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Driver's Distraction and Understandability (EOU) Change due to the Level of Abstractness and Modality of GPS Navigation Information during Driving.

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Abstract

With the advance of technology, the Global Positioning System (GPS) navigation has become an essential device for the driving experience. While the growth of GPS navigation has increased dramatically, the distraction from the GPS usage also became an issue. The researches warn the potential danger of devices, which distract the driver's attention. In this paper, we present the strategy to mitigate the level of distraction, while drivers seek navigation information from the GPS systems. Many researches have already explored strategy to minimize the driving distraction, but only few researches have focused on the strategy to minimize the distraction behaviors with system design. By manipulating the type of information and the mode of modality, we explore the best strategy for delivering the navigation information to drivers. Consequently, the drivers understood the direction easily and safely, even though the drivers had limited time, only enough for a quick glancing action.

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1. Introduction

Technology advances in Global Positioning System (GPS) navigation system have provided drivers with increased variety of way-finding information. With the rapid growth of the navigation system market, the usage of the navigation has saturated into the society dramatically. Now the GPS navigation system has become one of top selling technology and frequent research subject of in-vehicle experience [13]. However, the growth of the GPS system utilization also brought up the issues regarding driver distraction and driving safety. According to Brooks' research [4], the driver distraction contributes more than 20% of the motor vehicle crashes. The researches support

the fact that watching and controlling navigation system during driving situation are closely related to those contributions to car accidents [10]. Thus, driver's safety issue is now one of the important factors for the navigation system design.

To confront issues between the effectiveness of navigation and the distraction level of driver, several researches have been conducted in various fields. The researches regarding the driver distraction and the way finding are the leading research fields, which aim to pursue the safe driving experience and the effective way finding features [11][16][17][21]. Driving distraction researches concerns the external and internal factors from the driving environments [4]. The factors of driver distraction are defined as any stimuli that drag drivers' attention away from primary driving tasks. The factors include visual, auditory, biomechanical and cognitive distractions such as sudden changes in visual attention, blood alcohol level, anxiety of driving etc. [21]. However, the concept of the driver distraction is not scientifically constructed. The driver distraction is more likely the result of the dispersion of the driver's attention caused by any environmental or changes in driver's attribute [9].

The focuses of prior researches of driver's distraction were on distraction factors and the strategy to deal with them. The distraction factors dealt above are the behavior of the drivers, who use mobile devices, such as cellular phones and navigation systems, in the vehicle [14][17][18][20][22][23]. Green [10] introduces the categories of the strategies dealing with distraction. These strategies reflected the distraction factors and the task environment during driving experience. Among the strategies, we focus on the 'design out the hazards', which mitigate the potential hazard factors by manipulating the environment.

Table 1. Strategies for dealing with distraction/overload [10]

Strategy	Description
Selection	Test drivers using some set of in-vehicle devices and only allow drivers to use those devices for which they achieve some desired score.
Training	Classes could be created to teach drivers how to timeshare with devices while driving.
Licensing	Drivers are legally forbidden to perform certain tasks (using the phone) while learning to drive.
Ban	Have laws that make the use of some devices while driving illegal.
Minimize risk with a workload manager	A workload manager is a hardware/ software system that determines the workload the driver is experiencing at any given time and, based on the estimated workload, decides what the driver is permitted to do (for example, by locking out certain functions).
Design out hazards	To design out the hazard, human factors specialists examine each task and determine the method and devices to be used to complete each task along with the information to be presented.

The research of way finding can be applicable in designing navigation contents. The overall goal of way finding is to relocate oneself from one place to another accurately and quickly within a large-scale space [8]. The process of way finding include 3 steps: 1) determining the location and direction to establish orientation; (2) understanding where the destination is and planning a route to the destination; and (3) executing the route in active and passive ways [12]. The research of 'way finding aid' provides verbal and graphical guiding features assisting the drivers. Those aids generally classified in two categories, active aid and passive aid. The active aid is to assist people to understand the information necessary to follow the route, while the passive aid is to provide best path algorithm [15]. Many active aid researches involve designing process or features for drivers to understand the navigation information. Wu et al. [24] presented "view in view: multi-layered display" map to help the cooperation of the

drivers and the navigation systems. Other researches tried to enrich the navigation information by presenting contextual information related the destination or enhancing the visual legibility and scales [1][15][19].

The passive aid is about suggesting best path to the drivers. Like Mackinlay et al.'s research [16], providing a recommendation derived through algorithm to the drivers, is the main focus of the passive aid researches. However, too much dependency on the navigation systems constrains the driver's opportunity to interact with the environment [24]. Prior researches have warned the lack of interactivity with environment results in the failure of the spatial and environmental awareness [7]. These are actually one of the distraction factors introduced above.

In this paper, we presented a study to focus on the user experience of the GPS navigation systems. Our goal is to present guideline to reduce the distraction level while sustaining the understanding of the navigation information. To achieve the research goal, we observed the behavior of the glancing the GPS information, which is inevitable during driving. Following the strategy of 'Design out hazards', we have set up the experiment manipulating the abstract level of the information and the modality type of information presentation. In order to design a better system, enabling the users to understand the information easily with low distraction level, is necessary for reducing hazard of the driving distraction. The rest of this paper is organized as follows: section 2 introduces experimental design, section 3 describes our experimental setup and the results, and section 4 presents directions for future work and the conclusions.

2. Experimental Design

2.1. Abstraction level and Modality of the Information

According to the prior researches introduced above, it can be inferred that the design of navigation information is closely related to the driver's distraction level. Numerous GPS navigation design researches have been focusing on modality design of the system as one of the methods to deliver the navigation information to the drivers. The results of prior researches suggest that drivers understand the information differently according to the system modality [10]. Regarding the distraction, Jensen [13] compared influence of the navigation information to driver's distraction in three modality conditions (auditory, visual, and cross modal). The result showed the auditory information produced the least distraction. However, the research reported that many participants preferred the use of cross-modal (both auditory & visual) information during post-hoc interview [13]. Moreover, difference in modality did not affect the driver's task performances [13]. This result indicates the necessity that modality and understanding of the drivers must be considered together in designing the navigation system.

In this research, the abstract level of the information representation will be manipulated in order to investigate the understanding of the navigation information. It is difficult to find researches directly linking the concept of the information abstractness to the design of GPS navigation. But many cognitive psychology and linguistics researches covered these issues regarding abstractness and concreteness of information. Borghi [3] tested the relation between the information abstractness and the modality of information that concrete words evoke more manual information; abstract words elicit information induced from verbal behavior. This result is based on the prior research findings; sensorimotor and linguistic information play a significant role in conceptual representation. A similar process is required to understand the navigation information, which includes the representation of the road and the landmarks in linguistic and pictorial forms. This may indicate the information abstractness level and the type of system modality may produce different representation that would influence the ease of understanding and the distraction level, when they seek navigation information from the system.

2.2. Experiment Condition and Manipulation

Based on the assumption above, we designed 3x2 (with-in subject) experiments as shown on table 2. The modality has 3 conditions that common GPS navigations can deliver. In each condition, the navigation information will be presented in different modalities of the system as below:

Table 2. Experiment Design.

Type of Modality / Abstract Level	Abstract	Concrete
Auditory	AA	AC
Visual	VA	VC
Visual + Auditory	VAA	VAC

- **Auditory:** The information is presented verbally. Directional, road, landmark information will be presented through speakers.
- **Visual:** The information is presented graphically. Directional, road, landmark information will be presented in the screen.
- **Visual + Auditory:** The information is presented both verbally and graphically. The information will be presented in the screen and spoken through speaker verbally.

Abstract Level of the navigation was manipulated in 2 conditions: ‘Abstract’ and ‘Concrete’ information. One standard way of differentiating between concrete and abstract words is to refer to their ability to be perceived [3]. The concrete information can be perceived without further entities; on the other hand, abstract information may need transcendental experience to understand the actual meaning. In this experiment, those perceivable levels are manipulated as abstract condition and concrete condition according to the visual and auditory representation of the visual and auditory information. The basic criterion of diminishing the level of abstract and concrete for each representation are as below:

- **Visual Information:** The map information is presented in egocentric view and exocentric view. According to Dede[6], the exocentric frame of reference provides a view of an object, space, or phenomenon from the outside as 3rd party, while the egocentric frame of reference provides a view from within the object, space, or phenomenon. This difference allows human to perceive the world in different view. The egocentric view allows the people to be more immersive and motivated through embodied, concrete learning, while whereas exocentric perspectives foster more abstract, symbolic insights gained from distancing oneself from the context [6]. Based on the evidence, the egocentric map is provided as Fig 1 (a) with detailed 3D model for concrete condition. In the abstract condition, the map as Fig 1 (b), which only presents brief information of the roads and the landmarks.
- **Auditory Information:** Based on the definition of concrete and abstract word, the sentence is composed to guide the task of the driver. Concrete words refer to entities that can be perceived through the senses. Abstract words refer to entities more detached from physical experience [3]. The abstract instruction includes the minimum information required to perform the task provided in a simplest form of sentence. The concrete instruction provides details regarding land mark and road information, allowing driver to form best mental model of the navigation and map information.

The followings are the examples of the manipulations utilized in this experiment:

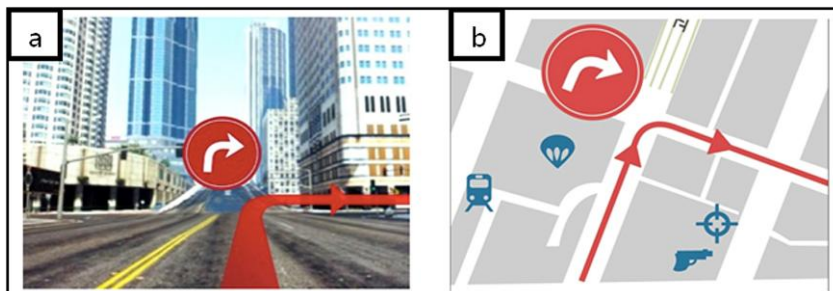


Fig. 1. Visual Representation of (a) concrete condition; (b) abstract condition.

Table 3. Audio Representation.

Abstract	Concrete
Turn left at the intersection	Make a left turn at the intersection after the construction yard, 300M ahead.
Turn right at the intersection	Make a right turn at the intersection in front of the overpass, 300M ahead.

2.3. Experiment Environment.

The experiment environment was conducted with a driving simulation game. Xbox 360 and wireless steering wheel are utilized to set up driving environment. The iPad Air replaced the GPS navigation system to present the manipulated information. The navigation program is programmed with JavaScript with audio recorded through TTS (Text to Speech) program. The goal of the environment set up is to provide similar in-vehicle environment with reality. The devices were arranged according to the typical arrangement in real-life vehicles. For the driving simulation, GTA5 game was used as software. The reasons why the GTA5 game is selected are: (1) the scene of GTA5 is on virtual world generated based on the real city; the various geological features such as road and landmarks are presented in precise 3D model. (2) In GTA5, the traffic situation is simulated. There are other vehicles and pedestrians running on the streets under the obedience of the traffic regulation. Also, traffic facilities, such as traffic light, crosswalk, are properly installed utilized in the world. Finally, (3) the driving experience provided by the game is similar to real. The view from the driver's seat is real-life view. With the wheel controller, the drivers experience similar sense of vehicle control. The presentation of the navigation information was manually controlled. One researcher was always present in the experimental room to check the participants' status and monitor the information.

2.4. Experiment Procedures and Measurement

The experiment included 7 trials. First trial was a pre-test that participants can familiarize with the environment. Since the experiment was within-subjects design experiments, it was important for the participants to get used to the control of the vehicle and the simulated environment in the game. The main trials tested the difference of the understanding and the distraction level according to 6 manipulated conditions stated above. In each trial, the participant was instructed to drive vehicle to indicated destination. The driver must obey the driving regulation, which was based on the Korean Law. The GPS system presented three different navigation information stimuli in each trial as driver's tasks.

The measurement of dependent variable was conducted in the end of each trial. Ease of understanding is measured via survey. The questionnaire (7pt. Likert scale) was generated based on the ease of understanding measurement used in Brown's research [5]. Due to the difference of the research language and domain, the questionnaire was translated into Korean and modified according to the experimental environment. The distraction level was measured as frequency of driver's glancing at the navigation system. The distraction level can be justified in various ways. However, the direct and inevitable distraction produced by the navigation is the glancing behavior about the navigation system. This behavior disrupts the driver's attention from the road and referred as commonly applied measure for driver attention [13]. In the experiment, the frequency of the glancing was measured through counting the number of eye movement from the main simulation to the iPad screen, which presented the navigation information. To detect the exact movement, the iPad was placed outside of the participant's center of gaze in order to evoke dramatic movements, when glancing the navigation information.

3. Data Analysis and Result

A repeated measure ANOVA (analysis of variance) was conducted with IBM SPSS 21.0. Overall 21 people, 11 male and 10 female, have participated in the experiment. To control the driving experience, the participants with Korean driving license and actual driving experience are recruited. The participants are mostly undergraduate and graduate students in the age group of 20 to 35. The data of 20 participants was analyzed due to unreliable responses.

3.1. Main Effect of Abstract Level

The mean value of EOU was slightly higher in the concrete condition ($M=5.475$, Std. Err. $=0.151$) than abstract condition ($M=5.404$, Std. Err. $=0.187$). This result opposes the FOG in that the mean value is higher in the abstract condition ($M=2.739$, Std. Err. $=0.203$) than the concrete condition ($M=2.617$, Std. Err. $=0.195$). However, The effect of abstract level was not statistically significant to both the ease of understanding (EOU, $F(1, 19)=0.107$, $p=0.747>.05$) and the frequency of glancing (FOG, $F(1, 19)=0.835$, $p=0.372>.05$).

3.2. Main Effect of Modality

The main effect of modality is statistically significant to both EOU ($F(2, 38)=5.333$, $p=0.009<.05$, $\eta^2=0.219$) and FOG ($F(2, 38)=42.967$, $p=0.000<.001$, $\eta^2=0.693$). The mean of EOU was highest in the Visual+Auditory condition ($M=5.850$, Std. Err. $=0.152$), descending in order of Auditory ($M=5.269$, Std. Err. $=0.175$), Visual ($M=5.200$, Std. Err. $=0.213$). The mean of FOG was highest in the visual condition ($M=4.001$, Std. Err. $=0.270$), descending in order of visual+auditory ($M=2.717$, Std. Err. $=0.321$), Auditory ($M=1.317$, Std. Err. $=0.117$).

To testify the statistical significance of each condition, we conducted a paired comparison analysis. For both EOU and FOG, the mean differences between all the conditions were statistically significant to each other ($p < 0.05$), except the difference between the visual and auditory conditions of EOU ($P=0.796>0.05$). This means the influence of auditory modality and visual modality on EOU can be the same.

3.3. Interaction Effect of Modality and Abstract Level

As an interaction effect, the effect of the abstract level influences the effect of the modality on both EOU and FOG. The statistical significance of this interaction to FOG is also valid ($F(2, 38)=10.549$, $p=0.000<.001$, $\eta^2=0.357$). The interaction effect to EOU was valid ($F(2, 38)=10.979$, GreenHouse-Geiser $p=0.001<.001$, $\eta^2=0.366$). However, since the main effect of the abstract level to EOU was not statistically significant; the statistical validity of the interaction effect to EOU is comparatively lower than FOG's.

As the representation is more concrete, the influence of the modality on EOU is increased in the auditory and the visual+auditory conditions. However, the influence on EOU decreased in visual condition, when information gets more concrete. On the other hand, the influence of the modality on number of FOG decreased in visual and auditory conditions according, when information is more concrete. In the visual+auditory condition, the number of FOD increases, when representation is concrete.

Table 4. Mean (SE) of the interaction

Dependent Variable	Abstract Level	Modality	Mean (SE)
FOG	Abstract	Auditory	1.367 (0.139)
		Visual	4.402 (0.310)
		Visual+Auditory	2.450 (0.321)
	Concrete	Auditory	1.268 (0.125)
		Visual	3.600 (0.277)
		Visual+Auditory	2.984 (0.370)
EOU	Abstract	Auditory	5.775 (0.241)
		Visual	5.025 (0.248)
		Visual+Auditory	5.413 (0.225)
	Concrete	Auditory	4.763 (0.331)
		Visual	5.375 (0.245)
		Visual+Auditory	6.288 (0.122)

4. Conclusion

In this research, we tried to identify how to design navigation with lower distraction and high understandability levels by manipulating the information modality and abstract level. Based on the result, we found out that the abstract level does not influence the ease of understanding (EOU) and the distraction level (as frequency of glancing; FOG) solely. There was a slight difference between each condition of abstract and concrete information; however, the difference was not statistically significant. We may anticipate the cause of this result based on Borghi and Cimatti's research [2] that the word can be perceived differently according to the abstract level. This implies that the amount of information is close related to the level of representation in human perception. The GPS systems only include the information necessary to identify the roads and few landmarks, mostly patterned according to certain social schema. Moreover, the behavior of checking the navigation information in the middle of driving induced complex process of cognitive dispersion, because the behavior includes both primary and secondary tasks, driving and seeking the information [25]. This might be the cause of the deficiency of effect on the EOU and FOG.

However, the influence of modality of information was statistically significant. The FOG mean value was lowest in auditory condition, which is similar result to Jensen's research [13]. However, the EOU experiment results explain the reason why the preference in the Jensen's finding was on the cross modality condition. The significance of this research lies in the interaction effect. As stated above, the modality effect may vary according to the abstract level of the information. The designers will be able to deploy the combination of modality and abstractness of the information strategically according to the driving situation. For example, it can be inferred from the result that EOU is highest when information is presented in concrete and multi-modal form. However, the distraction level is also high in that condition. Therefore, for the situation, in which the distraction level is minimized, the information in auditory and abstract representation can be alternative solution because it provides adequately high level of EOU and low level of FOG. The below is the exemplified guideline of GPS navigation with multi-representation mode, which represent different set of information according to speed of driving:

- 1) Low Velocity Driving Condition (low distraction hazard level): Multimodal information with concrete representation.
- 2) High Velocity Driving Condition (high distraction hazard level): Auditory information with abstract representation.

This research, however, also includes limitations that further considerations are necessary. First, the simulated driving environment does not represent the reality exactly. The gaming environment is adopted in the experiment for the safety and convenience issue, but the verification of the experiment result is necessary in more precise environment such as real driving condition. Secondly, the measurement of FOG needs to include complex context based on the real in-vehicle environment. This measure needs higher measuring devices such as eye-trackers and high-speed cameras that are able to capture the micro changes in driver's eye movement.

In navigation system design, balancing between driver's distraction and information understandability is a tricky question. There may not be the best solution for general driving experience. However, many alternatives are viable, depending on the driving situation. The strategy and the guidelines proposed in this study are also one of those alternatives. To address the overarching problem, balancing the distraction and the understandability of GPS systems, further work is necessary to develop the strategies to resolve the issue, depending on the driving situation.

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