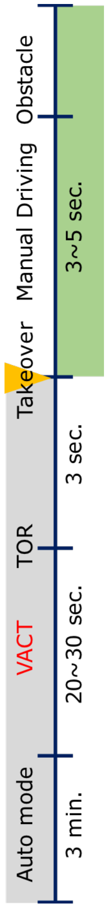

Figure 1: An experimental process that starts from automated driving. Visual Assistance Concepts are then presented followed by Takeover Request(TOR). Participants continue manual driving until they encounter an obstacle sign.

"Are You Ready to Take-over?" : An Exploratory Study on Visual Assistance to Enhance Driver Vigilance

Naeun Kim
HCI Lab. Yonsei Univ.
Seoul, South Korea
agnekim@gmail.com

Kwangmin Jeong
HCI Lab. Yonsei Univ.
Seoul, South Korea
vgb899@gmail.com

Minyoung Yang
HCI Lab. Yonsei Univ.
Seoul, South Korea
minyoung.yang@yonsei.ac.kr

Yejeon Oh
HCI Lab. Yonsei Univ.
Seoul, South Korea
yejeon.oh@gmail.com

Jinwoo Kim
HCI Lab. Yonsei Univ.
50, Yonsei-ro, Seodaemun-gu,
Seoul, South Korea
jinwoo@yonsei.ac.kr

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Abstract
In the near future, drivers are expected to face vulnerability under the takeover phase in automated cars of level 2 or 3. We focused on the problem resulted from decreased vigilance and difficulties in shifting attention while drivers take over the control from the automatic mode. In order to address this problem, we explored 'VACT (Visual Assistance Concept for Takeover)', which applies dynamicity to shift visual attention. From a thorough literature review, we have come up with two windshield interface concepts to enhance drivers' vigilance and readiness before the takeover: Useful Field of View (UFOV) and Object-View (OV) Interface. To evaluate the UI concepts, an in-lab experiment was conducted with 57 participants in a semi-naturalistic driving environment. Implications for interface design of visual assistance and its impact on brake reaction time, mental workload and perceived usefulness are discussed.

Author Keywords
Automated car; windshield display; transition of control; takeover; cognitive science

ACM Classification Keywords
H.5.2. Information interfaces and presentation (e.g., HCI): User Interfaces;

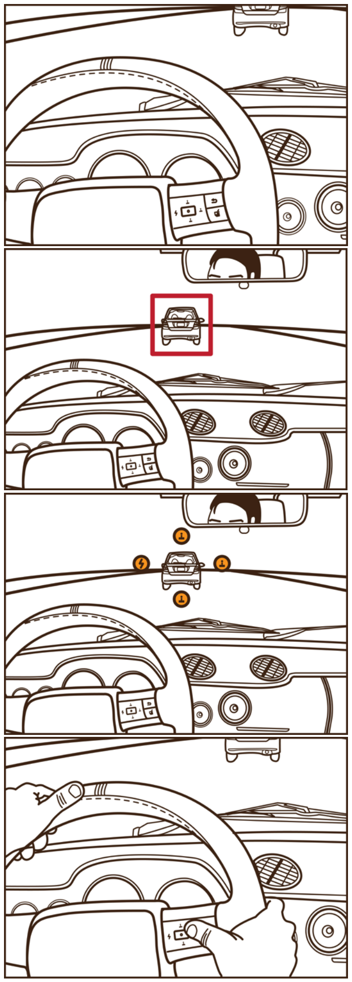


Figure 2: (1) Automated mode. (2) The rectangle appears (3) and then icons blink. (4) The driver pushes a button on the wheel that indicates the direction of a target icon.

Introduction

For decades, the promise of automated vehicles has been filling drivers' minds with rosy dreams of increased safety, comfort, and efficiency. While riding in a Level 2 or Level 3 automated vehicle [22], drivers may engage in non-driving-related tasks. However, drivers will most likely encounter situations in which they must engage in a structured or unstructured takeover of the automated system. Even in planned transitions, the quality of driving performance will be determined by the driver's readiness to resume control [17]. Such vulnerability can lead to an increased probability of human error and even serious accidents.

The vulnerability is specifically addressed as 'out-of-the-loop' performance problems during which drivers are devoid of manual skills or situation awareness (SA) [3]. As a result of automated driving, a driver's workload will decrease, which often results in boredom and lack of vigilance [17, 18]. Also, a shift from passive information processing to active processing requires time and effort [32].

The transition of control, from car to human, has been studied in various fields dealing with automation systems. Many researchers have conducted studies on emergency takeovers, as well as Take Over Request (TOR) [23], especially focusing on reaction time [7,19]. However, few studies have taken a systematic approach to aid drivers' visual attention.

As driving requires quick and precise visual awareness [25], the human-computer interface design within vehicles has to consider various ways to aid drivers' visual field and attention during critical periods. Lorenz et al. studied how an augmented reality (AR)-based contact-analog display influences the ease and speed of the takeover [18]. Miller et al. suggested that using in-car media could help maintain attention by preventing driver drowsiness [17]. In this sense, more studies should be conducted on enhancing drivers' readiness to takeover.

Therefore, in this paper, we generated windshield interface concepts that integrate dynamicity called Vision Assistance Concept for Takeover (VACT). By infusing dynamicity, we intended to direct drivers' visual attention to driving tasks. We have chosen the windshield display as an interventional interface, given that it can be used to grab attention quickly to the road ahead. Windshield displays are expected to be widely used in automated vehicle environments [8,9,10].

VACT Components from Cognitive Science

Based on the theories explaining cognitive mechanisms of attention, the main idea lies in an application of dynamic visual cues. Abrams & Christ showed how the onset of motion could attract attention [1]. When a person captures a movement of any kind, he/she not only benefits from a fast attention shifting, but also from directing attention to the captured location for a brief period of time. In this sense, we looked thoroughly through the literature to identify integral cognitive components in order to come up with novel design ideas. Among various theories, we focus here on two: the driver's field of view and object-based visual attention.

Useful Field Of View

In order to increase situational awareness in a dynamically changing environment, drivers perceive a wide range of the surrounding scene with each glance. To do so, drivers scan the focal area in their visual field and at the same time use peripheral vision to

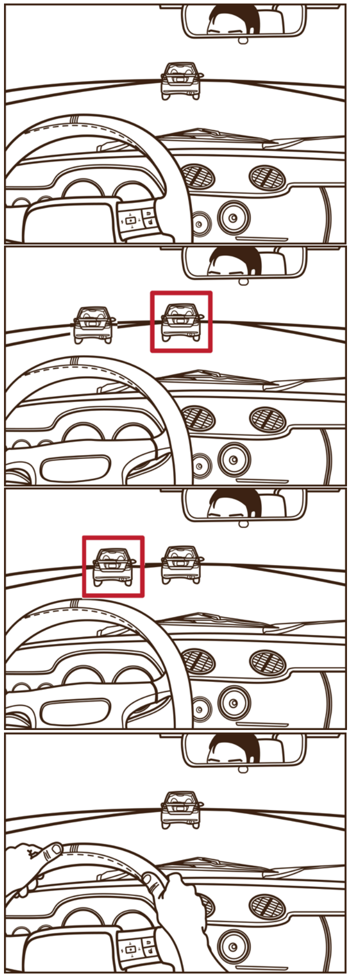


Figure 3: (1) Automated mode. (2) A red rectangle blinks on a surrounding car. (3) It appears on another vehicle. (4) Manual driving after takeover.

constantly monitor upcoming events [4]. The range within which a driver can process information is the *visual field*. Across the visual field, drivers distribute attentional resources automatically, which can result in both divided and selective attention [25].

The useful field of view (UFOV) task assesses divided attention and processing speed. Several studies have found correlations between low UFOV test scores and frequency of crashes [21]. The UFOV task is also used for cognitive training [5]. Here, we explore the potential of a UFOV test to expand a driver's field of vision during a transition period.

Object-Based Attention

Automated vehicles gather environmental data from sensors. In existing interfaces, both windshield displays and HUD (head-up displays) utilize this sensing data to be alerted of nearby cars and pedestrians by representing each of them as simple rectangles or figures [2]. Most of the reviewed studies on contact-analog HUD concepts focus on representing potential obstacles and hazards as AR objects [11, 27].

This representational methodology is modeled after human object-based stimuli processing. Given that a human's attention works through selectivity, the visual system determines which points to pay attention to [26]. As such, visual attention automatically distributes and divides attention according to object-based stimuli [30]. In parallel, drivers can benefit from the same-object effect, which suggests that a person can divide attention with less effort if each displayed object is of the same quality or category [20]. Furthermore, this object-based attentional selection is salient in a dynamic environment, wherein multiple objects have to be tracked over time [28].

Dynamic Interface Concepts for Takeover

UFOV interface

Inspired by cognitive analyses of the useful field of view test, we have designed a prototypical UFOV interface that modifies the icons and display process (see Figure 2). Here, an AR rectangle appears in the focal field, at which point four icons surrounding each side of a rectangle appear after the rectangle disappears. The icons blink in a half-second. Then, drivers have to indicate in which direction a targeted sign appears. He/she pushes a button on the wheel according to the direction in which the target appeared.

The UFOV interface also uses sensor data to display visual symbols of the surrounding environment. As the driver is prompted to choose the very direction the targeted icon appeared, he or she must pay attention to the front and widen their visual field to track broader area. The system can give drivers feedback on whether or not they correctly guess the trajectory of icons, thereby reassuring them of their ability to notice the surrounding hazards.

Object-View Interface

Given that quickly directing attention to the front of a vehicle when potential hazards are present is often imperative, the object-view interface orients a driver's attention based on objects. Further, this interface considers each driver's visual field (see Figure 3). The system detects surrounding vehicles so that drivers' decisions can be perpetually guided by a proprioceptive awareness of elements in the surrounding environment which they may or may not be aware of. We have chosen red rectangles to increase perceived immediacy of the AR stimuli. The rectangles first identify the vehicle in front of the ego car and subsequently move focus to identify surrounding vehicles. By alerting a

Figure 4: The first and second pictures show captured scenes from the prototype we have developed with MATLAB (Mathworks, Natick, MA). The last picture shows the example icons for UFOV interface. The lightening sign was a target icon of which drivers had to find the direction.

driver to one surrounding vehicle at a time, drivers might allocate their attention according to the moving rectangles. As their eyes track the moving rectangles, they can increase their situation awareness with visual reinforcement at all potential sites of visual attention.

Experiment Design

We mainly selected VACT type (UFOV interface, Object-View interface) and Driving Experience as experiment variables. The main dependent variable was braking reaction time [12]. We adopted NASA TLX scale for subjective mental workload [14], and scales for perceived usefulness from Ghazizadeh's work [6].

When a warning sign was suddenly displayed during manual driving mode suddenly, the participants were told to brake as soon as possible. The warning sign was a red triangle which was designed to pop up at the center of the windshield. Brake RT was calculated automatically in MATLAB psych toolbox (Mathworks, Natick, MA). We selected the braking reaction time as it shows how fast the participants perceive certain stimuli and it could represent how well they allocated their attentional resources after the takeover.

For a moderating variable, we categorized the participants into 'Experienced' and 'Novice' drivers. We adopted two standards in categorizing novice and experienced drivers. We mainly used 'driving hour per week' and 'years since licensure' as a secondary rule [29]. In particular countries, owning a driver's license does not necessarily mean he/she drives on a regular basis. Thus, the researchers set a one-hour rule arbitrarily, assuming an hour per week is the least required driving hour in order to be deemed as possessing driving skills. We redefined novice drivers as the ones who drive less than an hour per week.

Apparatus

For the experiment, we developed a simulated driving environment with Logitech steering wheel and brake. G27 model was used and configured using Matlab software (Mathworks, Natick, MA). In order to give the participants a sense of naturalistic drive, we adopted the environment setting from Soro et al. and Nees et al.'s work [24, 31]. They benefited from the method to generate abundant design ideas. Regarding the cost of an actual windshield application, their study showed a fast and effective way to develop an idea into experience. Similarly, we used blackbox driving videos to build a semi-naturalistic driving environment. We selected three driving videos from Youtube channel, all containing a similar driving environment and scenario [8, 9]; all three driving were on the highway, with little lane changing and no accidents happening (Figure 4). The video was displayed on a 42 inch' LCD monitor, 1920x1080 resolution.

Participants & Procedure

In total, 67 persons participated in the experiment. Undergraduate and graduate students who have a driver's license attended. In total 57 persons' data were used (36 males, 21 females) as data of 10 participants were discarded (3 due to the system error, 7 were outliers).

The participants were asked to sign consent forms for data collection. An introduction session was provided to the participants, including explanations of automated cars, the transition of control, and windshield display. Then they were told there were two conditions of display and how they should interact with each of them. For UFOV condition, they were told to look for a lightening sign and push the button accordingly. For

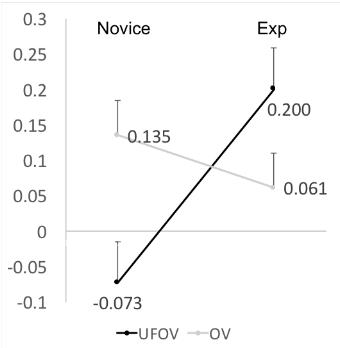


Figure 5: The estimated marginal means of the difference measure of Brake Reaction Time (Baseline - Condition)

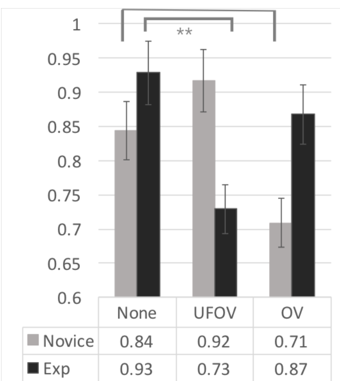


Figure 6: The estimated marginal means of the difference measure of Brake Reaction Time (Original Value)

Object-View condition, they were told to watch and push nothing.

The whole trial included three sessions, first baseline condition (control condition with no additional interface) was provided and then the other two interface conditions were given in random order. When the driving session starts, the drivers did not conduct any additional non-driving-related tasks [15] but looked at the screen and thought about sad movies or novels. We instructed the participants to tell the experimenter afterwards about a sad movie or story to let them fall into mind wandering [15]. Also, we deliberately lengthen the automated driving mode to 3 minutes in order to naturally spur a mental underload state. Then with a sound alarm, one of the visual assistance conditions was provided. The VACT icons (Figure 4) were blinked for 200ms~500ms, 5 times each. After providing with VACT, a takeover request was presented through TTS with the message "You must take over now". The participants prepared to takeover by grabbing the wheel and pushing the accelerator. As they were instructed to drive without lane changing after the takeover, they did not need to steer the handle. After several seconds, a red triangle appeared in the center of the screen. As soon as the participants saw the warning sign (red triangle), they braked. After each trial ended, the participants answered the survey questions (Figure 1).

Result

We ran a repeated-measure ANOVA, with Experience as a between-variable and VACT type (UFOV or Object-View) as within factor. For comparison, the brake RT data was subtracted from the baseline condition. An interaction effect between the VACT type and Experience was found, $F(1,55)= 12.019$, $p< .05$, $\eta G^2=$ 0.071 (Figure 5). Reduction in RT was higher in UFOV conditions for experienced drivers (M=0.2, SD = 0.39). However, for unexperienced drivers, the reaction time in UFOV condition got slower than the baseline (M=-0.073, SD=0.434).

We also analyzed the brake reaction time with the original values. The result revealed an interaction effect between the VACT type and the driver experience, $F(2,110) = 5.932$, $p< 0.05$ (Figure 6). The post-hoc analysis was conducted with paired samples t-test for each group. In the novice group, the result showed a significant difference in brake reaction time between baseline & OV condition and OV & UFOV condition ($t(35)=2.854$, $t(35) = 3.596$, $p<.01$, both two-tailed p-value). In experienced group, a significant difference was found between baseline & UFOV condition ($t(20)=2.3$, $p<.05$, two-tailed p-value).

Mental workload was measured using NASA TLX scale. The task definition stated 'the whole process of the takeover including interaction with displays'. A main effect for VACT type was showed, $F(1,55) = 13.858$, $p<.05$, $\eta G^2 = 0.106$. Except for Novice-OV condition, mental workload was increased in other conditions (Figure 7). The UFOV interface was found to especially burden both groups of drivers. However, in Novice-OV condition, mental workload was decreased (M=-0.53, SD=5.67).

Perceived usefulness was analyzed with the original values and the baseline condition was not to be answered by the participants. A main effect of VACT type (UFOV and OV) was found, $F(1,55)=11.806$, $p<.01$. Also, an interaction between the VACT type and driving experience was statistically significant, $F(1,55)=22.662$, $p<.01$ (Figure 8).

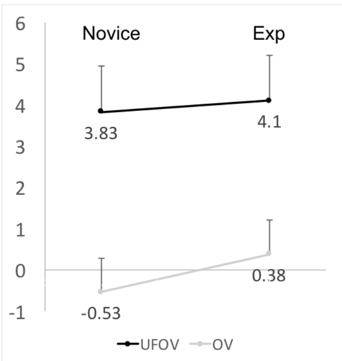
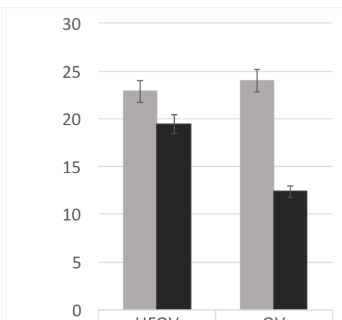


Figure 7: The estimated marginal means of the difference measure of NASA TLX (Condition-Baseline)



	UFOV	OV
Novice	22.89	24.03
Exp	19.43	12.38

Figure 8: The estimated marginal means of the difference measure of Perceived Usefulness (Original Value)

Qualitative Results

After the experiment, the participants answered questions about how they felt during each condition. We mainly questioned about the relative merits and pitfalls of the three conditions (baseline, UFOV interface, Object-view interface). Regarding the UFOV interface, some participants commented that they were not able to see the road properly due to the UFOV task. Also, they reported that the UFOV task was 'too hard', 'distracting', or 'buzzing'. Other participants commented that the interface actually helped them focus before they took over the control. It was 'good' as it successfully warned them to drive again and they felt that 'the situation was under control'.

Regarding the Object-View interface, a number of participants mentioned that they liked it as they 'could see what is perceived by sensors'. They said they thought the (automation) system detected surrounding vehicles for them when red rectangles appeared on the screen. Also, some drivers reported they could look out for road situations well and easily. Compared to the UFOV interface, the interface 'captured their attention at a right amount' as they did not have to push any buttons additionally. However, others said they 'did not really see the red rectangles' as they did not have to move actively to give an answer like with the UFOV interface.

Discussion & Conclusion

Our study explored possible solutions to the unsolved problem, driver passivity. As the experiment was conducted in a limited lab environment, it might be hard to generalize the result that providing VACT types lead to actual cognitive training effect such as improved attention capacity or widened field of view. However, the study underlies an opportunity area in future automotive interface design. The findings suggest that an intermediary system might be needed for drivers to gain vigilance before they take over control from his/her car. By providing a 'preparation session' for drivers, even for a short period of time, he/she might get refreshed from non-driving-related tasks and have their mind and body ready to regain the control.

The interaction effect in the reduction of brake RT implies an interesting aspect in designing vision assistance system. In the case of an experienced group who drives on a regular basis, the UFOV interface could be useful to shift attention and regain vigilance. Although the size of reduction in RT could seem small, the result showed that the UFOV and OV interfaces could affect the reactivity after the takeover. In real road situations, a subtle change of responsiveness in milliseconds could mean saving a critical safety margin. For novice drivers, the OV interface could appropriately capture their attention, providing contextual information.

In this study, we showed how dynamic interfaces could be exploited in takeover scenarios. Implementing visual assistance might increase readiness to takeover for an automated system, and that readiness could be a critical factor for safe driving. Even though the study is at an exploratory stage, we expect to inspire the HCI community to conduct further researches in this area.

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