To Read or to Take Over? A Case Study of Safety Aware Reading Experience on Self-Driving Cars

ABSTRACT

In autonomous cars with a high level of automation, drivers are required to take over the control when the vehicle cannot operate safely. However, the chances of the "takeover" to take place is little, since the technology has advanced to tackle most of the situations. As a result, the drivers will have a large amount of free time in the car, but they still have to maintain awareness of the road condition in case of the occurrence of "takeover." We have developed an in-car reader that help the human drivers to utilize their free time effectively and safely. In addition, we derived 7 different strategies for displaying the reading content. In this paper, we present what we have discovered from the explorative experiment with 41 participants. We have come up with several combinations of reading methods that provides safety and pleasant reading experience.

KEYWORDS

Autonomous driving; RSVP; in-car entertainment; HUD display; handover

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1 INTRODUCTION

Riding an autonomous car is no longer a fantasy. There are significant advances in the field of autonomous vehicles these years. We can see autonomous vehicles made by the tech giants such as Google/Waymo, Tesla, Apple, GM, Toyota etc. being tested on the road in the U.S.. This motivates study of computer-human interactions in autonomous cars.

SAE, standing for the Society of Automotive Engineers, defines the intelligence level and automation capabilities of vehicles, ranking through 0 to 5 [3]. At level 0, vehicles are fully controlled by human, i.e., there is no automation. At level 5, which is the highest level, vehicles are fully automated and no human intervention is required. In between these two extremes, semi-autonomous vehicles come into the picture. These vehicles have a certain level of automation, yet the human drivers are required to stay vigilant at all times in case they need to take over the control of the car.

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Most of the autonomous vehicles currently on the market are in level 2 or level 3, where an Advanced Driver Assistance Systems (ADAS) allows the vehicle to automate certain parts of the driving experience, but human driver remains in most of the control [5]. Examples of level 2 and level 3 intelligence include keeping vehicles in lanes and self-parking. In the near future, level 4 vehicles will be in the market. These vehicles can operate without human input under vast majority of situations. However, when the ADAS encounters situations that it couldn't handle or operate safely, it would return the control to the human driver. This transition process is called *handover* [18]. A computer-human interaction system in these vehicles should help drivers successfully handle the situations as soon as possible.

On the other hand, since drivers in level 4 vehicles are free from the driving task most of time, they usually get bored easily and may choose to do something else that results in lack of vigilance [8]. This could seriously jeopardize the safety of handover. There is a crucial need for an in-car interactive system that allows users to do whatever they want and meanwhile keep them aware of the road conditions so they can respond accurately and quickly when handover occurs.

In this paper, we study the design of an in-car interactive system that allows users to *read* safely. Reading is a common activity people engage when commuting. However, a good reading experience seems to be a conflicting goal with safety. For example, a driver can read a real book and use a way (e.g., flipping pages) he/she is already familiar with to interact with book to get a "good" reading experience. But reading a real book is a dangerous behavior in car because it keeps the driver's gaze off the road, which may jeopardize driver's ability of handover. We then ask the question: how to design an in-car reading system such that it can deliver good reading experience and at the same time ensure driving safety.

Safety is no doubt of the highest priority when it comes to designing in-car reading systems. When handover occurs, a driver needs to 1) understand the current situation (e.g., looking at the road and searching for dangerous objects) and 2) perform physical movements (e.g. turning their head or putting their hands back on the steering wheel) in order to drive manually. Thus, we focus on in-car readers that 1) keeps the driver's gaze on the road and 2) keeps the driver's hand on the steering wheel. With recent development of HUD (Heads Up Display) [1, 4, 6, 15] that allows text to be projected on a large portion of the windshield and keeps a driver's visual focus on the front, we propose using an HUD as the display of text. Furthermore, a modern car usually have control buttons on the steering wheel. We require the driver to interact with the HUD display through those buttons such that he/she will keep hands on the steering wheel when reading.

We propose 8 in-car reading methods following the above principles. These methods takes different approaches in 3 key design aspects: 1) should the text be displayed on road or off road? 2) should the text be displayed at a fixed position or a dynamic position changing according to road conditions? and 3) should text be displayed paragraph by paragraph, sentence by sentence, or word by word? We conduct experiments to evaluate how these design aspects affect the trade off between reading experience and driving safety. Our results also give some insights into the future in-car reading systems.

The rests of the paper is organized as follows. In Section 2, we review existing studies on in-car interactive systems. Section 3 proposes 8 in-car reading methods aided by the HUD and buttons on the steering wheel. We details our experiment design in Section 4 and show the results in Section 5. Section 6 discusses the results and their implications. We show to improve our experiments in Section 7. Finally, Section 8 concludes the paper.

2 RELATED WORK

Autonomous driving is a new driving paradigm which has recently emerged because of the rapid development in Artificial Intelligence (AI) and control technologies. In a self-driving vehicle, the driver no longer have to stick to the driving task all time. Instead, he/she becomes available for other tasks, and these tasks might even become the main tasks when riding an autonomous vehicle in the future [18]. Such a significant change leads to an imperative necessity to redefine and redesign the in-car computer-human interactive systems [16]. However, there are relatively few studies on this direction so far.

While riding an autonomous vehicle is like being a front seat passenger in the car. Osswald et al. [14] give a probing study of the desires and needs of front seat passengers. Among many candidates, the ability to read was listed as one of the desires of the front seat passenger. Moreover, an interesting way to in-car reading was proposed. The authors proposed letting users tilt their chair and read from a screen installed on the roof. The original design meant to extract the reader from the context of the car. However, in the autonomous vehicles, handover, despite of its low chance of happening, needs to be handled by users correctly and quickly to ensure driving safety. Letting users tilt their chairs and lie without seeing the road is obviously a too risky method to take.

Krome et al. [9, 10] proposed gamifying an exertion activity in the autonomous vehicles in order to prevent drivers from being bored and to keep them aware of road conditions. They believe gameful activities can help retain the driver's competency. Drivers have to complete the segments through a work-out via the exercise bike. To complete the game, one of the steps is to predict the traffic situation. They not only measured the user's satisfaction but also their perception of the traffic situation. In another paper, Krome et al. [11] proposed a music game that is connected to the movement of autonomous vehicles, aiming to replace the driving task with interesting non-driving task ans meanwhile maintaining their awareness of road conditions. However, no reading activity was discussed.

3 IN-CAR READING METHODS

An in-car reading method should have at least two goals: 1) to let driver read comfortably, and 2) to ensure smooth handover and driving safety. One naive way to in-car reading is to let the HUD project as much text as possible on the windshield and let the drivers to scroll down to new lines using the buttons on the steering wheels. However, this is clearly not a good design because on a large HUD display the text may block drivers' road sight, preventing them from observing the road conditions. We argue that limiting the displayed text to a small region, called *reading zone*, would be a better choice, even the HUD could have projected text onto a much larger area. With the concept of reading zone, we have to make design decision in:

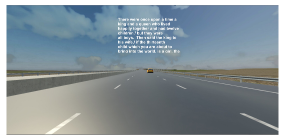
(1) Should the reading zone be placed on the road or off road?
(2) Should the reading zone be displayed at a fixed position or a dynamic position changing according to road conditions?
(3) Should text in the reading zone be displayed paragraph by paragraph, sentence by sentence, or word by word?

In the following, we discuss the design choices in each of the above aspects and propose hypotheses reflecting our intuitions.

On Road or Off Road?

Another decision to be made regarding the design of the display method is the vertical position of the text box on the HUD. With our setup, the HUD space can be split into two sections, the lower "Road" section over the road and the upper "Sky" section over the sky. Since the handover incident almost happens exclusively on the road, it is plausible to place the reading zone on positions in the "road" section. There is, however, a potential drawback to this choice of

Table 1: Table of Display Methods

	Paragraph-by-Paragraph (On-Road)	Paragraph-by-Paragraph (Off-Road)	Sentence-by-Sentence	Word-by-Word (RSVP)
Static				
Dynamic				

placement. Since the background of the reading zone is kept transparent, the drivers are subject to distractions caused by the moving objects beneath the reading zone. Having significantly more moving objects (e.g. Cars) than the "Sky" section, placing the reading zone on the road section might hurt reading comfort. This is confirmed with our survey where multiple participants have reported distraction caused by the moving background. As an alternative, we can place the reading zone to the sky to remedy this problem. The hypothesis can be formally defined as follow: *By placing the reading zone to an off road section (Sky), one can expect drive to have better reading performance.*

We have designed an alternative setup for the Paragraph-by-Paragraph representation. The reason why we chose to test this hypothesis on the Paragraph mode is that it is the representation that most closely resembles conventional text displays, testing on this representation removes most other factor that might affect reading comfort. The newly designed representation method is named Paragraph-Sky.

Static or Dynamic Positioning

One of the main assumption we're trying to verify was whether limiting the drivers' gaze will have an effect on the handover response time. With the dynamic positioning mechanism, the text will be projected on the areas that the autonomous driving system deems unsafe. This way, even when not actively driving, by reading with our system, the drivers' center of view will rest near the high risk zones. The hypothesis regarding the positioning mechanism can be formalized as: *Dynamic reading zone positioning can help driver locate the position of the incident faster, resulting in a shorter response time* On the other hand, the movement of the text might reduce reading performance. Or more formally: *Dynamic positioning induces extra movement of the text, thus may reduce reading performance.*

The high risk zones can be obtained with deep reinforcement learning techniques. Works that implements dynamic spatial attention in Recurrent neural networks to predict future accidents have been proposed. [2, 12, 19]

When dynamic reading zone positioning is not active, the text are set to project on the center of the HUD horizontally. A matching set of static display modes served as control group to test the effectiveness of dynamic positioning. Also, in systems that implements dynamic positioning, when the system does not detect any high-risk zone, the text box is default to move back to the center of the road.

Content Display

While the reading zone positioning determines the movement (or the lack thereof) of the text. The manner of which the text is displayed is another key aspect to the performance of the reading experiment. Three representation are considered in this work:

- Word-by-Word
- Paragraph-by-Paragraph
- Sentence-by-Sentence

In order to fully evaluate the effectiveness of the dynamic positioning mechanism, the displaying of the text should encourage the driver to keep his/her center-of-view near the designated risk area. However, majority of the writing systems used nowadays are oriented horizontally, while the traffic incidents ahead of the driver are oriented in a vertical manner. Due to this inconsistency in eye movement directions, we are unable to keep drivers gaze from scanning horizontally when they read in a conventional setup with text going as wide as the screen. All the display methods that we implemented here represents different level of restriction on the drivers gaze. With Word-by-Word (RSVP) mode imposing the strictest limitation of only the size of a word.

Word-by-Word (RSVP). RSVP, abbreviation for Rapid Serial Visual Presentation, is an experimental model frequently used to examine the temporal characteristics of attention [7, 13, 17]. It is also used in several reading softwares such as Spritz or Velocity to increase reading speed. When presenting texts with the RSVP method, readers are allowed to maintain fixation at a single location on a display as a sequence of words is presented in quick succession. The execution of eye movements is not required at all. For this characteristic, we have chosen the RSVP to represent the most extreme version of the dynamic reading zone positioning, where the drivers gaze are kept in closest proximity of the identified high-risk zone. In other words: *Displaying text in RSVP can reduce response time.*

However, RSVP is not without its downsides. As the length of the passage increases, RSVP readers suffers from a decrease in comprehension rate, a increase in visual fatigue. This effect should be verified in our experiment as well. The hypothesis is then: *Reading in RSVP could limit comprehension.* If the assumption of the decrease in response time holds, implementing RSVP becomes a trade-off between handover safety and reading performance.

Paragraph-by-Paragraph. Aside from RSVP, we must also examine display modes that more closely resembles a conventional, horizontal reading experience. Paragraph-by-Paragraph content display shows the whole paragraph of a passage in a scrollable text box. The text box background is partially transparent, a design intend to allow the driver to still peek through the text to check on the road condition. The text box has a width of about 15 characters and height of 7 lines. Each line of the text is kept under a relatively short length as an attempt to keep the horizontal movement of the eye in a reasonable margin. In our experiment setup, the span 15 characters roughly equals to 10 degree field of view. Representations using this display method more closely resembles the text we normally see in other displays such as phones, tablets and computers. It is supposed to be a configuration that is targeting more at reading comfort, but theorized to give a slightly longer response time.

Sentence-by-Sentence. During the early stage of the experiments, we have created a similar driving simulation in hope to collect user feedbacks on various representations. And there were prevalent comments on the paragraph representation. One is that the bigger size of the paragraph content display hovering on the road prevented drivers from seeing the road ahead, and this was causing a higher sense of insecurity and mental stress for the participants. The sentence level representation is designed to test if we can lessen the blocking of view without sacrificing too much reading comfort. The sentence level presentation is basically a paragraph level representation with less lines. Only one sentence is displayed at a time and the blocking of the view is improved significantly. We test this improvement in our experiment: *Reading in Sentence-by-Sentence mode cause lower mental stress than reading in Paragraph-by-Paragraph mode.*

Hypotheses

To sum up, we have six hypothesis for our research:

(1) By placing the reading zone to an off road section (Sky), one can expect drive to have better reading performance.
(2) Dynamic positioning induces extra movement of the text, thus may reduce reading performance.
(3) Dynamic positioning can help driver locate the position of the incident faster, resulting in better handover performance.
(4) Sentence-by-Sentence content display leads to better reading performance than Paragraph-by-Paragraph display.
(5) RSVP content display limits reading comprehension since there is no chance to look back.
(6) RSVP display can lead to better handover performance due by limiting gaze.

4 EXPERIMENT DESIGN

Participants

We have recruited 41 people for our experiment. They are all external personnel and unrelated to this research team. Each of the participants are well-oriented by the authors before conducting the experiment. Additionally, they are adults with adequate driving experience.

Driving Simulator Description

The experiment was conducted in a Unity3d environment. The driving experience is similar to those of a regular sedan. It is presented with a 26-inch IPS display, with the center of the screen 80 centimeters away from the driver. The fully textured graphics are generated by a PC hardware that delivers a 60Hz frame rate at 1920x1080 resolution. The vehicle can be controlled using a Logitech G29 Steering Wheel Set with pedals and clutch. PS4 style joystick buttons can be found on the steering wheel and is used to control text movements of the reader. The design is intended to keep the drivers' hands on the steering wheel even in automatic driving modes, this way the drivers can immediately gain control of the wheel upon Handover, hence reducing response time even further.

Driving Environment

The driving environment consisted of a three lane highway in a rural setting with no intersections. A steel beam bridge is included in the scene. Driver's car is driving at approximately 45 miles per hour. Traffic in the opposite lane is presented

Figure 1: The handover alert scene: Once the incident take place ahead, the screen turns red to alert the participants of the handover

Figure 2: The response task: After the handover, the participants should press the corresponding arrow button on the steering wheel as soon as they identify the incident.

at a rate of about 1 per minute. A light traffic of non-player vehicles consisting Trucks and four-seat sedans can be seen.

The Reading Task

There are eight distinct reading passages for the eight sessions. Buttons on the steering wheel can be used to control the scrolling of the text. For the word-by-word displays, the participants pressed the same two buttons to adjust update speed. One press increases/decreases the speed by 10 wpm(words per minute). Attention to the reading passages was required as the participant were asked to answer reading comprehension questions at the end of each session.

Handover Scenarios

We have designed several different handover scenarios, all of them are implemented in the same highway terrain mentioned above. The scenarios involves different types of vehicles on different part of the highway. They are modeled in such a way that they resembles those accidents that do occur in real-world roads. Here are descriptions of some of the scenarios:

- The driver's car is trailing behind a truck. The truck loses control and crashes to the guard rail on the outermost lane.
- The hatchback in front of the drivers car coming to a skidding stop after crashing on the jersey barriers on a causeway bridge.
- Two sport cars are involved in a rear-end collision in the takeover lane and come to a sudden stop.

Flow

In our design, there are a total of eight different reading methods that we aim to evaluate (see Table 1). We examine each of those representations with a simulation session. Thus, the participants will experience a total of eight handover situations along with eight kinds of reading methods.

Ordering of these eight sessions are purely random to avoid performance gain through increasing in mastery of the system. Each session starts in the auto-driving mode with the reading content displayed on the windshield. The auto-driving mode lasted for roughly 1 minute, and a handover scenario would occurred. The screen would flash red with the text "Handover!!" on the center of the screen (see Figure 1), and the steering wheel generates haptic feedback to alert the driver to take over the control of the vehicle. On the position of the incident in the handover scenario, an arrow would appear (see figure 2). The arrow was randomly generated from the four directions of up, down, left and right. The participants had to press the corresponding button on the steering wheel as soon as they identified the location of the incident [8]. This design helps us record the time each participants requires to locate and identify the incident. Once they successfully pressed the right button, the handover process was completed, and the auto-pilot mode was disabled. Only then can the participants regain control of the vehicle. They needed to brake or to accurately steer the wheel to avoid crashing into the accident. The process is repeated for eight times for each of the reading methods.

Procedure

Upon arrival, the participants were asked to make themselves comfortable at the driver's seat, with an adjusted seat height that their feet can easily step on the pedals, their hands can comfortably put on the steering wheel, and there eyes 80 centimeters away from the screen.

We then started to inform the participants their duties as well as the rules they need to follow throughout the experiment. This was followed by a 2-minute practice drive, in which the participants get familiar with the various display methods and practiced their control function. Within the practice drive, the participants also learned the position of the four arrow buttons that they needed to press in order to complete the handover task. Additionally, the exact same sensitivity of the steering wheel, acceleration and brake of the vehicle were included in the practice drive as well. Then, we proceeded to the trial with eight sessions, each lasted for roughly 90 seconds. At the end of each session, the participant must answer questions whose information can be found in the text. After each session, the participants were asked to finish a questionnaire regarding reading comprehension of the drivers, the overall experience and their preference for all the reading displays.

Measurements

There are two main metrics to evaluate our research. First, the response of the driver when the a handover occurs during reading. Safety is no doubt the most important issue when it comes to transportation, thus a quick and accurate response can improve driving safety significantly. Second, the reading performance. In order to provide a pleasant reading experience, the reader should be able to read smoothly, and can perfectly understand the content displayed on the windshield.

Response Behavior. To evaluate how well the driver response to a handover, we recorded the response time of the driver in every session. The response time is defined as the time spent from the handover occurs till the moment the driver pressed the corresponding arrow button. If the driver successfully presses the right button, it means the driver has located the incident and ready to respond. Hence, the response time tells us how fast the driver pinpoint the position of the incident, which is also a strong indicator of whether dynamic positioning of words helps drivers to identify the point of the incident quickly.

Additionally, to evaluate the driver's behavior after the handover, we kept track of the car trajectory and established a list of unsafe behavior including crashing into the accident car or hitting the guardrail. In our handover scenario, a proper response to avoid crashing into the accident would be steering the wheel to dodge or hitting the brake to stop the car. However, if the car loses control or the driver overreacted and hit other vehicles, it seriously damaged the safety of handover. We can infer from this phenomenon that the driver isn't physically or mentally ready to take over the control.

Reading Performance. Reading performance was evaluated by two indexes. Firstly, in our questionnaire there were several reading comprehension questions, we calculated the accuracy of those questions to know how well the participants understand the reading content displayed on the windshield in the auto-driving mode. The point of reading is to absorb knowledge and comprehend the content, thus this is a very important indicator of reading performance.

Besides, reading comfortableness is crucial as well, because it shows whether the participants enjoy the experience. From the questionnaire, the participants ranked the six sessions based on their comfortableness. We also measured their reading speed in each drive. If their reading speed is faster or the same as their normal reading speed when they read physical books, it means they didn't have to constantly rewind and can see the content clearly at the first time.

5 RESULTS

We measured how display method influence the performance of handover from various aspects through the explorative experiment conducted by 41 participants.

Reading Performance

We have measured three metrics to evaluate the reading performance of each display method: Accuracy of reading comprehension questions, reading comfort and reading speed.

Accuracy of Reading Comprehension Questions. How well the participants comprehend the reading content is one of the important metrics to evaluate reading performance. Based on Table 2, participants show higher comprehension when the content is displayed sentence-by-sentence with an average accuracy of 90.63%, which is significantly higher than the other two. This is because the participants can easily rewind to check the previous sentences without losing track. If reading a Paragraph-by-Paragraph content, the participants reported that they lost track easily because too much content is displayed at a time. Thus, the accuracy of Paragraph-by-Paragraph content is lower than Sentence-by-Sentence content by 10%. Reading in RSVP content leads to the lowest accuracy of 66.25%. Most of the participants experience the RSVP reading method for the first time in the experiment, thus they aren't familiar and not used to read in this method. They commented that they cannot understand the context of the passage if the words are displayed separately. It leads to the poorest performance of only 66.25% accuracy.

We have also discussed whether dynamic positioning influence the participants reading comprehension. According to Table 3, static positioning of the reading zone results in an average accuracy of 85.48%, which is almost 8% higher than dynamic positioning of the reading zone. The result is understandable because moving text is hard to comprehend. However, we can see a significant difference between the static and dynamic content positioning in Paragraph-by-Paragraph content. The participants reported that when there were less content shown, even if they were shifting, they could easily track the content. However, when a long paragraph was displayed at a time, they couldn't focus on the text they were reading when shifting. Thus, the difference

Table 2: Reading Comprehension Questions Accuracy

Reading Method	Paragraph-by-Paragraph content	Sentence-by-Sentence content	RSVP content
Static	85.63%	**88.75%**	65%
Dynamic	72.5%	**92.5%**	67.5%
Avg.	79.1%	**90.63%**	66.25%

Table 3: Reading Comprehension Questions Accuracy

Reading Method	Static	Dynamic
Paragraph-Road	**87.75%**	78.0%
Paragraph-Sky	**87.75%**	69.45%
Word-by-Word (RSVP)	**70.0%**	68.2%
Sentence-by-Sentence	**96.4%**	95.05%
Avg.	**85.48%**	77.68%

in accuracy in other three content display method isn't as significant as in the Paragraph-by-Paragraph content.

Reading Comfort. Reading comfort is also important when it comes to reading. Moreover, it also affects the reader's mood and reading speed. The Off-road positioning was specifically designed to increase reading comfort, because the complexity of the background on-road may effect reading comfort. However, only 20.8% of the participants enjoy this positioning. It turned out that comparing to the complexity of the background, participants still prefer to keep the road traffic in their sight. Moreover, In our results (see Figure 5), 74.4% of the participants perceived the content display method of Sentence-by-Sentence content as pleasant, while only 23.6% and 3.9% enjoyed reading paragraph-by-paragraph content and word-by-word content. This perfectly fits the result of the accuracy in reading comprehension questions, and proven a correlation between both metrics. There are several reason resulting in the extreme low pleasant rate of 3.9% and the highest unpleasant rate of the RSVP content display method. Reading comprehension problem explained in the above section is one of the reason. Additionally, participants couldn't rewind to check previous sentences.

On the contrary, participants can read smoothly and easily in the other two method, which results in higher reading comfort.

Static and dynamic reading zone positioning also influence reading comfort. In average, 52% of the participants perceived static positioning as pleasant, while, only 34.5% of them enjoy dynamic positioning. This also matches the explanation stated in accuracy of reading comprehension questions section.

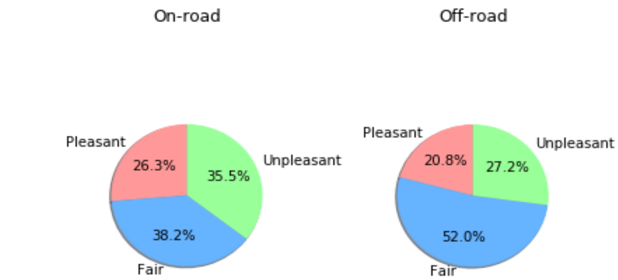


Figure 3: Comfort of each Display Mechanism

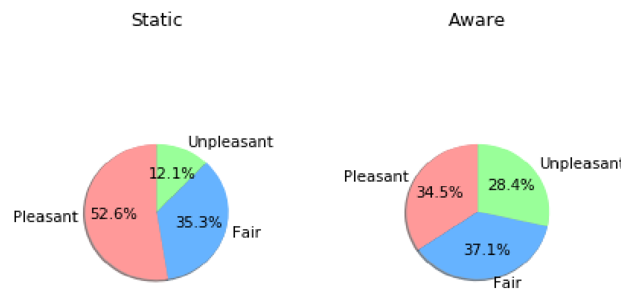


Figure 4: Comfort of each Display Mechanism

We have expected that content displayed paragraph-by-paragraph would lead to the best reading performance. However, the accuracy of displaying paragraph-by-paragraph is lower comparing to displaying sentence-by-sentence. Since displaying content paragraph-by-paragraph resembles our reading habit the most, we have suspected that readers can perfectly comprehend the content. Notwithstanding, the participants commented that, if showing too much content at a time, they often lost track when they look back to remind themselves of previous plots. This not only contributes to a lower accuracy, but is also the reason why most of the participants considered the reading experience fair but not pleasant.

Reading Speed. The eight reading passage are all of the same length. The reading speed percentage represents the percentage of the passage the participants have read during the experiment. According to Table 4, the participants can read fastest in Sentence-by-Sentence content, followed by Paragraph-by-Paragraph content. In average, participants have read 73.2% of the passage in one minute, which is 10% more than average reading speed. Content displayed Sentence-by-Sentence allows people to grasp the main idea quickly and move on to the next sentence. The reading speed of RSVP hit a extreme low percentage of 10.23%, because

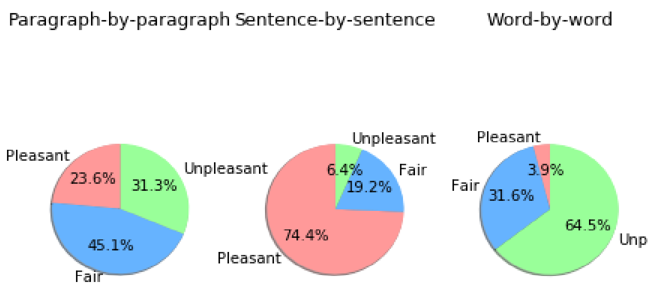


Figure 5: Comfort of each Content Representation

Table 4: Reading Speed

Reading Method	Paragraph-by-Paragraph content	Sentence-by-Sentence content	RSVP content
Static	68.96%	74.51%	11.01%
Dynamic	48.22%	71.89%	9.45%
Avg.	58.59%	73.2%	10.23%

Table 5: Reading Speed

Reading Method	Static	Dynamic
Paragraph-Road	**77.46%**	45.45%
Paragraph-Sky	**60.47%**	50.99%
Sentence-by-Sentence	**74.51%**	71.89%
Word-by-Word (RSVP)	**11.01%**	9.45%
Avg.	**55.86%**	44.44%

the participants cannot rewind, they read extra slow and careful to make sure they could comprehend. The results corresponds to reading comfort that Sentence-by-Sentence content has the best reading performance, with RSVP content has the poorest. As for the influence on reading zone positioning, dynamic positioning performs slower reading speed which is also plausible because generally we have to pay more attention and time when reading moving text.

Response Performance

In our study, we used three metrics to evaluate the drivers' response performance: successful response rate, response time and stress level.

Successful Response Rate. The rate of participants that successfully performed the response task is shown in table 6. In most of the trials, participants are able to successfully perform the correct response task before their vehicles crash, with success rates all exceeding 90%.

Table 6: Successful Response Rate of Different Reading Methods

Reading Method	Static	Dynamic
Paragraph-On Road	95.12%	**97.56%**
Paragraph-Off Road	97.56%	**100%**
Word-by-Word (RSVP)	97.56%	**100%**
Sentence-by-Sentence	90.24%	**97.56%**
Average	95.12%	**98.78%**

Table 7: Response Time of Different Reading Methods (Unit: second)

Reading Methods	Static	Dynamic
Paragraph-On Road	0.98	**0.97**
Paragraph-Off Road	1.04	**0.95**
Word-by-Word (RSVP)	0.88	**0.79**
Sentence-by-Sentence	1.19	**1.01**
Average	1.02	**0.93**

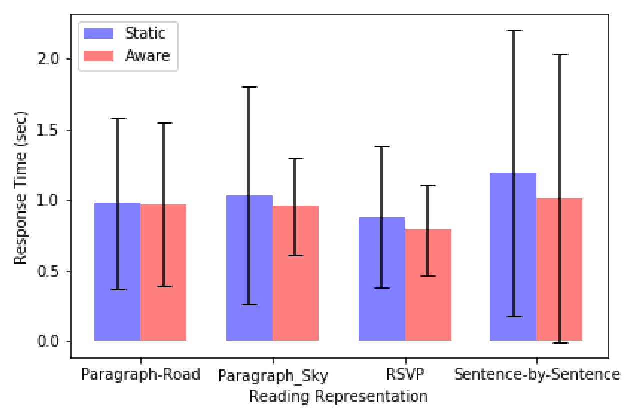


Figure 6: Response Time of different Reading Methods

Still, we can observe that reading methods with dynamic positioning of reading zones generally have a higher success rate. This corresponds with the assumption that dynamic positioned texts boosts a safer handover.

Response Time. Table 7 and figure 6 depicts the mean response time for each content display method. In some of the trials, the participant failed to press the correct button all the way until they crashed into the accident car. These failed trials will have response time of 3.2 seconds, since the drivers have approximately 3.2 seconds to react until their car crash into the vehicle(s) that caused that handover. However adding this "penalty response time" has caused the standard deviation to increase by quite a bit. It is worth noting that otherwise the response time are not that scattered.

Consistent with the trend in Successful Response Rate, average response time decreased by almost 9 percent when dynamic reading zone positioning is used.

Across the content display methods, Word-by-Word (RSVP) content has the lowest overall response time. In fact, the best performing reading method has over 30% shorter response time than the worst performing method. Aside from the theorized effect of limiting eye gaze. There are other factors that could contribute to this outcome. Among the participants' feedback, one prevalent response is how difficult reading in RSVP is to them. It is evident that RSVP is not a very common display method, and for many participants, this is the first time they ever try reading on one. Because of this, many participants anticipated RSVP to be a difficult task, and ends up lowering the RSVP update rate far below average reading speed. The unusually low word count of RSVP display method is an evidence of such effect. At such a low input rate, the reading task became too undemanding. The drivers could then devote more attention on the road condition in between the change of words, hence the lowest response time.

Sentence-by-Sentence contents require the longest response time. Coincidently, it is also the display method that enjoys the highest reading comfort, scoring best in all of our metrics. Observing both of these trends, we have theorized that the high reading comfort of the sentence-by-sentence display would prompt the driver into investing too much in the reading task. In fact, it is reasonable to conclude that, the over immersion in the reading experience could make the handover transition slower and more sluggish.

Stress Level. After each session, the participants were asked about how stressed they felt using each reading method. The response were compiled into figure 7. From the figure, we can see that the sentence-by-sentence content induces least mental stress. Which makes sense since it solves the road blocking problem of paragraph-content methods , while simultaneously requires less attention than RSVP-content methods. Aside from sentence-content displays, RSVP performs slightly better than both of the paragraph-content displays, which again we theorized to result from less blockage of road view.

6 DISCUSSION

Through the experiment, we have come up with several satisfying combinations that help in-car reading to be a pleasant and safe experience. Along with some surprising results. Below we validate our original hypothesis and discuss the implications of our design.

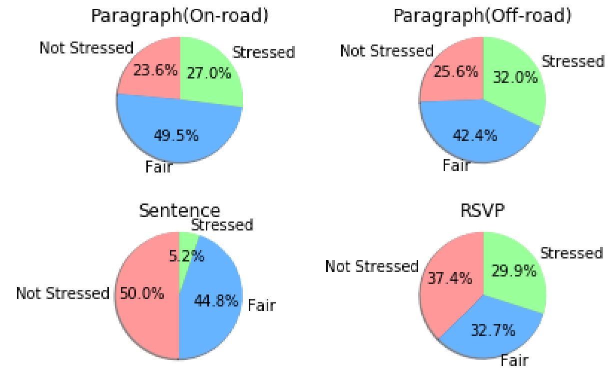


Figure 7: Response Time of different Reading Methods

By placing the reading zone to an off road section (Sky), one can expect drive to have better reading performance

On-road traffic is often a distraction for the drivers, so we have speculated that simpler background could increase reading comfort. Notwithstanding, more participants enjoy the on-road positioning than off-road positioning. The result refute our original hypothesis. In conclusion, participants still prefer to keep their eye gaze on the road comparing to avoiding complex backgrounds.

Dynamic positioning induces extra movement of the text, thus may reduce reading performance

We have explored the correlation between reading performance and dynamic positioning of the reading zone. According to the results, dynamic positioning not only decreases participants' comprehension, but also lower the participants' reading speed. Furthermore, the majority of them enjoy static reading more than dynamic reading. Thus, it validated our original hypothesis that dynamic positioning may limit reading performance. This shows that when design in-car reader, text movement should be minimized to maintain a pleasant reading experience.

Dynamic positioning can help driver locate the position of the incident faster, resulting in better handover performance

The dynamic positioning of the reading zone were designed to keep the driver's eye gaze at high-risk area to further reduce response time. Based on our experiment, participants were able to response faster when the reading zone were positioned dynamically, especially with the RSVP method. We can conclude that dynamic positioning of the reading zone is indeed beneficial to response time.

Sentence-by-Sentence content display leads to better reading performance than Paragraph-by-Paragraph display

The feedback from the participants shows that when it comes to perceived risk of different reading methods, Sentence-by-Sentence contents performed significantly better than other reading methods. This agrees with our hypothesis, implying that as the blockage of the road view increases, the driver would feel an increasing sense of anxiety and unsureness.

RSVP content display limits reading comprehension since there is no chance to look back

Despite being implemented in speed reading technologies, in our study, comprehension score suffers and reading speed was reduced dramatically when RSVP method is being used. This coincides with our assumption: although RSVP reading method performed very well in response tasks, if reasonable reading performance are required, it would be best to consider alternative content presentation method that allows a better reading experience.

RSVP display can lead to better handover performance due by limiting gaze

From hypothesis 3, we have shown that by limiting the drivers' gaze on certain areas, the response time can be improved. Resulting from the same logic, being a more extreme version of gaze restriction, it make sense to see RSVP perform well in response tasks. Whats surprising however, is how well even the static RSVP methods performed. We have deduct that this phenomenon is cause by the participants over-anticipating the difficulty of RSVP methods. For this reason, it might be important for future works to consider the participants' perception of the task implemented..

7 LIMITATIONS & FURTHER IMPROVEMENTS

In our experiment, we have explored eight various display methods, with four content display settings (Paragraph-Road, Paragraph-Sky, Sentence-by-Sentence, Word-by-Word(RSVP)) and two positioning methods (Static, Dynamic). We pursue the goal of presenting a safe and comfortable reading experience by measuring response behavior and reading performance. However, more display methods can be explored. In our simulation, we displayed the text and alerted handover only visually, while real life handover could involve audio warning. The text boxes displaying our text in modes except RSVP are fixed size, while future studies could further evaluate the influence of the difference of text box sizing. There are still many more attributes could be discussed, such as the font of the text, font color and font size. We believe more combinations could be explored to make the in-car reading a more mature activity.

The driving simulator was made by Unity3d, with Logitech G29 Steering Wheel Control Set. We have optimized our simulation to be more realistic and make the participant feel that they are virtually in the traffic. However, this lab-based experiment still has limitations. The participants wouldn't have real world risks and consequences. They might be more willing to take risk, or respond sluggish because there wouldn't be life-threatening danger.

The target vehicle of our experiment, which is level 4 or above, is rarely seen in the current market. Most of our participants have never driven a autonomous vehicle before. Since the driving method of driverless car doesn't match their old driving habits. Some struggled to read relaxingly because they didn't fully trust the ADAS and still feel like having the responsibility to control the car. This could effect drivers performance throughout the experiment.

8 CONCLUSION

The results of our experiment shows that reading Sentence-by-Sentence benefits driver's reading performance the most. In particular, it leads to increased pleasantness while reading. As for response behavior, reading in RSVP mode could assist the driver response faster. We managed to strike a balance between safety and level of comfort. In general, we suggest the off-road, dynamic paragraph-by-paragraph mode, which not only assured safety, but didn't compromise reading performance.

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