put on the vibrating toolkit using medical tape before each block of trials according to the conditions assigned. The vibrating toolkit (if worn) warns the participants to brake when the front vehicle is braking. The taillights of the front vehicle are illuminated every time the front vehicle brakes.

5.11. Ensure that the participants are given 2 min rest upon completion of each block to reduce carryover effects.

5.12. Ask the participants for their preferred location for the vibrating toolkit and the perceived vibration intensity with a 7-point Likert scale upon completion of all trials. The usage rate of each daily wearable accessories (i.e., watch, glasses, earphones, and ring) is also recorded. In the preference scale for the location of the vibrating toolkit, "1" represents "least favorite" and "7" represents "most favorite", while in the vibration intensity scale "1" represents "weak feeling" and "7" represents "strong feeling".

6. Data analysis

6.1. Collect the driving behavior data of the participants at 50 Hz using the driving simulation software, including the brake response time, vehicle speed, steering wheel reversal rate, lane position (SDLP), and headway distance, etc.

6.2. Perform data analysis of the driver's performance.

6.2.1. Conduct an outlier analysis using the normal distribution with cut-off as three standard deviations from the mean to determine what data to be included for further analysis.

6.2.2. Calculate the brake response time by subtracting the time when the participant vehicle brakes (i.e., a minimum reduction of 1% of the brake pedal[36,42]) from the time when the front vehicle starts to brake.

6.2.3. Label the data as "no brake response" if the brake response time is larger than or equal to 5 s (i.e., a failure to brake within 5 s after the front vehicle brakes).

6.2.4. Divide the number of successful brakes by the total number of brakes performed by the front vehicle to calculate the brake response rate.

6.2.5. Average all the values of each participant to obtain the mean brake response rate and brake response time of each condition and compute the standard deviation on those values for further analyses.

REPRESENTATIVE RESULTS:

The exemplar study reported in this paper combines the car-following task using the driving simulator and vibrating toolkit, which has also been published previously in an academic journal[22]. It is noteworthy that the older version of the vibrating toolkit was used when conducting the exemplar study, while a new version of the vibrating toolkit was introduced in the above protocol. The study was a within-subject design experiment with vibrating warning location as the only factor: finger, wrist, temple warning condition, and driving-only condition as a control. Each condition consisted of 13 random brake events, resulting in a total of 52 experimental trials. The order of conditions was counterbalanced with the Latin square design and all participants underwent all four conditions during the experiment

The exemplar study also included a survey that recorded participants' preferred location for the vibrating toolkit and the perceived vibration intensity of each location (i.e., finger, wrist, and temple) with a 7-point Likert scale upon completion of all trials. The usage rate of each daily wearable accessories (i.e., watch, glasses, earphones, and ring) was also recorded.

Since there was no previous meta-analysis as a reference for determining sample size for the exemplar study, upon completing the power analysis with the median effect size (η_p^2 = 0.06)[43,44], 23 participants were required to reach 80% power and 30 participants were required to reach 90% power. A total of 28 participants with normal or corrected-to-normal vision, a valid driving license, and driving experience for over a year were recruited from the neighborhood community of Tsinghua University. Four participants were excluded from the data analysis with one participant withdrawing from the study, and three participants failed to follow the experimental instruction. An outlier analysis has also been conducted using a normal distribution with cut-off as three standard deviations from the mean. The remaining 24 participants (17 males and 7 females) that were included for data analysis have a mean age of 23.88 years with a standard deviation of 6.62 years, fulfilling the minimum required sample size (i.e., 23 participants). Instructions for the experiment were given to each participant and a signed consent form was obtained from all the participants upon their arrival to the laboratory. All the participants were aware of the purpose of this experiment and reported no concern after the completion of the practice trials before the actual experiment began.

The driving simulation experiment took place in a bright environment, with the designed simulated scene similar to driving on the highway on a clear day. **Figure 5** showed a screenshot of the simulated environment that was used in the exemplar study. It was set to only enable the simulated car-following task with each trial lasting 12 min. The lead vehicle was set to move forward at an average speed of 40 mph (60.4 km/h), and the time interval for the random brakes of the front vehicle was set as 30 to 60 s with each brake event duration of 5 s. The average acceleration of the front vehicle was 0.6 m/s^2 which went by the default settings[35].

[Place **Figure 5** here]

Both the frontal and lateral wind settings were enabled and set to remain as the default settings. The minimum and maximum frontal wind interval, wind duration, and frontal wind force were 3 s and 13 s, 2 s and 3 s, and 500 N and 1,000 N, respectively[36]. The minimum and maximum lateral wind interval, wind duration, and lateral wind force were 3 s and 8 s, 2 s and 3 s, and 1,000 N and 2,000 N, respectively[36].

A one-way repeated measures analysis of variance (one-way ANOVA) on brake response rate showed that the effect of the four task conditions was significant, $F_{(3,69)} = 3.08$, $p = 0.049$, $\eta_p^2 = 0.31$. Post hoc analyses using pairwise Bonferroni-corrected *t*-tests indicated no significant pair-wise comparison difference (as illustrated in **Figure 6**).

[Place **Figure 6** here]

The analysis of the brake response time using one-way ANOVA generated significant results, $F_{(3,69)} = 4.76$, $p < 0.01$, $\eta_p^2 = 0.17$. Upon completion of the pairwise Bonferroni-corrected *t*-tests, the recorded brake response time was significantly shorter when the task was performed with the vibrating toolkit located on participants' finger (M = 1.04 s, SD = 0.35 s) and wrist (M = 1.00 s, SD = 0.33 s) in comparison to the driving-only condition (M = 1.29 s, SD = 0.36 s) with $p = 0.004$ and $p = 0.008$, respectively. However, no significant result was found when the participants were driving with the vibrating toolkit located on the temple area in comparison to the driving-only condition (*M* = 1.08 s, *SD* = 0.50 s), $p = 0.22$. With reference to **Figure 7**, the results pointed out that the application of tactile warnings could facilitate drivers' reactions toward upcoming hazards while driving, especially when the warning device was located on the drivers' finger or wrist.

[Place **Figure 7** here]

Analysis of the preference of the warning location (i.e., finger, wrist, and temple) showed a significant effect, $F_{(2,46)} = 7.05$, $p < 0.01$, $\eta_p^2 = 0.23$. Post-hoc pairwise Bonferroni-corrected *t*-tests were, therefore, also conducted. The results indicated a significant preference for the finger (M = 4.88, SD = 1.75) and wrist (M = 4.83, SD = 1.31) than the temple area (M = 3.13, SD = 2.05) where $p = 0.03$ and $p = 0.02$ respectively. There was no significant difference between the finger and wrist locations ($p = 1.0$). Moreover, a significant effect for participants' perceived intensity of vibration for the three locations was found, $F_{(2,46)} = 7.37$, $p < 0.01$, $\eta_p^2 = 0.24$. Participants perceived the highest level of vibration in the temple area. However, further analysis showed that the perceived level of vibration was only significantly lower than the temple area (M = 5.75, SD = 1.42) when the vibrating toolkit was located on the wrist (M = 4.17, SD = 0.92), $p < 0.01$. When the vibrating toolkit was located on the finger (M = 4.71, SD = 1.63), it showed no significant difference with neither the temple area ($p = 0.09$) nor the wrist ($p = 0.56$). Interestingly, as shown in **Figure 8**, while participants perceived the highest level of vibration in the temple area, the preference for the vibrating toolkit to be located at the temple area was the lowest.

[Place **Figure 8** here]

Lastly, analysis on usage of daily wearable accessories (i.e., watch, glasses, earphones, and ring) among participants reflected that over 50% of the participants wore a watch in their everyday life, suggesting the feasibility of adopting wearable vibrotactile devices as a warning system in real life (as illustrated in **Figure 9**).

[Place **Figure 9** here]

With multiple smart wearable accessories such as smart rings, smartwatches, and smart glasses now available in the market, the application of tactile warnings on wearable accessories is right around the corner. The current research confirmed the effectiveness of wearable vibrotactile devices as a valuable warning system in facilitating drivers' emergent brake response time. The average brake response time was reduced by 297 ms, 251 ms, and 210 ms for wearing the vibrotactile devices on the wrist, finger, and temple, respectively, in comparison to not wearing a tactile warning device. The current results showed that vibrating warnings delivered on the wrist produced the fastest brake response time, resulting in a 23% decline in brake response time compared to not receiving any tactile warning. However, other factors such as gender[46], age[46,47], and individual differences[48,49] in tactile sensibility can also affect the effectiveness of tactile warnings. Further investigation that includes more factors is therefore required to determine the optimal location for placing the tactile warning devices. The findings not only indicated the value of developing wearable vibrotactile devices, but also proposed a potential alternative form of tactile forward collision warning system that is less expensive, more feasible, and highly operative in comparison to other tactile warning systems such as vibration seat[10] or vibration vest[50].

FIGURE AND TABLE LEGENDS:

Table 1: List of default settings for the driving simulation software. A list of the default values of all the associated configurable options of the driving simulation software along with a detailed description of each option.

Figure 1: An image of the driving simulator. The driving simulator consisted of a steering wheel and gearbox, three pedals, a vehicle, and an 80-inch projection screen with a resolution of 3840 × 2160.

Figure 2: Images of the vibrating toolkit. The vibrating toolkit consisted of four individual modules that can be activated separately. Each module has a dimension of 67 x 57 x 29 mm.

Figure 3: A labeled screenshot of the codes in Supplemental Coding File 1. The labeled screenshot of codes provides an easier reference for the vibrating toolkit configuration and preparation. These codes are used to set the vibration frequency of the toolkit, and to synchronize the brake events in the driving simulation software and vibrating toolkit to generate vibrating warnings.

Figure 4: Road map used for driving simulation. The road used is a one-way road with four curves (maximum length 15,000 meters), three lanes, and with no traffic lights. The driving simulator software offers other road design options such as options to include road signs or billboards. An EEG-compatible version is also available. All these parameters can be adjusted, if necessary.

Figure 5: A screenshot of the driving simulation environment. The driving simulation experiment took place in a bright environment. The rear light of the front vehicle lights up when the front vehicle brakes. The bottom of the screen shows the drivers their gear and speed of their vehicle.

Figure 6: Brake response rate. Mean brake response rate among participants under each of the four conditions (i.e., finger, wrist, temple, and driving-only). Error bars represent standard deviations. This figure has been modified from Zhu et al.[22].

Figure 7: Brake response time. Mean brake response time in seconds among participants under each of the four conditions (i.e., finger, wrist, temple, and driving-only). Error bars represent standard deviations. This figure has been modified from Zhu et al.[22].

Figure 8: Subjective ratings on preference for warning locations and perceived intensity of vibration among participants. Mean preferred warning location on a scale from 1 (least favorite) to 7 (most favorite) against mean perceived intensity of vibration on a scale from 1 (weak feeling) to 7 (strong feeling) for finger, wrist, and temple area of all participants. Error bars represent standard deviations. This figure has been modified from Zhu et al.[22].

Figure 9: Usage of daily wearable accessories among participants. Mean percentage of daily usage for each of the four wearable accessories (i.e., watches, glasses, earphones, and rings). This figure has been modified from Zhu et al.[22].

DISCUSSION:

The driving simulation systems and vibrating toolkits reasonably mimicked the application of potential wearable vibrotactile devices in real life, providing an effective technique in investigating driving-related research. With the use of this technology, a safe experimental environment with high configurability and affordability is now available for conducting research that is comparable to real-world driving.

There are several steps that require more attention. Firstly, during the configuration process using the "expconfig.txt", researchers should ensure the training mode has been set to False before conducting the actual experiment to turn off the audio prompt which is designed for practice driving. Secondly, it is important to note that during the calibration process of the steering wheel, researchers should ensure the amplitude towards both directions of the steering wheel are balanced and that, both brake and throttle pedals are floored completely. Thirdly, researchers should also examine whether the vibrating toolkit has been placed on the participant firmly with medical tapes before the driving simulation begins.

To cope with concerns regarding the external validity of driving simulation as much as possible, the introduced driving simulation software provides a wide range of options for researchers to configure an ideal driving environment. For instance, modification of frontal and lateral wind intensity can be adjusted to replicate the wind resistance that drivers would experience on a highway in real life. On top of the available configurations provided on the "expconfig.txt" document, researchers can also design their own road using the open-source simulation software to construct an environment that mimics the real-life scenario. Researchers may also show concern regarding the possible wireless vibrating toolkit onset delay, which could affect the measured response time. Yet, typical operating characteristics of the vibration motors only included a lag time of 16 ms and a rise time of 28 ms. In contrast, the typical response time of drivers is between 0.5 s and 1.5 s[51]. Therefore, the effect of the onset delay is relatively small and can be neglected. Furthermore, whenever researchers experience any difficulties during the configuration and preparation process, restarting the whole system and re-calibrating the steering wheel, accelerator, and brake pedal are recommended. If the UDP option has been enabled but no data has been received by the other devices, ensure that the other devices have been set up as a UDP Server instead of a UDP Client to facilitate data transfer.

Nevertheless, the proposed method has its limitations. In a real-life setting, different driving abilities and skills will be required on multiple aspects, including relative demands of physical, cognitive, behavioral, and perceptual abilities, etc. Depending on the contextual determinants, different degrees of demand are placed on the drivers' cognitive-perceptual skills. For instance, the level of abilities required for a driver to drive safely in a light traffic sunny weather will be less intensive in comparison to driving in a heavy traffic inclement weather environment[52]. The driving simulator cannot fully simulate the complex real-world driving condition, yet it can provide a more controlled environment that eliminates potential confounding variables that may contaminate the outcome of the experiment. Adjustment to the reported driving simulator can also be made depending on the experimental needs. Even so, an on-road study should still be conducted to increase the ecological validity of this line of research. In addition, due to its low-cost, the presented driving simulation platform does not consist of a motion platform, meaning that it is not able to provide horizontal and longitudinal travel experiences.

Corresponding to the exemplar experiment, while vibrations can be caused by external contexts such as driving on a patchy road, no vehicle vibration was provided to the participants during the driving simulation. However, the proposed method does allow us to control the velocity and brake interval of the front car in the car-following task in a laboratory setting, providing us the ability to control the driving difficulty for the participants. In addition, a Simulation Sickness[53] Questionnaire (SSQ) has not been included in the experiment. Despite the missing consideration, the results were not being affected as the length of each trial was relatively short, and no participant has reported any symptom[53] of simulation sickness upon completion of each trial. This study also has an imbalance number of male and female participants. Future studies should ensure to exclude participants with simulation sickness[53] using the appropriate questionnaire[54], and aim to recruit an equal number of male and female participants to achieve a stronger conclusion of the results.

The exemplar study is a within-subject design car-following experiment with vibrating warning location as the only factor: finger, wrist, temple warning conditions, and driving-only control condition. In the future, we intend to conduct further testing on other locations such as the chest and behind the ear, providing alternative locations of wearable devices for forthcoming development. Further analysis can be conducted to investigate the variation of brake pedal deceleration across different conditions. Moreover, the results suggested that participants perceived the highest level of vibration at the temple area, yet, the area was also the least preferred location for placing the device. It would also be interesting to further investigate the effect on brake reaction by adjusting the vibration intensity on the temple area. Additionally, in comparison to visual and auditory warnings, vibrotactile warnings contain lesser information. More research should be conducted to investigate how vibrotactile warnings can be used to deliver complex information.

While this study only conducted an experiment on the effect of the wearable vibrating toolkit on forward collisions, this test design can also be applied in other behavioral research such as research on autonomous vehicles, lane departure warning systems, driver distraction study, and driving fatigue study. Although the driving simulation used in the exemplar study does not include a setup for autonomous driving, researchers may revise the codes with reference to other published materials[55,56] to achieve this goal. In addition, the vibrating toolkit can be used in multitasking driving research, including the detection response task (DRT)[57–59], surrogate reference task (SuRT)[37,58], and N-back task[37]. Researchers can customize vehicle behaviors and events according to their needs while using the driving simulator. Other research fields that use vibration warning devices to study human behavior such as biomedical engineering[31,32] could also benefit from the proposed method.

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The authors declared no financial disclosure or conflicts of interest.

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Figure 1

Click here to access/download;Figure;figure 1.psd

Figure 2

```
import socket
import bluetooth

devices = bluetooth.discover_devices(lookup_names=True)
serverAddress = '20:18:12:03:09:85'  # The MAC address of vibrating toolkit

port = 1
blue_s = bluetooth.BluetoothSocket(bluetooth.RFCOMM)
blue_s.connect((serverAddress, port))

s = socket.socket(socket.AF_INET, socket.SOCK_DGRAM)
s.bind(('127.0.0.1', 2222))  # The UDP target address. 127.0.0.1 by default

print(111)
vibr = b'11'  # '11' Means lead vehicle braking
before = b'0'  # '0' Means lead vehicle is driving normally
while True:
    data,addr = s.recvfrom(1024)
    leadCarStatus = data.split(b'leadCarStatus:')[-1]
    if (b'11' in leadCarStatus) and (b'11' not in before):
        blue_s.send('5')
        print("send 5 to bluetooth") # '1-5' Means different frequency
    before = leadCarStatus
    print('Braking')
```

Relevant codes for synchronizing the brake events from the driving simulation software and vibrating toolkit.

Codes for selecting the appropriate vibrating frequency. 1, 2, 3, 4, and 5 refer to 14 Hz, 28 Hz, 42 Hz, 56 Hz, and 70 Hz, respectively.

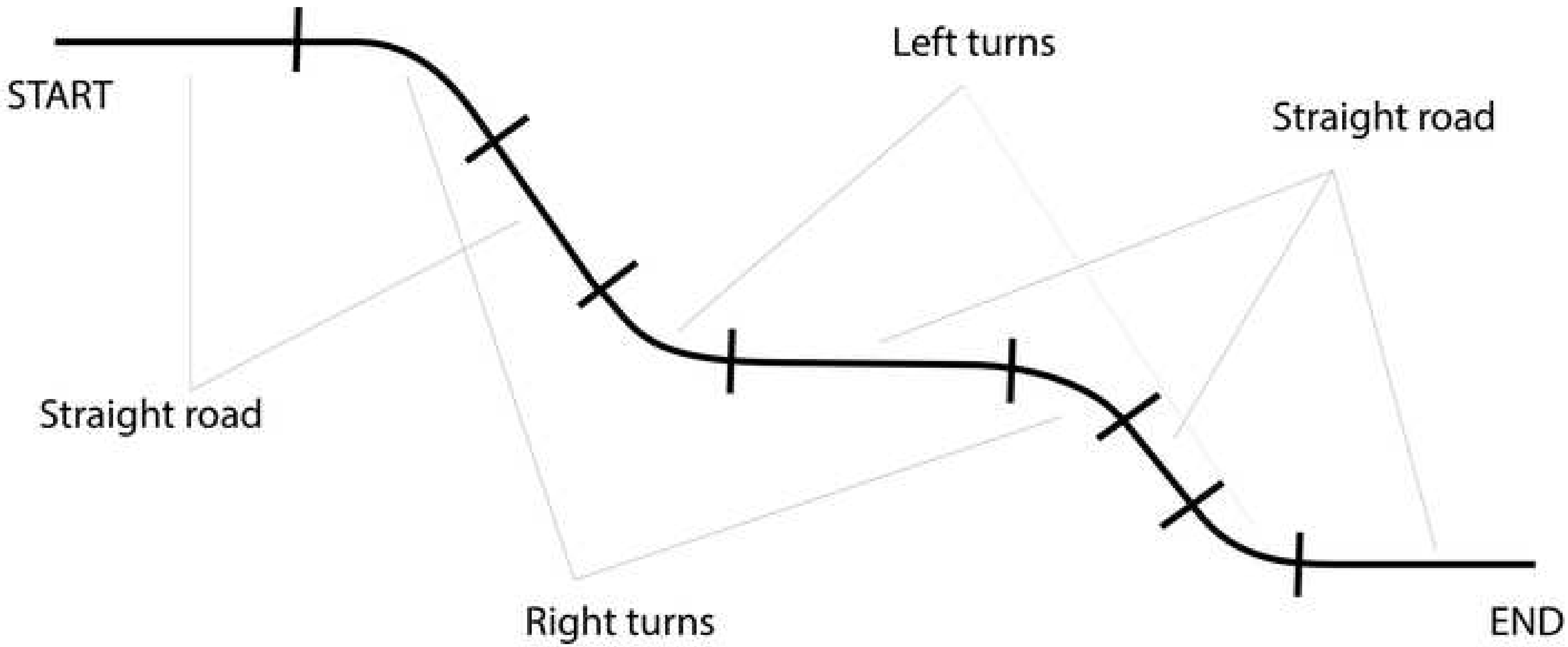

START
Straight road
Left turns
Straight road
Right turns
END

Figure 5

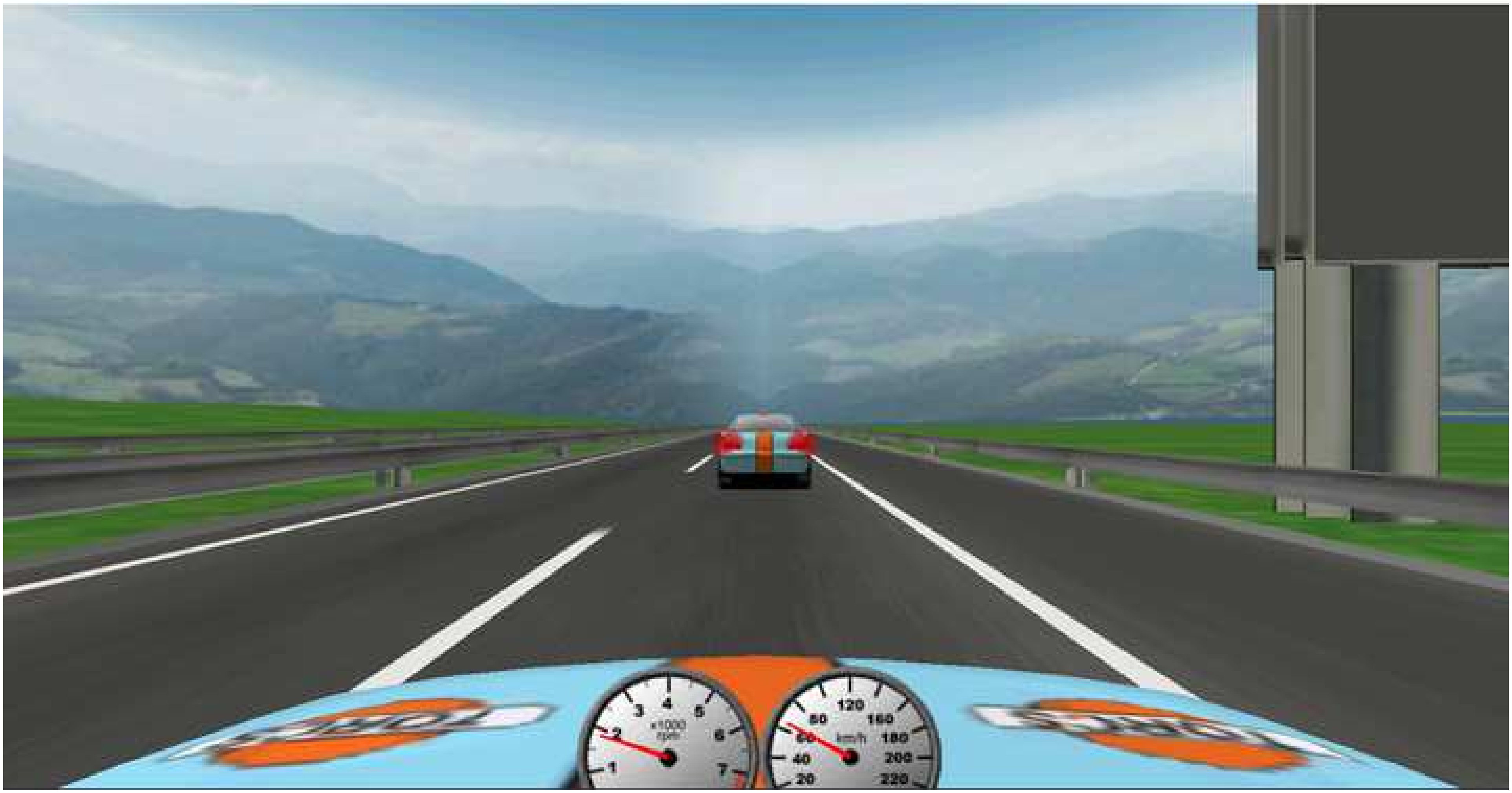


Figure 6

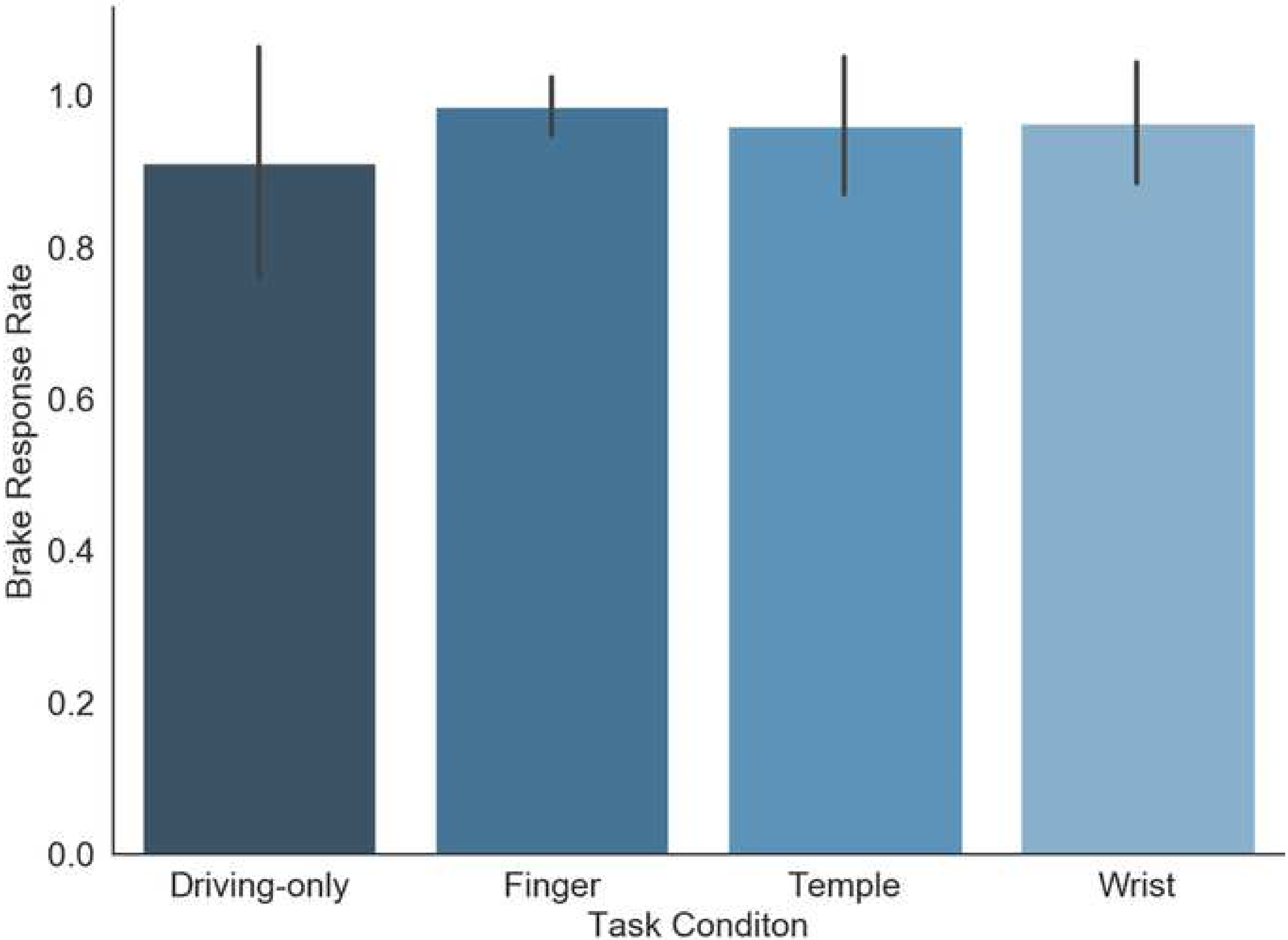
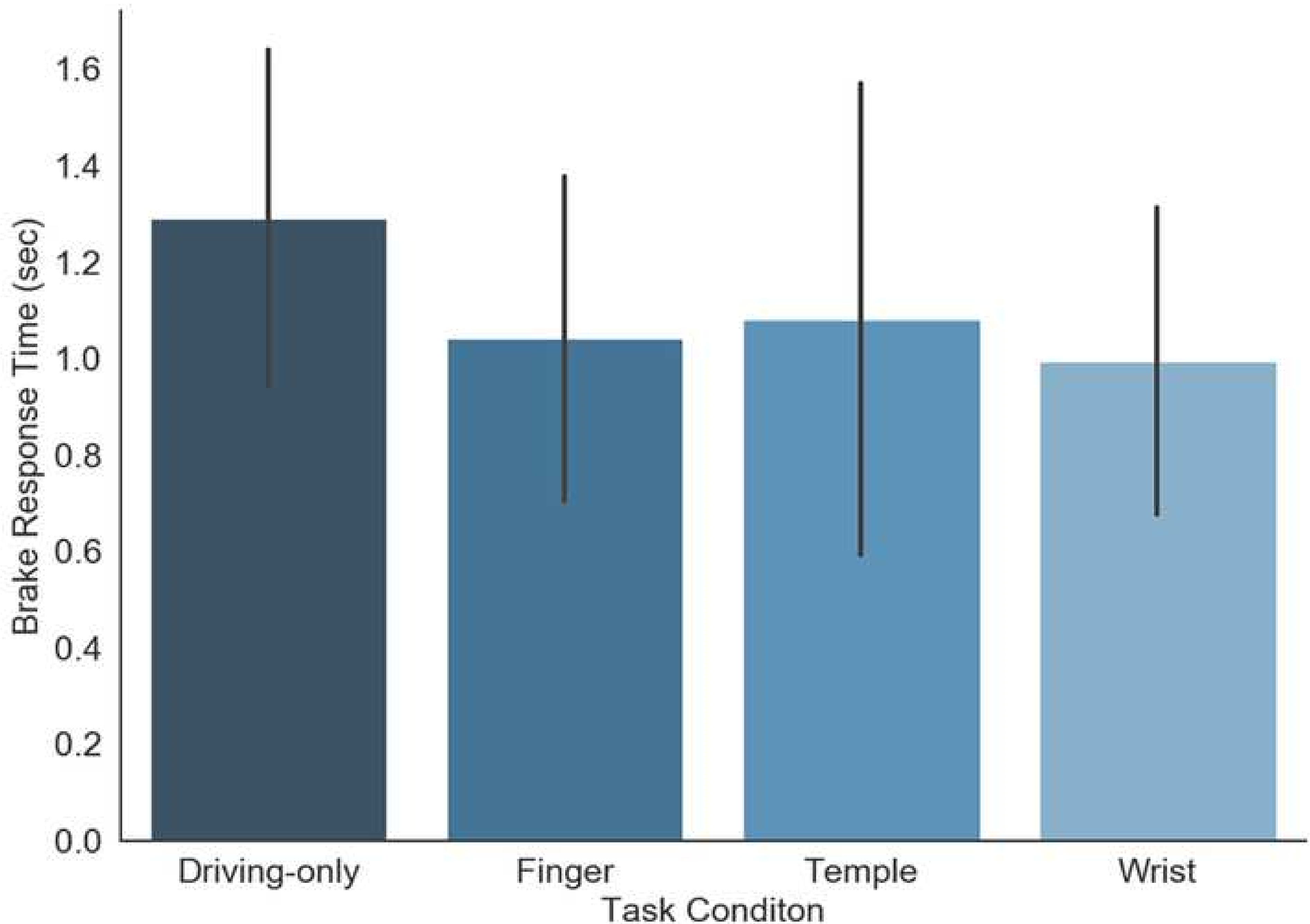
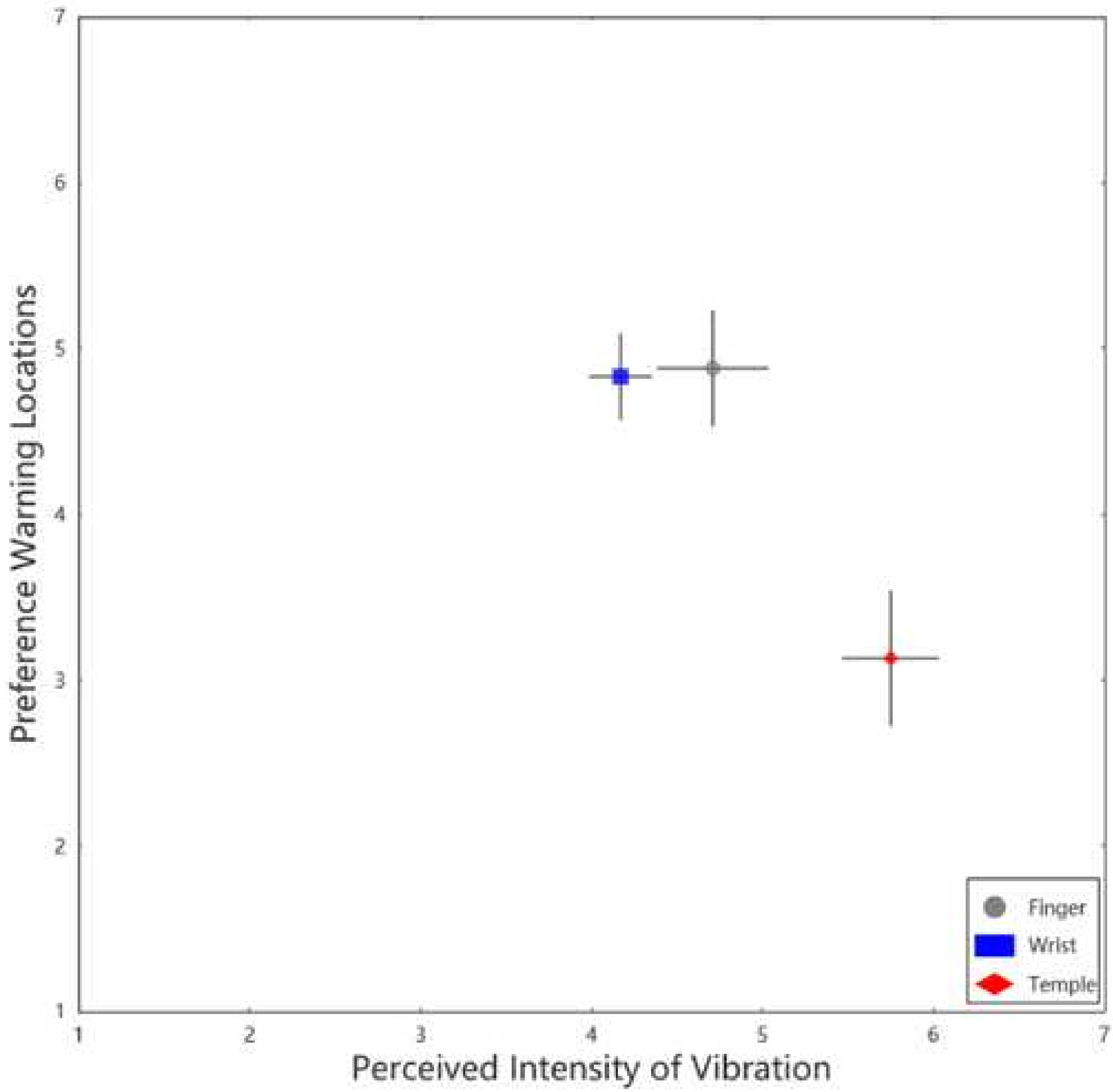

1.0
0.8
0.6
0.4
0.2
0.0
Brake Response Rate
Driving-only
Finger
Temple
Wrist
Task Conditon

Figure 7



1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Brake Response Time (sec)
Driving-only
Finger
Temple
Wrist
Task Conditon

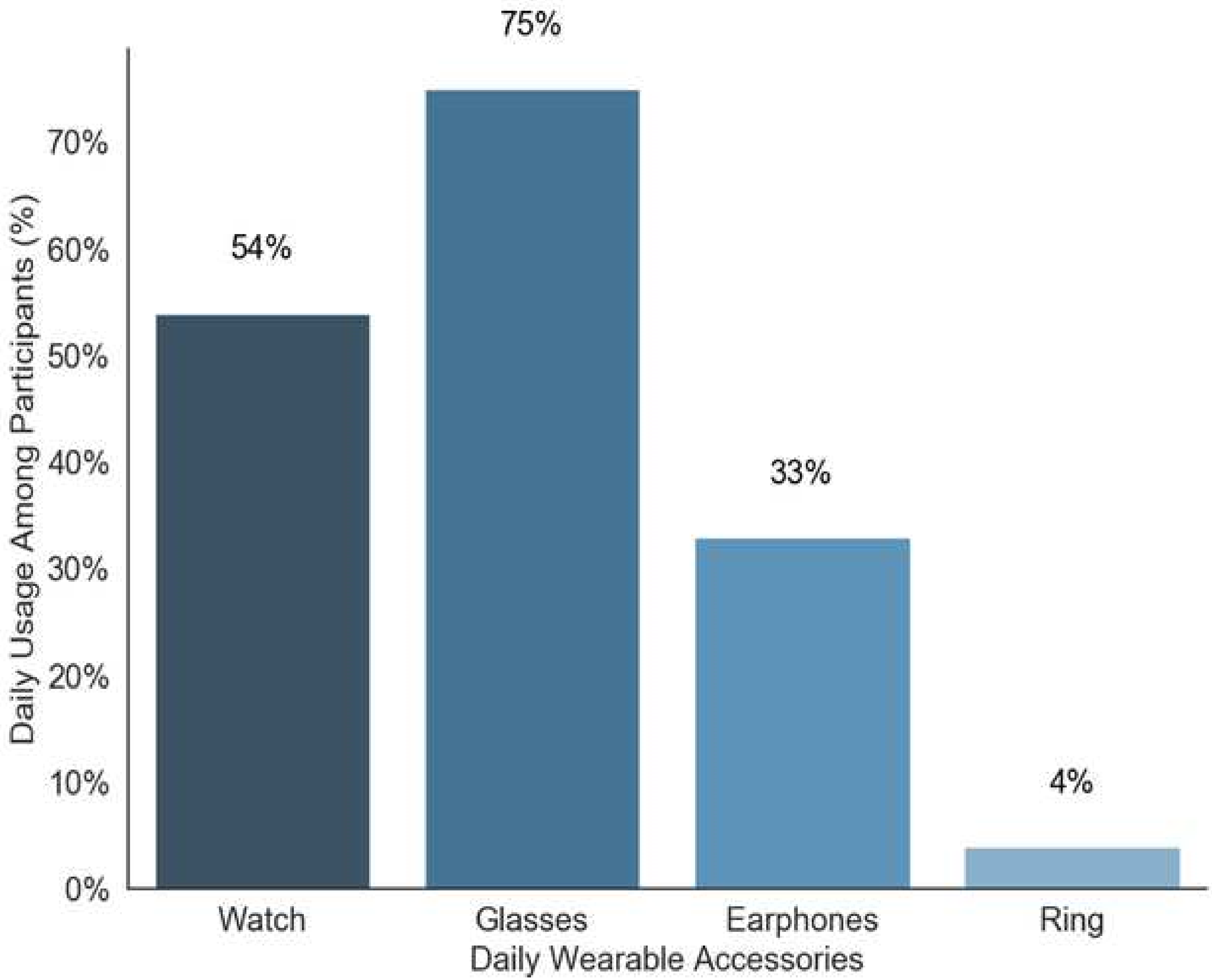
Figure 8



Preference Warning Locations
Perceived Intensity of Vibration
1
2
3
4
5
6
7
Finger
Wrist
Temple

Figure 9

Click here to access/download;Figure;figure 9.psd



Configurable Options
endExpByTime
endExpAfterMinute
endExpByDist
endExpAfterMeter
enableRandomFrontalWind
frontalWindIntervalMin
frontalWindIntervalMax
frontalWindDurationMin
frontalWindDurationMax
frontalWindForceMin
frontalWindForceMax
enableRandomLateralWind
lateralWindIntervalMin
lateralWindIntervalMax
lateralWindDurationMin
lateralWindDurationMax
lateralWindForceMin
lateralWindForceMax
leadCarConstantSpeedMPH
leadDistToStartWaiting
leadDistToStopWaiting
leadCarBrakeIntervalTimeMin
leadCarBrakeIntervalTimeMax
leadCarBrakeEventDuration
enableRandomSMSSound
randSMSIntervalMin
randSMSIntervalMax
enableRandomNbackSound
randNbackIntervalMin
randNbackIntervalMax
enableUDPSendData
enableUDPSendDataAdStudy

UDPTargetIPa1 UDPTargetIPa2 UDPTargetIPa3 UDPTargetIPa4
UDPTargetPort
UDPcycleNumber
enableUDPQNConnection
UDPQNtoTORCSPort
UDPTORCStoQNPort
leadCarBrakingByWebCommand
Far_Point_Time_Ahead
enableCarFollowingTraining
carFollowingTrainingWarningInterval

Descriptions	Default Settings
Whether or not to use clock time as a trigger to end experiment.	false
End the experiment after these minutes.	10.0
Whether or not to use driver's car travelled distance as a trigger to end experiment. When both time and distance triggers are used, end the experiment with the one occurs first.	false
End the experiment after these meters have been travelled from the start line.	5000.0
Whether to enable frontal wind, (i.e. a force pushing the car to the rear direction) with random interval and duration.	true
Minimum value (seconds) of the frontal wind interval.	3.0
Maximum value (seconds) of the frontal wind interval.	13.0
Minimum value (seconds) of the frontal wind duration.	2.0
Maximum value (seconds) of the frontal wind duration.	3.0
Minimum value (newton) of the frontal wind force.	500.0
Maximum value (newton) of the frontal wind force.	1000.0
Whether to enable lateral wind (i.e. a force pushing the car to the left or right direction) with random interval and duration.	true
Minimum value (seconds) of the lateral wind interval.	3.0
Maximum value (seconds) of the lateral wind interval.	8.0
Minimum value (seconds) of the lateral wind duration.	2.0
Maximum value (seconds) of the lateral wind duration.	3.0
Minimum value (newton) of the lateral wind force.	1000.0
Maximum value (newton) of the lateral wind force.	2000.0
Constant speed of the lead vehicle (mph).	40.0
The lead vehicle will start waiting for the driver's vehicle when the distance (meters) between the lead vehicle's tail and driver's vehicle's head is larger than the indicated number.	100.0
The lead car will wait until the distance (meters) ahead of the driver's car is smaller than this number.	80.0
Minimum random time interval (seconds) for the lead vehicle to brake.	30.0
Maximum random time interval (seconds) for the lead vehicle to brake.	60.0
The lead vehicle brake event duration (seconds).	5.0
Whether to enable short message server notification sound played with random intervals.	false
Minimum random time interval (seconds) from the onset of the first SMS notification to the onset of the second SMS notification.	2.0
Maximum random time interval (seconds) from the onset of the first SMS notification to the onset of the second SMS notification.	2.0
Whether to enable N-back number sound played with random intervals.	false
Minimum random time interval (seconds) from the onset of the first sound to the onset of the second sound.	2.33
Maximum random time interval (seconds) from the onset of the first sound to the onset of the second sound.	2.33
Whether to enable time stamp data synchronization to a specific local network IP.	false
Whether to enable data to be sent to the following IP for the advertisement study. Note: Conflict with enableUDPSendData.	false

IP address for the UDP transfer	/
Target UDP port.	1234
Control how frequently the time stamp is sent. Data will be sent after every UDPcycleNumber of TORCS cycles with each cycle is usually 20 ms.	1
Whether or not to enable QN-Java model drive simulation with the UDP server and client are the same computer.	false
The UDP QN port to the simulation port number.	5678
The simulation port to UDP QN port number.	8765
Whether to connect to a website for the lead vehicle's braking signal.	false
The parameter used in vehicle control model.	2.0
Whether or not to enable the simulated car-following task in training mode.	/
Time interval from the last warning sound onset to the next warning sound onset of the training mode.	2.0

Name of Material/Equipment	Company	Catalog Number
80-inch LCD screen	WOKEMA	8026
Connecting program(Python)	-	-
G*power	Heinrich-Heine-Universität Düsseldorf	None
Logitech G29	Logitech	941-000114
Tactile toolkit	Hao Xing Tech.	None
The Open Racing Car Simulator(TORCS)	-	None

Comments/Description

Screen

Using to connect the TORCS with the tactile toolkit to send the vibrating instruction

Using for calculate the required number of participants

Steering wheel and padels

Using for warn the participants

Driving simulation software. The original creators are Eric Espié and Christophe Guionneau, and the version used in experiment is modified by y Cao, Shi.

Reviewer #4:
Minor Concerns:
The authors have addressed most of my comments and the protocol has certainly improved, however, they still need to back-up the power analysis (effect size of 0.06 and power of 80%) with appropriate references.

Authors' Response:
Thank you for your review and comments. We have now included two references to back-up the power analysis we used. Please refer to reference 473-474 for your record.

Reviewer #6:
Manuscript Summary:
Overall, the study design is sound and the results are properly interpreted. This paper contains more information than is typical in a driving simulation research paper. I would say the detail largely leans to benefit researchers who wish to use the open source driving simulation software rather than some of the key pieces of information for more general considerations relating to participant recruitment (see below about sim sickness), driving scenario validity, or expectancies. I expected to see more information about the vibro-tactile apparatus, programming, and application, but it was a bit lacking. One big drawback to the methodology used was the repeated exposure to the stimuli. This likely muted the differences that may exist in vibration location. However, running a between subjects design with fewer exposures to the braking event would require more participants and be more time consuming. Ultimately, one must consider these hard decisions in developing a study design. This should make for a pretty visually appealing demonstration if turned to video.

Major Concerns:
I was mostly concerned with limited information in these three areas.

Comment 1:
Participants: the biggest recruitment consideration I face with recruitment is simulation sickness. This should be a major point in terms of exclusion criterion and screening if you are helping other researchers learn to conduct driving simulation studies. You may not have had an issue given that you use one single screen, but this is an issue that should still be raised as a consideration researchers should take, especially if their sample is older. See: Brooks, J. O., Goodenough, R. R., Crisler, M. C., Klein, N. D., Alley, R. L., Koon, B. L., ... & Wills, R. F. (2010). Simulator sickness during driving simulation studies. Accident analysis & prevention, 42(3), 788-796.

Authors' Response:
Thank you for your reminder. Upon reviewing additional literatures, we noticed that there might not be a solid method to screen whether the participant has simulation sickness during the recruitment process prior to a test drive. We have therefore included this missing consideration in the Discussion as a limitation, and advised future researchers to take simulation sickness into account when determining which data to be excluded prior to data analysis. The sentences have been amended as follow:

“In addition, a Simulation Sickness Questionnaire (SSQ) has not been included in the experiment. Despite the missing consideration, the results were not being affected as the length of each trial was relatively short, and no participant has reported any symptom of simulation sickness upon completion of each trial. This study also has an imbalance number of male and female participants. Future studies should ensure to exclude participants with simulation sickness using the appropriate questionnaire, and aim to recruit an equal number of male and female participants to achieve a stronger conclusion of the results.”

Comment 2:
I do not see where you include the spec on the vibration duration. Based on the title and abstract, I was expecting more information about the vibration kit, its specs, how it was applied, etc.

Authors' Response:
Thank you for your comments. We have now included more details of the vibrating toolkit in both the Introduction and Protocol section. Please refer to line 95-100 and section 4 of the protocol for more details.

Comment 3:
No information is shared about monitoring the performance of the N-back task. It is mentioned several times, indicating its prominence in the methods, but lacking in the analysis. This should be a key component as tasks such as these are difficult to observe an effect among alert drivers. It is important to stress their mental workload so that they are less able to respond easily to the event without some assistance. The small differences in this study may simply be because the drivers were not distracted or overloaded sufficiently. Ultimately, researchers new to driving simulation should be aware that crashes in real life are exceedingly rare (on a per mile/km basis), so you really must create a perfect storm of conditions to observe performance differences with assistance technologies (etc.). If N-back performance was not monitored, then that should be stated as a limitation in that you may not know how much participants engaged in the task, the number was set high enough, or if participants gave true effort to do it correctly.

Authors' Response:
Thank you for your comment and we apologize for the confusion caused. Please be noted that although the option to enable the N-back task is available in the simulation software, the exemplar study only used the car-following task in the experimental design. We have revised the manuscript to avoid future confusions accordingly.

<u>Minor Concerns:</u>
Comment 4:
Improve the resolution on Table 1.

Authors' Response:
Thank you for your comment. The original Table 1 that was uploaded to the system has a resolution of 300 dpi as required by JoVE. We believe that the submission system automatically compressed the image, resulting a much lower resolution of Table 1. We will be providing a

submission to the editor via email to ensure that a full resolution of the figures can be maintained.

Comment 5:
The abstract language (and other places throughout the paper) could use some tightening up. Phrases like "It is also good for performing N-back tasks" sounds a bit too casual and should be re-written with terminology that is more scientific and intentional. Additionally, I would rephrase "commercial driving simulators". If you mean high-fidelity, commercial simulators, then I would state as such. There are some very low fidelity/low quality driving simulators that are commercially available, and some custom built (and of course expensive) driving simulators that are extremely high fidelity.

Authors' Response:
Thank you for your detailed review. We have proofread the manuscript and rewritten phrases that were too casual to more professional phrases. As per advised, we have also rephrased "commercial driving simulators" to "high-fidelity, commercial simulators" to prevent any future confusion.

Comment 6:
While I applaud any attention paid to speed-related crashes, this statistic is not very appropriately applied to forward collisions. Given that your scenario is focused on rear-end crashes, you could reference the research that has shown how effective front crash protection can be (https://www.iihs.org/news/detail/front-crash-prevention-slashes-police-reported-rear-end-crashes). You could also reference fatal crashes that are the result of a collision with a non-fixed object (e.g., car, pedestrian, animal, etc.) as the kind of evidence you are looking for (which also comes to a similar percent of the fatal crashes as you are citing).

Authors' Response:
Thank you for your advice. We have conducted additional research and included new references regarding rear-end crashes accordingly.

Comment 7:
I would rephrase how you reference visual and auditory workload. While tactile warnings may draw on another pathway, they may draw from the same resources (depending on which theory of mental workload you subscribe). Instead, I'd state something similar to "tactile warning systems do not take compete with drivers' visual or auditory processing." But again, it is not a certainty that the driver has any available resources to devote to the vibrotactile pathway if all mental resources are exhausted from high demand from other channels. While only upsides are presented for the vibrotactile pathway, a major limitation of this alert method is that limited information is conveyed in this manner. Where visual and auditory alerts can be very specific about what they are alerting, vibrations contain little information. This should be pointed out in the limitations section. While the feasibility of deployment sounds great, my smart watch vibrates at me all throughout the day. How would I know that a vibration from it would pertain to my need to brake?

Authors Response:
Thank you for your suggestion. We have revised the sentence when describing the mental resources as suggested accordingly:

"In comparison, tactile warning systems do not compete with drivers' visual or auditory processing."

Regarding your concern over certainty of resource sharing over each perceptual channel and the information each channel carries, we agreed that these have been one of the greatest challenges when investigation alternative alerts to drivers. Our team is currently conducting a meta-analysis to investigate whether tactile alerts yield the shortest drivers' response time in comparison to visual and auditory alerts, which might be able to provide us a better understanding of the effectiveness of tactile alerts. We have also included in the Discussion that future research should investigate how we can deliver complex information using tactile alerts.

Comment 8:
The phrases "on one hand" "On the other hand" usually apply to contradicting or contrasting options. Rephrase.

Authors' Response:
Thank you for your comment. We have revised the manuscript accordingly to ensure that messages have been phrase clearly and correctly.

Reviewer #7:
Manuscript Summary:
The authors present a method article on a low-cost driving simulator for investigating haptic collision warnings, and a previously published user study conducted with the system. In general, the topic is timely and relevant. I believe that the subject is in the interest of the human factors researchers in both automotive and haptic interaction domains. The introduction is compact, well-organized and it gives a clear motivation for the conducted research. Critical discussion about future studies required for assessing the functionality of wearable gadgets in mediating warnings during a realistic driving situation would be needed (e.g., the possibility that an intuitive reaction to an unexpected vibration of a smart watch might shift a driver's visual attention to the wrist rather than to a traffic hazard on the road scene ahead).
The comments for improving the paper follow next. Unfortunately, I neither had a possibility to install the driving simulator nor the possibility to use the vibration apparatus. Thus, my review could not fully cover the individual steps described in chapters 2-5.

Comment 1:
The example study results are published earlier in Reference 22 (Zhu et al., 2020). This original paper should be cited in the beginning of the Representative Results chapter.

Authors' Response:
Thank you for reading the original paper of the exemplar study. As per your advice, we have cited it at the beginning of the Representative Results accordingly.

Comment 2:
According to the JoVE publication criteria, the authors need to express that the permission for republishing data or results is agreed with the original publisher. Possibly this has been communicated with the editor already, but this information was not visible for the reviewers.

Authors' Response:
Thank you for your reminder. We have now properly stated such information in the Figure Legend of the manuscript.

Comment 3:
The self-developed vibration toolkit is a central component of the proposed method, but it is presented only superficially. A detailed description of the actuator type/model used, design and functioning of the apparatus and, very importantly, pictures would be needed to be able to reproduce the system, to replicate the experiment, to understand what the toolkit is about, how it can be adjusted, and adapted to different scenarios, etc. A more detailed description of the stimulus apparatus (excluding the vibration motor model) is provided in Reference 22 (Zhu et al., 2020), and this should be communicated clearly when presenting the vibration toolkit in the Introduction. Please add information about the vibration actuator model.

Authors' Response:
Thank you for your comments. We have now included a more detailed description of the vibrating toolkit in the Introduction and Protocol section. Please refer to line 95-100 and section 4 of the protocol for more details.

Comment 4:
Multiple standards (e.g., ISO) and recommended practices (e.g., SAE) have been developed for driving-related research to promote replicability of studies and to enhance the comparability of results between different experiments (see e.g., Green (2012; 2013) for a review).

Authors' Response:
Thank you for your suggestions. An ISO standard was used when developing the vibrating toolkit. We have added this reference back to our manuscript and we apologize for this information previously.

Comment 5:
Correspondence between the selected variables (e.g., the distance between a lead vehicle and a participant's vehicle, as well as the brake response time) and their definitions in the research standards should be specified. Regarding the definition of brake reaction time [Page 10, Line 394], reference 36 (He et al., 2014) appears irrelevant as it does not seem to deal with brake reaction time measurement.

Authors' Response:
Thank you for your comments. Please be noted that the definitions of the brake response time and brake response rate used in the exemplar study were provided in point 6.2.2 to 6.2.4 of the Protocol section as part of the Data Analysis as future researchers are free to define such

information according to their own needs. About the definition of brake reaction time, the driving simulation software was setup with reference to He et al., 2014. As stated in the paper, "The speed control input ranged from −1.0 to 1.0, where −1.0 meant that the brake pedal was at its maximum depression while the accelerator was not depressed, 0 meant that neither the accelerator nor the brake was depressed, and 1.0 meant that the accelerator pedal was at its maximum depression while the brake was not depressed." We therefore cited this paper as a reference to provide the audience an idea of how a reduction of 1% of the brake pedal can be defined in the software.

Comment 6:
A separate section regarding the statistical data analysis is needed for clarifying the following things:
Specifying that one-way repeated measures ANOVA was used.
Specifying that pairwise Bonferroni-corrected t-tests were used for post hoc tests. Specifying and naming the independent variable more clearly and specifying its levels (i.e. conditions). I found the term "wearing position" [Page 11, Lines 443-444] ambiguous. It fits well for the finger, wrist, and temple conditions, but not that well for the driving-only condition.

Authors' Response:
Thank you for your clear advice. As per your guidance, we have rephrased the relevant information to increase the clarity of the experiment and results.

Comment 7:
Improvements for the results report:
Explaining that four levels were involved in the brake response analysis and three levels were involved in subjective rating analyses. Consistent terminology of the conditions should be used throughout the paper (cf. "driving only" and "no vibration warning" referring to a same condition).

Authors' Response:
Thank you for your advice. We have proofread the manuscript to ensure all terminology used are consistent with each other and that, the levels of the different analysis were noted in the relevant sections.

Comment 8:
Term "main effect" [Page 11, Lines 462 and 467] is used for factorial designs only (i.e., ANOVAs with two or more independent variables). The currently used one-way ANOVA results should report an "effect" of the independent variable.
[Page 11, Line 450] "Upon completion of the Bonferroni correction, the recorded brake response time…" gives an impression that Bonferroni correction is a post hoc analysis method of its own. However, the test is a paired samples t-test and Bonferroni correction is only used for adjusting the alpha of the multiple t-tests to avoid Type I error.

Authors' Response:
Thank you for your guidance. We apologize for such an important error and for any confusion caused. We have updated the manuscript and revised the Representative Result section

accordingly.

Comment 9:
When using a wireless stimulation apparatus and measuring participants' reaction times, the issues related to the control of the stimulus onset delay is worth to mention in the Discussion.

Authors' Response:
Thank you for expressing your concern on this matter. We have conducted a research on potential wireless devices onset delay and confirmed that such onset delay is too small to affect the reported results. To address this concern properly, this information has been provided in the Discussion as suggested as follow:

"Researchers may also show concern regarding the possible wireless vibrating toolkit onset delay, which could affect the measured response time. Yet, typical operating characteristics of the vibration motors only included a lag time of 16 ms and a rise time of 28 ms. In contrast, typical response time of drivers are between 0.5 s and 1.5 s. Therefore, the effect of the onset delay is relatively small and can be neglected."

Comment 10:
Human factors research on the new challenges and possibilities regarding autonomous driving is very topical. The possibilities to configure the simulator software for self-driving scenarios is briefly mentioned, but this could be opened more concretely [Page 14, Lines 595-596]. I believe that this information would be in the interest of the target audience.

Authors' Response:
Thank you for your suggestion. While the codes used for the exemplar study did not provide an option to enable autonomous driving, multiple resources have been published to achieve this goal. We have now included some references for the target audience.

Comment 11:
Missing reference [Page 4, Lines 129-130]. It is unclear which ISO standard is referred to - please specify and provide a reference.

Authors' Response:
Thank you for your suggestions. An ISO standard was used when developing the vibrating toolkit. We have added this reference back to our manuscript and we apologize for this information previously.

Comment 12:
-Missing reference for the driving simulator. TORCS website provides a following citation example: "If you use TORCS for your research, please cite it as follows: B. Wymann, E. Espié, C. Guionneau, C. Dimitrakakis, R. Coulom, A. Sumner. TORCS: The Open Racing Car Simulator, v1.3.6, 2014."
(http://torcs.sourceforge.net/index.php?name=Sections&op=viewarticle&artid=30#c6_2)

Authors' Response:
Thank you for your comment. As per JoVE publication criteria, we are not allowed to cite the software or any commercial names (including software names) in the manuscript. This information has been provided in the Table of Materials according to the publication criteria.

Comment 13:
Missing references in the body text regarding Figures 3-7.

Authors' Response:
Thank you for your comment. We have added the references in the relevant section of the manuscript accordingly.

References
Green, P. (2012). Using standards to improve the replicability and applicability of driver interface research. In Proceedings of the 4th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (pp. 15-22).
Green, P. (2013). Standard definitions for driving measures and statistics: overview and status of recommended practice J2944. In Proceedings of the 5th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (pp. 184-191).

RE: JoVE61408R2

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Re: Some questions about using presented data for a scientific video journal

寄件人： Kristin Falco (k.falco@ieee.org)
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****

On Wed, Sep 16, 2020 at 11:40 AM Jibo He <hejibo666@mail.tsinghua.edu.cn> wrote:

Dear editor,

I hope all is well.

We are planing to submit an article to the Journal of Visualized Experiments (JoVE), which is a scientific video journal that requires representative results to be reported. We are therefore writing to ask for your permission to use the published data and figures from our article in IEEE Access (Digital Object Identifier 10.1109/ACCESS.2020.2971632) for the above submission. All the figures and wordings of the presented data will be redrawn and rewritten before submitting to JoVE.

Please also let us know if a citation is required in order to reuse the data after they have been rewritten.

Thank you in advance. We look forward to receiving your updates soon.

Sincerely，

Jibo He

--

Dr. Jibo HE (何吉波)

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Research Interest: Driving Simulator, Mobile Development, Big data, Usability, Eye Tracking

WeChat: hejiboqinghua

Weibo: https://weibo.com/professorhejibo/
LinkedIn: https://www.linkedin.com/in/hejibo/
Google Scholar: https://scholar.google.com/citations?user=MoHyml4AAAAJ
MAJOR INTEREST:

- Recruit international students to Join the international Master of Applied Psychology (iMAP) program at Tsinghua University. (Non-Chinese citizenship REQUIRED).

- Consulting services on Driving Simulator, Eye tracker and User experience

Sincerely,

Jibo He, Ph.D.

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