Driving Assistance with Conversation Robot for Elderly Drivers

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Abstract. On the one hand, mobility of elderly people is critical for their quality of lives and welfare. On the other hand, older drivers have higher crash rates per vehicle-mile of travel. In order to achieve the two conflicting goals, driving safety and mobility of the elderly, the present paper aims to discuss the possibility that intelligent artifacts can play a role of reducing crash risk of elderly drivers. A research design for obtaining empirical evidence on the effectiveness of robot presence in vehicles is also discussed.

Keywords: Driving, Crash risk, Passenger presence, and Conversation robot.

1 Introduction

Mobility of elderly people is critical for their quality of lives and welfare. According to summaries by Stutts and Wilkins [1] and the authors, loss of mobility among the elderly may lead to loss of identity and increased dependency; physical and mental problems such as increased depression, heart disease, fractures, and stroke; and decreased social integration, as measured by the number and frequency of social contacts. Therefore, it is important for elderly people to continue driving as long as possible.

A problem arises here, because older drivers have higher crash rates per vehicle-mile of travel [2] due to factors such as the decline in their driving abilities. Therefore, significant motivation exists to explore measures that would compensate for these deficiencies [3].

This motivation is gradually becoming stronger because the number of patients with dementia is expected to increase rapidly over the next few decades in many countries, including Japan. In Japan, according to [4], there were 1.49 million patients with dementia in 2002, and this number is estimated to increase to 3.85 million in 2040. Although dementia can impair driving and increase crash risk, the reality is that

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around one-third of drivers with dementia continue to drive [5]. Therefore, measures for reducing the risks of these drivers are strongly required.

It is often discussed that encouraging passengers to accompany elderly drivers in vehicles appears to be one of the most promising measures to compensate for the decline in their driving ability. As described in greater depth in the following section, earlier studies have consistently found that passenger presence has a protective effect for older drivers.

However, it seems too optimistic to believe that promoting elderly drivers to accompany their family members will be a dominant approach for crash risk reduction, because the family members do not necessarily have time to be with their elderly family members. Thus, it is meaningful to consider the possibility that intelligent artifacts can play the role of human passengers and reduce crash risks of elderly drivers, in place of human passengers.

Thus, on the bases of the earlier empirical findings of the authors, the present paper aims to discuss this possibility. The structure of the present paper is as follows. In section 2, findings of earlier studies of the authors are presented regarding the psychological influences of passenger presence on drivers. In section 3, ethnographic and experimental findings of the authors are presented regarding the attachment and other feelings of human toward intelligent artifact. Taking into account the contents of these two sections, section 4 discusses how robots are likely to play the supportive roles in vehicles as passengers. Section 5 considers research designs required to investigate whether and under what conditions the supportive roles of robots emerge.

2 Influences of Human Passengers on Drivers

Earlier studies have consistently found that passenger presence has a protective effect for older drivers. For example, Hing, Stamatiadis, and Aultman-Hall [6] found that the presence of two or more passengers negatively affected the probability of drivers aged 75 years or older being at fault in crashes. Lee and Abdel-Aty [7] found that drivers aged 60 years or older generally displayed safe driving behavior when accompanied by passengers and having more passengers reduced their crash risk. Engström, Gregersen, Granström, and Nyberg [8] also found that crash risk was higher for those who drove alone, regardless of their age, and that the protective effect increased with every extra passenger (up to eight). Rueda-Domingo et al. [9] found that the protective effect of passengers was higher for drivers aged more than 45 years and lower for drivers aged 23 years or less.

It is also known that passenger presence can be a risk factor for drivers in specific circumstances, especially when young (teenage) drivers are accompanied by passengers of the same generation [10].

Although the above mentioned influence of passenger presence on drivers is important, the psychological mechanisms underlying these effects on drivers are yet to be sufficiently understood. Many researchers have speculated on how these effects emerge, in order to account for the observed increase or decrease in crash risk with regards to the presence of passengers in specific circumstances. For example, Rueda-Domingo et al.[9] considered the possibility that decreased crash risk in the presence of passengers younger than 15 years is the result of a more defensive driving behavior by parents. They also considered that the protective effect of female passengers on male drivers is attributable to the active role of women in trying to modify male drivers' style towards safer practices. Hing, Stamatiadis, and Aultman-Hall [6] suggested that passengers pose a distraction to older drivers and enhance crash rates if the level of the distraction exceeds a certain point. Simons-Morton, Lerner, and Singer [11] considered that teen passengers cause distractions to the driver by various actions, such as talking, fiddling with the radio or CD player, moving about, or touching the driver. They also considered that teenage drivers are inclined to drive in a more reckless manner (e.g., drive faster, catch up with, and pass another vehicle) when accompanied by teenage passengers because the drivers perceive that the latter view such driving behavior as desirable or expected. Vollrath, Meilinger, and Krüger [12] considered the following possibilities: passengers help drivers in detecting critical situations; the presence of passengers leads to a more responsible driving behavior; and conversations with passengers draw drivers' attention away from driving-related tasks. Lam, Norton, Woodward, Conner, and Ameratunga [13] considered that passenger presence may be a distraction to drivers, because of the greater verbal interaction, music playing or even physical interactions with drivers. They also considered that passenger presence distracts drivers and impairs their ability to detect changes in the surrounding environment.

Not only after comprehensively identifying dimensions in reference to these earlier studies but also after adding new ones after brainstorming by the authors, the present paper considered the following as a tentative list of dimensions: (1) calmness, (2) distraction, (3) flattery, (4) overdependence, (5) pique, (6) direct pressure, (7) indirect pressure, (8) relaxation, (9) relief, (10) responsibility, (11) slackness, (12) shrinkage, and (13) vanity. Possible feelings of drivers are shown below that are associated with each dimension either positively or negatively.

1. Calmness

- With him/her as a passenger, I am less frustrated in traffic congestion.
- With him/her as a passenger, I can make decisions calmly.
- I appreciate him/her as a passenger because he also gets angry when I encounter dangerous drivers or when I am bothered by very slow drivers.

2. Distraction

- I want him/her to keep quiet while I drive.
- His/her wrong sense of direction makes me frustrated.
- With him/her as a passenger, I get frustrated because we do not have the same taste in music (or radio programs)

3. Flattery

- When signals change from blue to yellow, I accelerate over the cross sections in order to comply with his/her intent.

- I exceed the speed limit in order to comply with his/her intent.
- I reduce the following distance in order to comply with his/her intent.

4. Overdependence

- While entering main roads from restaurants or shop parking lots, I assume that he/she should be looking out for cars in the direction I am not looking.
- While turning right[1] at cross sections, I assume that he/she should be looking out for pedestrians and bicycles crossing the road that I am going to enter.
- While changing lanes, I assume that he/she should be looking out for cars approaching from behind in the new lane.

5. Pique

- When he/she gives me driving suggestions, I feel that my driving skills are underestimated.
- With him/her as a passenger, his/her suggestion hurts my self-esteem.

6. Direct pressure

- He/she pressures me by urging me to exceed the speed limit.
- He/she pressures me by urging me to reduce the following distance.

7. Indirect pressure

- I would like to follow his/her request to reduce the following distance.
- I would like to follow his/her request to drive faster.

8. Relaxation

- With him/her as a passenger, I cannot feel relaxed while driving.
- With him/her as a passenger, I can enjoy driving.
- With him/her as a passenger, I get less bored in traffic congestion.

9. Relief

- While entering main roads from restaurants or shop parking lots, I appreciate his/her advice on when to start the car.
- While entering main roads from restaurants or shop parking lots, I appreciate that he/she looks out for cars in the direction I am not looking.
- While turning right at cross sections, I appreciate that he/she looks out for pedestrians and bicycles crossing the road that I am going to enter.

10. Responsibility

- With him/her as a passenger, I feel that I do not want him/her to be injured by crashing while I am driving.

[1] Right-hand side traffic is adopted in Japan.

- With him/her as a passenger, I feel that I have his/her life in my hands while I am driving.
- With him/her as a passenger, I keep a longer distance between the car ahead in order to ensure safety.

11. Slackness

- With him/her as a passenger, I become big-hearted.
- With him/her as a passenger, I do not strongly feel that I have to follow the speed limit.
- With him/her as a passenger, I do not strongly feel that I have to fasten my seat belt.

12. Shrinkage

- With him/her as a passenger, I am afraid he/she will scold me if I make a mistake while driving.
- With him/her as a passenger, I am afraid he/she will scold me if I have difficulty in timely starting the car when turning right at intersections with heavy traffic or when turning left onto main roads.

13. Vanity

- With him/her as a passenger, I do not want to appear to be unskilled at driving.
- With him/her as a passenger, I want to show him/her that I am skilled at overtaking.
- With him/her as a passenger, I feel ashamed if I cannot smoothly park in parking lots.

These thirteen dimensions can obviously be classified into two groups according to whether they help drivers to concentrate on driving (dimensions 1, 8, 9, and 10) or they prevent drivers to do so (dimensions 2, 3, 4, 5, 6, 7, 11, 12 and 13). Although there is no empirical evidence in the literature, it is likely that dimensions in the former group are associated with reduced crash risks of drivers.

3 Psychological Effects of Robots on Human

Nowadays, we can see various forms of communication between human and intelligent artificial things such as toys with autonomy, communication robots, and nursing robots. Whether these robots can really play a role of human passengers and reduce crash risk is our greatest concern.

The authors have conducted two preliminary studies for identifying psychological effects of robots on human. This section reviews of the findings of these studies.

3.1 Study 1: Robot in Ubiquitous Home [14]

Within robotic engineering, there are several experimental efforts underway to bring the robot into people's daily life. Kanda et al. put a robot in the elementary school over 18 days with the purpose of examining the interaction between children and robots. The children became tired of interacting with the robots by the beginning of the second week, while they actively interacted during the first week [15]. Another experiment showed that users maintained long-term interaction with robots in their daily lives. Matsumoto et al. investigated the cognitive activities of residents who lived in the Ubiquitous Home with task-oriented robots. Interviews with the residents showed that the residents gradually came to consider the robot to be an artifact and they also see it as a cohabitant at the same time, although they had no affection for the robot in the early stage [16].

The objective of this study was to examine an unprecedented phenomenon in communication between human and intelligent artifacts within the home environment over the course of a 16 day-long experiment.

Experimental Design. The robot in the Ubiquitous Home is called “Phyno1.” Phyno is being designed as a visible-type robot for the Ubiquitous Home. It provides the owner with multiple services such as TV program recommendations (at living room), providing recipes (at living room and kitchen), and a reminder service (entrance room). In addition, the robot is able to turn on/off the light, TV, an alarm clock, and air conditioner. In the Ubiquitous Home, there are five robots in total at each room (entrance, living room, kitchen, bedroom, and study room). All robots have voice recognition and synthesis systems based on Julius2. The voice recognition result is preserved in the text data.

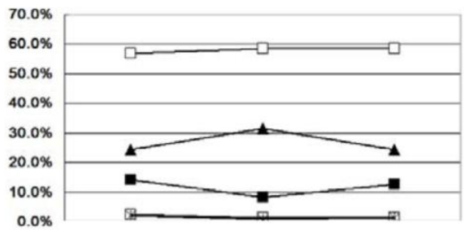
The subjects who resided in the Ubiquitous Home are a couple composed of a 64-year-old male and a 60- year-old female. Both have no contact with robots in daily life. Subjects resided in the home for 16 days from 14 to 29 January 2006. Subjects were asked to live an ordinary life at the Ubiquitous Home. The instruction was as follows: 1) The purpose of this experiment is a data collection of an ordinary life at the home of the future. 2) Please have as natural a life as possible, and talk to the robot freely. 3) Please turn on/off the light, TV, and air conditioner through the robot. Subjects read an easy manual for instructions on how to request tasks of the robot before the experiment.

Method of Analysis. The recorded voices of the subjects were transcribed and were classified into four categories: task request (e.g., “Turn on the light”), conversation with the robot (“Thank you”), evaluation of the robot (e.g., “Brilliant”), and description (e.g., “Phyno said something”) and direct action (e.g., touching, patting, hitting). Then it was analyzed how the frequency of voices in each category changed throughout the 16 days. This analysis was conducted by dividing the 16 days into three phases and comparing the frequencies in these phases.

Results and Discussions. From results of time-series analysis that utterance frequencies in the first term occupies about half (44.6%) (Table 1), it is interpreted that utterance frequencies decreases because users get accustomed to the intelligent artifacts, while they have strong interests in it in the early stage. In the utterance contents, the category "task request" does not have a significant difference within three phases (Figure 1). Users follow the instruction and use the robot consistently to request any tasks. The category "conversation", "description", and "direct action" were significantly different in each phase. The category "description" and "direct action" has a significant difference in plus in the first phase, gradually decreased in the middle phase, and again increased in the last phase. This may also indicate that users have contact to the intelligent artifacts with strong interests at first, and then gradually they get familiar with the robots. On the other hand, in the category "conversation" the ratio increased in the second phase (Figure 1). It is reported that people frequently talk to the object (cf. pet, toy, pet robot) which they have attachment emotions. In our research, the ratio of conclude that users' attachment for the intelligent artifacts had gradually grown.

Table 1. Utterance frequencies in three phases

The 1st phase	The 2nd phase	The 3rd phase
959 (44.6%)	572 (26.6%)	618 (28.8%)



Category	The 1st phase			The 2nd phase			The 3rd phase		χ^2 (4)
Task request	547	57.0%		334	58.4%		362	58.6%	ns
Conversation	233	24.3%	▽▽	180	31.5%	▲▲▲	151	24.4%	9.49**
Evaluation	24	2.5%		7	1.2%		9	1.5%	ns
Description	20	2.1%	▲▲	4	0.7%	▽	8	1.3%	4.91+
Direct action	135	14.1%	▲▲	47	8.2%	▽▽▽	78	12.6%	11.79**
Total	959	100.0%		572	100.0%		618	100.0%	

Fig. 1. Cognitive differences in time-series change

The results indicate that (a) users get accustomed over time to the intelligent artifact and attachment emotions are elicited gradually with the passage of time.

3.2 Study 2: Cooking Support Robot [17]

The next study aimed to examine the influences of the conversational robot in the cooking support system. Though many systems to support cooking activities have been developed [18,19], cooks have to cook solely in most of them. Solitary cooking makes cooks bored and tired. In addition, inexperienced cooks cannot sometimes carry on cooking because they have little motivation. A cooking support system should maintain their motivation for cooking by provision of not only pleasure but also motivator. Therefore, we developed a cooking support system with a conversational robot in our previous research [20]. This is because we hypothesized the robot in the cooking support system can cover the shortcomings of existing systems.

Experimental Design. The cooking support system instructs a cook by images, speeches and the robot. In our previous research, we used images and speeches originally used in PTC. After running PTC on the game machine, we captured images on the screen and speeches from the speaker. In the previous research participants complained of robot's speeches of the cooking instructions. Therefore we decided to change the original speeches into human voices. This could solve their complaints and provide them with a comfortable cooking environment. To create high-quality and profluent speech data, an announcer in our university's broadcasting station who has clear voice help us. We created high-quality speech data by recording and editing his speeches that he read aloud lines. In addition, an agent character appeared in PTC images was erased from the captured so as not to have effects on the result of the experiment. The captured image is shown on the cooking table by the projector installed in the ceiling. The speech is outputted from the speaker on the cooking table. The position and size of the image and the position and volume of the speaker were calibrated in advance so as not to interrupt the cook's activities.

The experiment is conducted by Wizard of Oz (WOZ) method. A microphone and camera are put to enable the experimenter to see what the participants are doing. The experimenter was in the bedroom, and controlled the timing of changing a cooking step and the robot's actions by monitoring the kitchen through the camera and microphone. We chose "Dashi rolled egg omelet" as a recipe for the experiment. This is because the participants can cook Dashi rolled egg omelet in a short time. In addition, Dashi rolled egg omelet is moderately difficult for cooking novices but they can develop their cooking skill by repeated practices. Two tasks are used in the experiment. One is a task using only the cooking support system (abbr. non-robot task), and the other is a task using the cooking support system with the conversational robot (abbr. robot task). In non-robot task, the participants cook according to an image projected on the cooking table and a speech from the speaker. On the other hand, in robot task, they cook according to a gesture of the robot in addition to the image and the speech.

We measured a cook's pleasure and motivation for cooking because we hypothesized that the effects includes improvements of the pleasure and motivation. The pleasure has two types; that caused by enjoyment and immersion. A decrease of the motivation arises cook' s tired and annoyed feeling. Therefore, the questionnaire includes four questions: "Did you enjoy the cooking?" and "Did you immerse yourself in the cooking?" for measuring pleasure, and "Did not you get tired of the cooking?" and "Did not you get annoyed with the cooking?" for measuring motivation.

The participants were twenty one males and five females. To minimize variability of the level of cooking, we had a questionnaire about the experience of cooking before starting the experiment. The result showed that eight participants have lots of experience and eighteen participants lack experience. Therefore, we assigned four experienced people and nine non-experienced people to non-robot task and robot task respectively.

The participants conducted one task either non-robot task or robot task. Ingredients and tools are prepared by the experimenter and put on the cooking table in advance. The experimenter provided the participants with prior explanation before starting the experiment. The prior explanation included how to use the cooking support system and ingredients. After finishing a task, the participants answered a questionnaire about the system. Here, if there are remaining tasks, they conducted the cooking and answered the questionnaire again. When the participants performed the task three times, the experiment was finished.

Results and Discussions. The results (enjoyed, immersed, not tired and not annoyed) are illustrated in Figure 2. It shows the mean value and standard deviation of each trial. The higher the value is, the higher evaluation is. As a result of t-test between the non-robot task and robot task, no significant differences were found, in spite of our expectation that robots would enhance the evaluation.

Then we evolved this system more sophisticated. The voice of the robot was changed into recorded voice of man from the synthesized speech. Speech of the robot was improved to vary de pending on the situation properly between courtesy and brevity. As a result of them, it was found that fine-grained control of the speech of the robot had a significant effect. It was also revealed that the effect acquired by adding a dialog robot to a cooking supporting system serves as the maximum to cooking beginners.

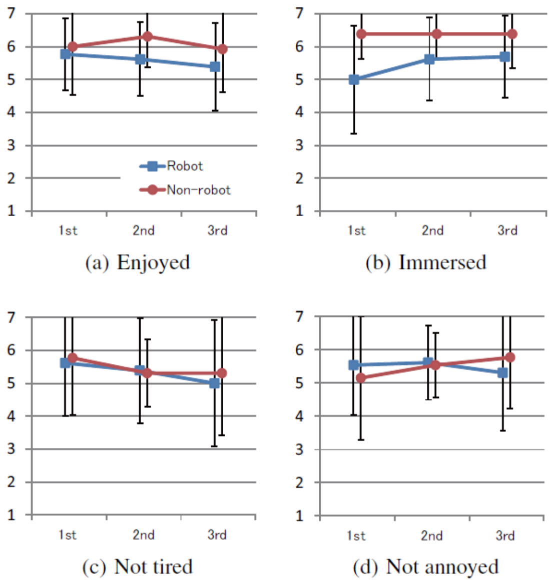


Fig. 2. Results of an experiment

4 Expected Effects of Robots as Passengers on Drivers

Section 3 revealed that human passenger presence can have influence on drivers. Taken together with the findings in Section 4, it is not too optimistic to believe that robots can have protective effects on drivers in place of human passengers. Furthermore, taking into account the fact that human passenger presence does not always influence drivers positively, it may be possible to design passenger robots so that they can have higher net protective effects on drivers than human passengers do. In this section, it is discussed what kind of empirical evidence will be necessary to come up with such a design.

4.1 Generating Positive Effects of Robot Passengers on Drivers

Among the thirteen dimensions on the psychological effects of human passenger presence on drivers, there were four dimensions that obviously have protective effects on drivers: (1) calmness, (8) relaxation, (9) relief, and (10) responsibility. Among these four, it seems that dimension (10), responsibility, can be generated by robots. In fact, if drivers feel attachment toward robot passengers, it is likely that drivers feel as if they are living creatures and have a sense of responsibility. Likewise, drivers can feel (1) calmness with such robot passengers.

The effects of (8) relief might also be generated by robots, but the mechanism of the emergence of this dimension should be different from that of dimension (10) responsibility. Drivers feel relief with human passengers if and only if they trust the passengers' ability to give useful information to them. This would be possible if robots provide vocal assistance through a safe-driving navigation system. Taking into account the findings of study 1 in Section 3, fine-grained control of the speech of such a system is critical for generating the sense of (8).

To summarize, emergence of some dimensions of positive effects depends on the presence of robots and the extent to which drivers feel attachment toward them, and emergence of other dimensions depends on how and what the robots speak.

4.2 Minimizing Negative Effects of Robot Passengers on Drivers

In order to enhance the net protective effects of robot passengers, it is also important to minimize negative effects of robot presence. In study 1 of section 3, semi-structured interview was also conducted after the experiment. The subjects had some complains on the function of the home robot such as "my voice is not easily recognized" and "I want the robot not to answer by mistake. In vehicles, drivers may well have similar feelings, and feel the sense of (2) distraction. It is an essential requirement to find how to minimize this effect is

5 Future Tasks for Designing Driving Assistance Robots

According to Vollrath, Meilinger, and Krüger [12] and other authors, the emergence of the protective effect of human passengers might depend on (i) characteristics of the situations under which driving is performed (e.g., location, weather, road surface, time of day, visual conditions, type of road, traffic density, and day of week), (ii) driver characteristics (e.g., gender, age, and familiarity with the region), and (iii) passenger characteristics (e.g., gender and age). Also, the authors previously suggested that whether the protective effect emerges for elderly drivers depends on the cognitive levels of the drivers.

Similarly, in order to design driving assistance robots, it is an essential requirement to identify conditions under which protective effects dominate negative ones. One promising measure of identifying these conditions is to conduct experiments using driving simulators, especially when we would like to identify personal characteristics (rather than situational factors such as weather) that moderate the association between robot presence and driving performance.

By doing so, we can efficiently collect data on the driving performance of treatment group (i.e., drivers accompanied by robots) and control group (i.e., drivers driving alone). All we have to do is to find conditions of personal characteristics under which driving performance of these two groups differs more. The candidates of such personal characteristics include demographic characteristics such as gender and age, personality characteristics measured by various psychological instruments, results of brain diagnosis using brain imaging, scores of cognitive tests, driving skills, and so on.

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