Collaboration while driving: how sharing communication affects driving efficiency

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Abstract. Increasing of the current development of autonomous driving makes communication in the vehicle more frequent while allowing interaction between the driver and the co-driver to be not only limited to verbal communication but also reflected in the in-car HMI. However, in the current autonomous driving stage, drivers still need to focus in driving primarily, which leads to the driver is prone to driving distractions when interacting with passengers via HMI. This paper focuses on discovering the main factors that affect driving performance when drivers interact with co-driver sharing HMI information. In order to figure out how factors related to driving effects, we conducted two different tests with comparable designs from both objective and subjective ways. We recorded and calculated their driving behaviors and satisfaction levels, and provide some suggestions for creating an interaction principle in the HMI collaboration system.

Keywords: HMI, collaboration, driver, co-driver, driving efficiency, user interface.

1. Introduction

Continuous development of autonomous driving allows vehicles to carry out certain social functions, and the car's communication between drivers and passengers is gradually increasing. In-vehicle human interface not only obtains navigation, media player, in-car theater, and other functions but also simultaneously provides passengers entertainment. The driver can share information and communicate with the passenger while driving via these interfaces. Thus, sharing behavior can be seen as a new way to extend vehicle functionalities to help drivers have enjoyable moments within cars.

The current in-car HMI functions and interactions are mainly focused on the drivers' side, and the entertainment functions and interactions are mainly limited to driving-related activities. During driving, the driver not only needs to pay attention to driving and perform sub-driving tasks simultaneously, which often affects driving performance to a great extent, but the passenger can face fewer distraction problems [1]. Güzin designed a navigation system in which the passenger provides information on a route characteristic to improve communication between the driver and co-driver to help the driver know about special road conditions in advance. However, the co-driver is equally important as the driver in the whole system. Passenger assistance can also be effectively reflected in the navigation system, such as guiding directions [3]. Some visual technologies, such as front windshield displays [4], also avoid driver distraction through passengers' control or behavior. All of these studies suggest in different ways that the provision of information by the passenger can be a positive aid to the driver.

Meanwhile, Inbar [5] argues that in-vehicle HMI systems should need to relieve passengers of boredom and provide them with more information, such as reducing the distraction and information load by the driver instead of sharing trip information with the passenger. Others analyzed the effects of various modalities, services, contexts, and information on most co-driver [6]. These studies agree that the role of the passenger within the driving space is vital and that HMI needs to provide a design that focuses on the passenger to provide them with more functions and services that can increase their user experience while sitting in the vehicle.

From a different perspective, the design thinking of the passenger HMI system can also be used to assist the primary driver [1], such as dedicated screens and dedicated information content, as well as more manipulable content and feasible modality. A passenger-centric interaction mindset can improve the user experience during the journey by reducing boredom, increasing trust between driver and passenger, and increasing passenger inclusion [5].

However, these studies do not discuss whether driver-passenger cooperative behaviors interfere with driving and lead to distractions. There is no objective analysis of how driving is affected by what kind of cooperation and whether the behavior of the secondary tasks affects driving performance. More studies only explore the impact of sharing mobile devices with the HMI on the driver. However, no study on the shared task on an integrated touch screen affects the driver's driving performance. This article will focus on how different design factors lead to the driver and co-driver' collaboration - how sharing affects driver performance, and verify the impact of design factors on driving performance through both subjective and objective perspectives. The paper will also suggest a comprehensive approach to improve driving performance and users' experience perceptions of information sharing in cooperative situations.

2. Method

2.1. Design Contents

Collaboration in in-vehicle driving activities usually considers several factors, the purpose, the role, the reason, and collaborative role relationships [7]. These collaboration factors determine the type of information that the human-machine interface needs to provide, such as the information density, the way of interaction, and other elements.

The driver's operation of the software in driving scenarios significantly affects driving safety in terms of braking reaction time, steering wheel holding ability, and vehicle speed [8]. In this test, we focus on which factors are more likely to affect driving performance at the interaction level. We will test and verify the above regarding ease of use in sharing operation, sharing accessibility, and sharing content readability.

2.1.1 Dual-Task 1 & Dual-Task 2

Comparison of sharing interaction methods. The driver will tend to operate on a shorter path [10] not to interfere with driving. Therefore, in the first test, the different sharing maneuvers of the driver will be compared.

Dual-Task 1 (DT1) requires the driver to slide the Music Playing card as Fig.1 on the driver's side (left side) to the right with two fingers to complete the sharing, and if the operation is successful, the Inquiry card appears on the co-driver side and ask co-driver to accept or deny. For Dual-Task 2 (DT2), the driver has to press the Music Playing card longer than 0.2s; when a small window pops up, the user needs to tap the share to co-driver button to share. In this comparison, we wanted to understand which way of sharing information would have the most negligible impact on the driver's driving efficiency.

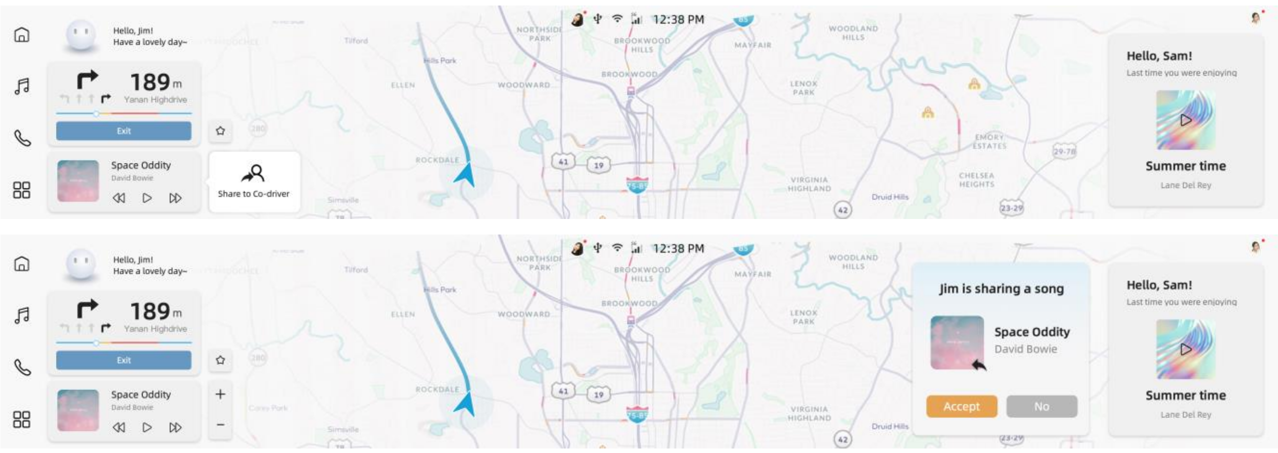

Figure 1. Sharing interface for DT1 and DT2

2.1.2 Dual-Task 3 & Dual-Task 4

In Dual-Task 3 (Fig. 2), the driver will get the Trip Changing card shared by the co-driver down below the voice recognition area (mentioned as vr area below), and the driver needs to click confirm the trip change. In Dual-Task 4 (DT4), the Trip Changing card is displayed further from the center than in the vr area. In this comparison, wanted to understand whether the driver preferred where to share content and which position was less likely to affect drivers' performance.

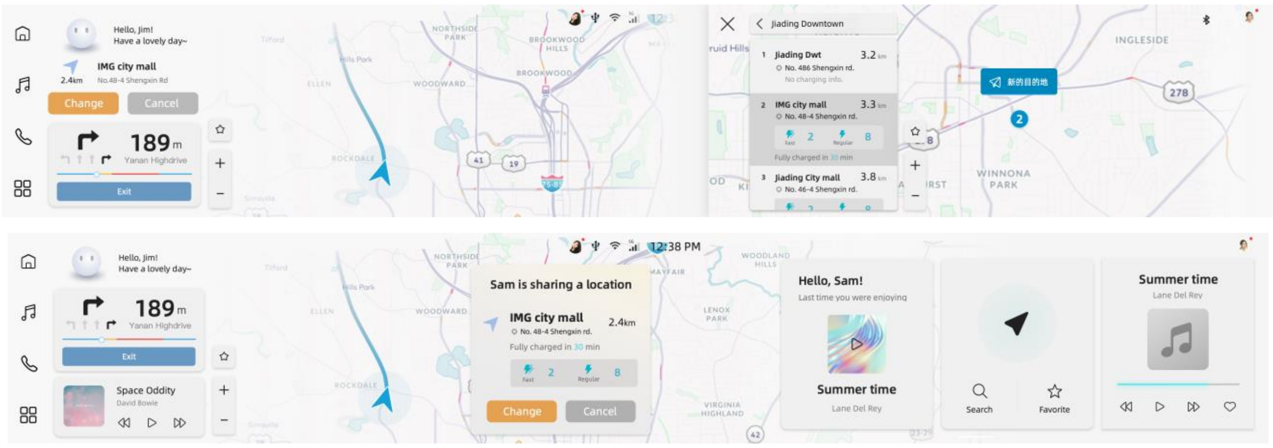

Figure 2. Sharing interface for DT3 and DT4

2.1.3 Dual-Task 5 & Dual-Task 6

Comparison of sharing display information. The more textual content to be read affects the user's time allocation while driving [11]. In Dual-Task 5 (DT5), shown in Fig. 3, the content shared by the co-driver to the driver is displayed in the vr area, and the driver needs to read and repeat the content. In Dual-Task 6 (DT6), the content shared is displayed at the center of the screen, and the driver needs to read the content aloud. The different positions require the user to read the text of the card in different positions, which affects the driver's processing time of the card information content while driving, thus affecting driving performance.

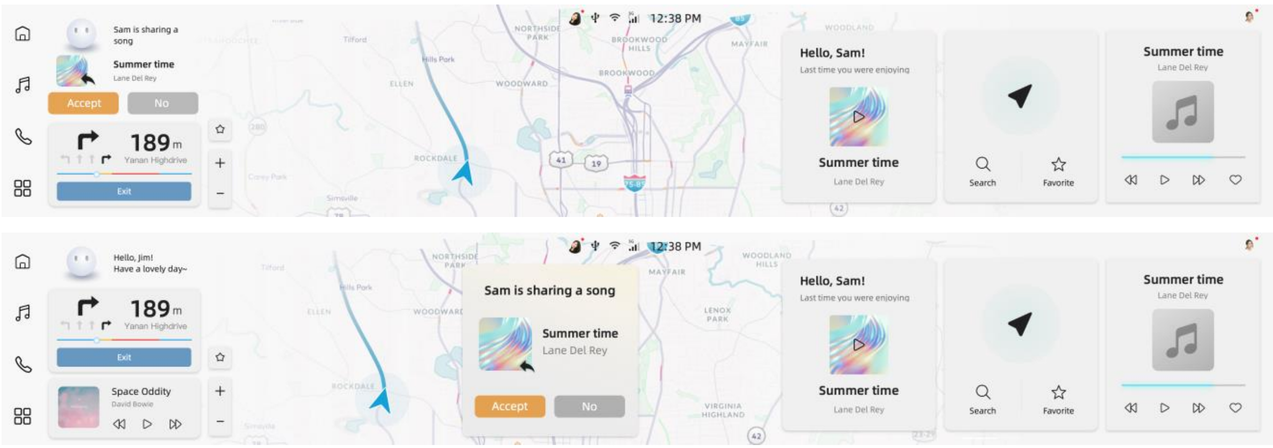

Figure 3. Sharing interface for DT5 and DT6

2.2. Experiment Design

2.2.1 LCT Test

The LCT-Lane Change Test is a quantifiable test method that measures the user's distraction while obtaining a task-specific simulation of actual driving [9]. The LCT test requires some essential equipment support, with the driver sitting in front of a driver simulation and a desktop computer being required to perform lane changes repeatedly prompted by road signs.

The driver is first required to perform a single lane change command task only, and system records the data. After completing Single-Task 1, the driver performs Dual-Task 1 following the task order in Fig. 4, and the test participant performs a lane change when observing a lane change sign from environment display screen in Fig. 5[9]. At the same time, he or she should perform the dual test command from the moderator, such as "Please share the music card to co-driver by long pressing." While performing the dual task, the user's offset, the system will record data. The lane change and dual-task command were performed 18 times in each dual test. After completing all six dual tasks, the user was asked to perform Single-Task 2, and the average value of single tasks became the baseline value for each participant. Fig. 5 shows the three lanes the driver will observe on the screen, with road signs on the left and right to remind the driver to change lanes to the indicated side. The black road in the middle is the difference between the standard form path and the actual travel path when the driver reacts quickly [12].

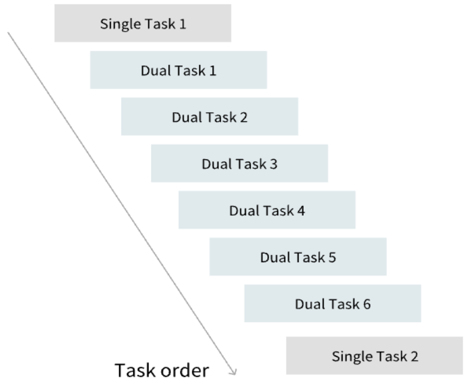

Figure 4. LCT Task order for participants

Figure 5. Image of LCT monitor view for driving task

2.2.2 Test Pocedure

Before the test, the moderator introduces the whole test procedure which in consisting of 2 different tests, the LCT driving test, and the user evaluation test, and allows the user to get familiar with the steering wheel pedals and make seat adjustments at the beginning. During the pre-test warm-up phase, the moderator asked questions about the simulation test in order for the participants to understand the test format. After the test practice is completed, the formal test begins. The test consists of two sub-tests where participants proceed LCT test, and the simulator automatically records the driver's driving performance. At the end of the LCT driving, the user will be compared and evaluated on the test items and provided with feedback.

2.2.3 Experiment equipment

The entire laboratory was built with a real-scale vehicle bench and a driving simulator with an actual steering wheel and pedal resistance (Fig. 6). In front of the steering wheel is equipped with a virtual instrument panel and a 27-inch integrated touch screen. In front of the bench, three 30-inch screens are built to simulate the external driving environment. The displaying screens carry a simulation software developed by Unity that can conform to the LCT driving environment.

Figure 6. Test Equipment Setup

2.2.4 Participants

A total of 8 participants were recruited, 4 female and 4 male. Because the test requires a high level of driving ability, the participants were recruited with at least 1 year of driving experience and were proficient in driving a car.

2.3. Evaluation

2.3.1 LCT Test analysis and evaluation

In the LCT test, the driver's performance is represented by calculating the difference in the area produced by the offset path. The red part in the middle is the area of the difference between the standard driving path and the path produced by receiving a quick response to the command when participants driving. When the difference is small, then the performance is better, and the area difference is larger for poorer performance. The calculation graph is displayed in Fig. 7, with Y-distance in the horizontal direction and X-deviation in the vertical direction. The final area, is our indicator of driving performance deviation, and a smaller area value (S) means less driving deviation. Ultimately, we will calculate the mean deviation in lane change path (Mdev) of S to analyze the user's driving performance.

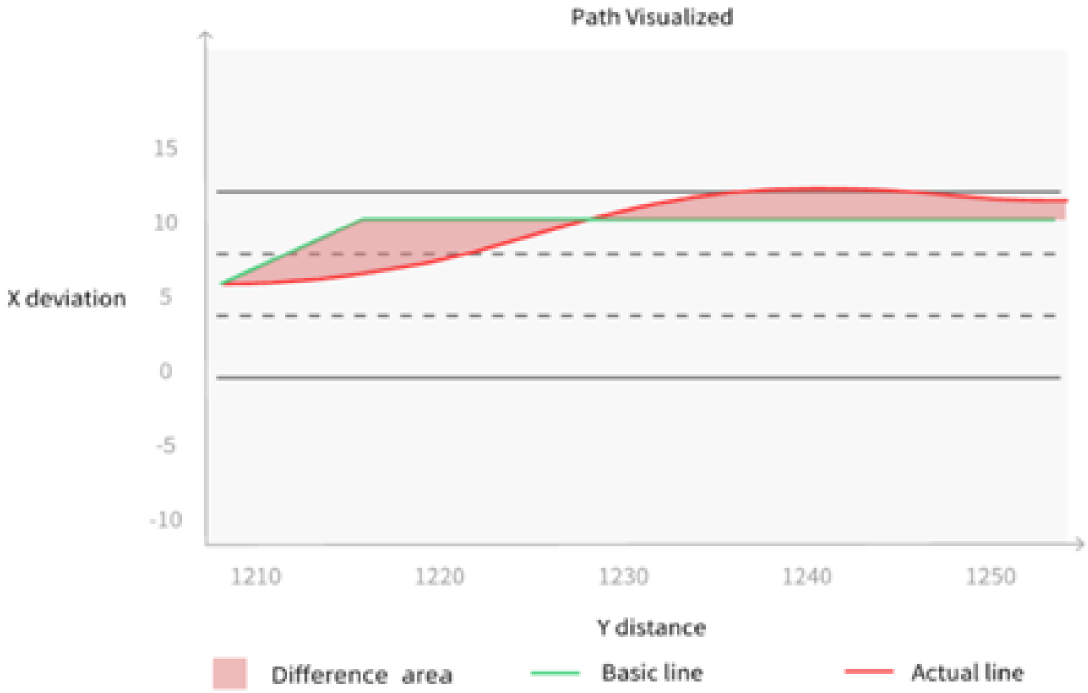

Figure 7. Path visualized of standard driving path and actual driving path in LCT test

2.3.2 5-points Likert scale

In addition to using the LCT test to measure the driver's driving offset data for performing the task, we arranged user interviews at the end of the LCT test. We asked the users to rate the previous driving tasks compared to each other and to perform a comprehensive rating (1-5) on a Likert scale from the perspectives of convenience, usability, feedback, and interaction method. These factors will correspond to the design features in the system and share the feasibility of the operating interface from the interaction perspective from the user's point of view.

3. Results and recommendations

3.1. Results

We summarize and analyze each test and calculate the Mdev of the path area difference. And also analyze the three aspects of usability, accessibility, and readability.

Figure 1. LCT test result

	ST 1	DT1	DT2	DT3	DT4	DT5	DT6	ST2	Avg (ST)
Mdev(S)	4.231	4.1163	4.1160	4.2249	4.2042	4.2947	4.21775	4.1702	4.2006

Figure 2. Likert test result

Task	DT 1	DT 2	DT 3	DT 4	DT 5	DT 6
Avg score	4.4286	2.2857	4.0	1.857	3.9	2.125

3.2. Design features

3.2.1 Ease of Use

We combined objective data with subjective data as the basis of our analysis. Using Fig.8, for drivers, the difference in sharing method does not make much difference for driving distractions. Because the operating position is close to the driver, both the two-finger blind operation and the long-press evoke operation allow the user to share content more quickly. Subjectively, drivers felt the convenience of two-finger blind operation (4,42) > (2.2857), with more natural interaction, faster operation, and no neck angle changing being the reasons for the higher score. Drivers can reach the state of blind operation without observing the screen display, significantly reducing the possibility of driving distractions. However, the feedback process provided by sharing is particularly important, with one user saying, "The feedback makes me believe that the sharing was successful, so I do not have to turn my head to confirm again. The more visual feedback increases the user's trust in the system and makes the user more willing to detail the system's convenience. The user needs to observe the result of the blind operation through the afterglow to judge whether the blind operation is successful, so the two interaction methods are close in terms of objective data.

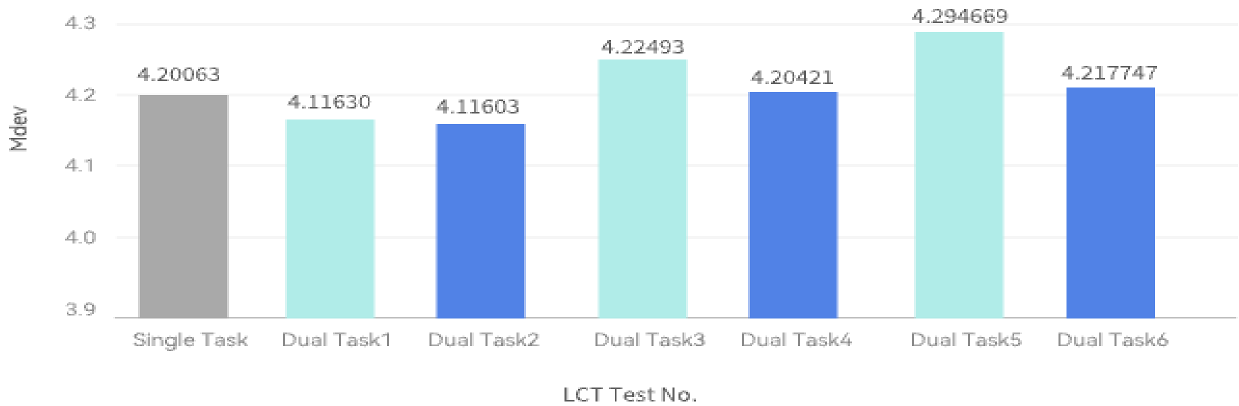

Figure 8. LCT Test Result of single task, and dual tasks

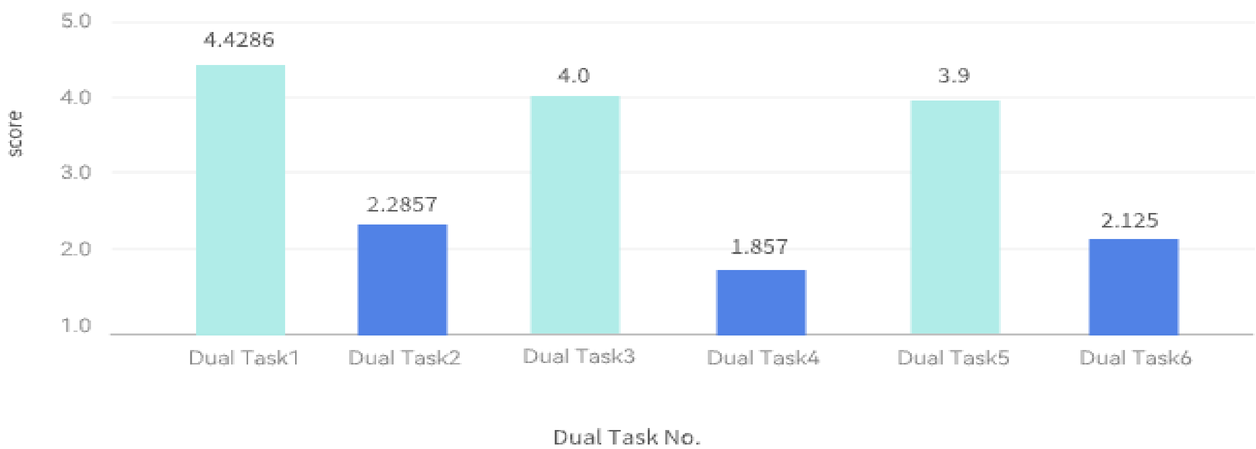

Figure 9. Likert Score of dual tasks

3.2.2 Accessibility

The usability of the card in the middle of screen is better than that of the card in the vr area (Fig. 8), i.e., it generates less distraction from driving. Regarding subjective responses, cards in the middle of vr area scored much higher than cards in the middle of screen. Therefore, we conclude that for usability, the card's location is subjective to the user's perception that the closer it is to the driver's seat, the better it is to maneuver. However, objectively speaking, its impact is not very significant, and the main reason for the greater impact on driving distraction lies in the size of the maneuverable area. As seen in this design, because the card needs to appear at the vr area, the information and the operable area are often more minor, and its operability is relatively reduced. The user needs to click multiple times to trigger the card, while the card appears in the middle that operable area is bigger, avoiding the problem of challenging clicks.

3.2.3 Readability

The objective data representation of Fig. 8 reveals that the card's information is more offset at the vr area than the card is in the middle area. For the driver, the text information is closer to the area but smaller in size, which causes a more substantial distraction than the location far text size is large. For the user's subjective perception, the recommendation is closer to the user at the vr area, with less line-of-sight offset, easier focus switching, and lower neck turning load, so the score is higher (3.9) > (2.125). The objective and subjective values create a contradiction in this item, where we believe that it is the size of the text, i.e., the content with high legibility, that most determine driving performance. Therefore, a larger and less dense information display text will be better read by the user, while we tend to display it closer to the driver.

4. Conclustion

The results of this study reflect the three components of the primary and secondary driver collaboration that need attention in designing for sharing. The study identified three perspectives of ease of use, ease of operation, and readability that intuitively impact driver performance. We found that several design principles were condensed for designing the sharing component of the primary and secondary driver collaboration. When designing content about sharing, it is important to note.

1) Principle 1

The operation of collaborative sharing needs to reflect a straightforward sharing process and feedback on the results of success or failure. Moreover, the design of the content needs to focus on the display position of the shared content.

2) Principle 2

Whether drivers are actively sharing or receiving information, they must be close to the driver's seat.

3) Principle 3

Content needs to be as simple as possible and text size needs to be large no matter where the sharing contents located to improve reading efficiency.

The current results effectively demonstrate the impact of targeting this part of sharing on driving performance. In addition, since the results are based on the driver's perspective on driving performance, designers can control and adjust the design with three principles proposed to minimize the impact of the sharing behavior on driving performance. For the driver and co-driver synergy, designers need to consider more influencing factors, such as the behavior of the co- driver, the information display to the co-driver, and the influence for the information included the driver. We can see there are still lots of need to be discussed in this topic, so we hope to explore these aspects in more studies in the future.

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