Effects of gender, age, experience, and practice on driver reaction and acceptance of traffic jam chauffeur systems

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This study conducted a driving simulation experiment to compare four automated driving systems (ADS) during lane change demanding traffic situations on highways while accounting for the drivers’ gender, age, experience, and practice. A lane-change maneuver was required when the automated vehicle approaches traffic congestion on the left-hand lane. ADS-1 can only reduce the speed to synchronize with the congestion. ADS-2 reduces the speed and issues an optional request to intervene, advising the driver to change lanes manually. ADS-3 offers to overtake the congestion autonomously if the driver approves it. ADS-4 overtakes the congestion autonomously without the driver’s approval. Results of drivers’ reaction, acceptance, and trust indicated that differences between ADS designs increase when considering the combined effect of drivers’ demographic factors more than the individual effect of each factor. However, the more ADS seems to have driver-like capacities, the more impact of demographic factors is expected. While preliminary, these findings may help us understand how ADS users’ behavior can differ based on the interaction between human demographic factors and system design.

The last two decades have witnessed rapid developments in automated driving technology. All aim to realize an old human vision of self-driving vehicles. The Society of Automotive Engineers categorized this vision into six levels of driving automation escalating from no driving automation to full driving automation1. Partial driving automation, which combines the features of lane-keeping assistance and adaptive cruise control systems, represents a borderline between conventional (human-controlled) vehicles and automated vehicles. Partial driving offers a shared responsibility of the dynamic driving task (DDT), which is divided into sustained lateral and longitudinal vehicle motion control (LVMC) that is performed by the system and objects and events detection and response (OEDR) that must be carried out by the driver2. Ultimately, when the partial driving system is engaged, the driver is driving, and thus he/she is required to monitor both the system and the roadway, respond appropriately, and retake the vehicle control where needed3. Concerns have been expressed on the potential effects of monotonous and predictable driving on drivers’ attention while supervising partial driving systems4,5. Such effects may impair drivers’ ability to interact appropriately with partial driving automation and perform the OEDR subtasks6–8.

With conditional driving automation mastering the LVMC and OEDR subtasks, the driver is no longer required to monitor the driving environment1. However, from the safety perspective, the driver should take control of the vehicle back from the system when necessary or, occasionally, requested by the system. The system’s request to intervene has motivated a large amount of research to understand the effects of drivers’ engagement on their takeover performance7. On the one hand, a considerable number of studies have highlighted the undesirable effects of drivers being out-of-the-loop on their ability to perform cognitive processing and retrieve manual control after automated driving8,11. On the other hand, some studies show that differences in drivers’ takeover performance when monitoring the roadway or engaged in non-driving-related tasks exist but are not significant12,13. When encountering a situation that requires driver intervention, is driver’s engagement during automated driving all that matters?

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In the aviation domain, automation is complex, and the pilots, usually a pilot and a copilot, must monitor a high number of parameters\(^1\). Although maintaining safety in such a complex system is an organizational effort, pilots are highly competent and trained to cope with the dynamically changing workload and situations\(^1\). The human–machine interface (HMI) in automotive automation could be less complex, but the driving environment is faster-paced and more complex than aviation, and drivers are less qualified than pilots\(^1\). In both aviation and automotive domains, the performance of the operation and tactical tasks and strategic decisions is highly dependent on humans’ ability to learn from heuristics and experience. These suggest a potential role of age and experience factors when operating airplanes and vehicles and deserve attention on these factors’ influence on control transition between humans and automated systems\(^6,17\).

Age has been found to affect humans’ hazard perception, reaction time, cognitive processing speed and quality, and task switching ability\(^8,19\). With manual driving, the driving performance of elderly and experienced drivers when exposed to secondary tasks is less affected than that of younger drivers who performed secondary tasks better with less attention to the driving task\(^20\). With automated driving, research has found that the takeover (the transferring of vehicle control from ADS to the driver) time by younger drivers was generally shorter than that of older drivers\(^21,22\). Further surveys have also highlighted the effects of drivers’ age on their acceptance of automated driving vehicles\(^23\). However, some studies have investigated the association between drivers’ age and gender and found, for example, a significant difference between younger male drivers and older female drivers in terms of reaction time and task performance during different conditions of manual driving\(^24\).

Recently investigators have examined the effects of training and practice on driver takeover during automated driving\(^25–28\). These studies established that prior familiarization and practice of automated driving affect drivers’ performance, acceptance, and trust compared to drivers presented with automated driving for the first time. Although the effects of driver demographic factors (e.g., gender, age, experience, and practice) on driver performance are not substantial, and trust have been investigated\(^29\), the effects of these factors and ADS designs on driver’s takeover decision and performance remains unclear. This study attempts to address this gap by evaluating drivers’ interaction with different ADS designs during non-critical automated driving while accounting for driver gender, age, experience, and practice factors.

This paper investigates the impact of human demographic factors on driver decision-making and control when exposed to different ADS designs and traffic conditions. The proposed ADS represents an idealized conditional driving system that can perfectly master the LVMC subtask at low speeds of up to 60 km/h and carry out the OEDR subtasks to a limited extent. The investigated scenarios replicate a conditionally automated vehicle approaching a traffic congestion (20 km/h) while the adjacent lane was available with light traffic circulating at 60 km/h. All test scenarios were not safety critical (no imminent crash), so the main focus could be understanding the accuracy and the promptness of the cognitive processing required to maintain safety during reactive control driving. It was hypothesized that the more the system requires drivers’ decisions and control, the less the drivers accept and trust the system. It was also hypothesized that the drivers would rather use the automated driving functions of the system when available than intervening in the automated process of the system. Finally, we anticipated that the combined effect of driver gender, age, experience, and practice would be more than the individual impact of each factor.

**Method**

**Participants and apparatus.** Forty volunteer drivers (Female = 20, Male = 20; Age\(_{min}\) = 22; Age\(_{max}\) = 69; Age\(_{mean}\) = 44.5; Age\(_{sd}\) = 15.4) holding a valid driver license participated in a driving simulation experiment. The experiment was approved by the ethical committee of the Faculty of Engineering, Information, and Systems at the University of Tsukuba, Japan. The experimental settings and design were performed in accordance with relevant guidelines and regulations published by the Japanese psychological association (https://psych.or.jp/). All participants signed informed consent and agreed to be a part of this experiment.

The experiment was implemented in a medium-fidelity driving simulator built by Honda (Fig. 1). The simulator consists of a dynamic car mockup mounted on four movable legs, in which an actual car seat and dashboard are placed with 120° projection screen and three small LCDs to simulate the front, rear, and side driving views, respectively. The simulator was equipped with conditional driving automation systems with a human–machine interface (HMI) to display the system state and roadway.

An ADS was available at a speed range between zero and 60 km/h based on traffic conditions. The drivers could activate and deactivate the system by shifting the gear stick between D for manual driving and D3 for automated driving mode. The system had four different states, as described in Table 1. These states were necessary lane-change maneuvers. However, the system may not return to HMI-1 (autopilot off) unless the driver shifts the gear stick to D3 or overrule the system operation by steering the vehicle or pressing the pedals.
ADS designs. The autopilot proposed in this study is a limited-speed traffic jam chauffeur (i.e., conditional automated driving) that can perform LVMC and OEDR subtasks for an extended time without driver intervention. It is different from the partially automated systems (e.g., Tesla’s autopilot) in which driver’s monitoring is necessary. When the automated vehicle approached a traffic jam on its main lane and the system displayed HMI-3 (Table 1), changing lanes was recommended to avoid slow traffic and recover the original speed. However, the system’s ability to detect and perform lane change maneuvers varied as follows:

(1) ADS-1 (baseline): the system could only keep the lane and continue automated driving at a slow speed (20 km/h). The driver could decide the next course of action whether to take over and change lanes manually or keep the automated driving at a slow speed on the left-hand lane.

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**Table 1.** HMI display of the automated driving system states. The HMI design was developed by Muslim et al.13

| System status                              | Description                                                                 | HMI                                      |
|--------------------------------------------|-----------------------------------------------------------------------------|------------------------------------------|
| Deactivated                                | HMI-1: The driver performs DDT entirely                                      | ![Auto Pilot Off](image)               |
| Activated at full speed 60 km/h           | HMI-2: ADS performs DDT entirely. Driver monitoring of ADS and traffic is optional | ![Auto Pilot On](image)                 |
| Activated during the traffic jam (< 20 km/h)| HMI-3: ADS synchronizes with the traffic jam ahead                           | ![Auto Pilot On](image)                 |
| Activated with action required            | HMI-4: ADS communicates with the driver to overtake the traffic jam          | ![Auto Pilot On](image)                 |
Experimental design and procedures. This experiment followed a within-subject repeated measures design such that each driver experienced the four ADS designs. For all participants, the experiment started with a demographic survey (5 min), a brief explanation (15 min), two training drives (5 min each), followed by four testing drives (8–10 min each), and ended with questionnaires. The familiarization and training phase started with a manual drive preceding an automated drive to introduce the participants to the driving simulator and automated driving. Each ADS design was tested once during the testing phase. The order in which the participants encountered the four ADS designs was randomized using the Latin-square method to reduce the order effects. Moreover, the participants were categorized based on their demographic factors, i.e., male and female drivers. Each demographic group was further subdivided into two subgroups (5 drivers each) based on age and driving experience (years of holding a valid driver’s license). The younger group consisted of drivers younger than 45 year-old with driving experience of more than 25 years. Each age group was further subdivided into two subgroups (5 drivers each) based on participants’ previous practice of automated driving within three months before the current driving experiment. At the end of each system, the participants had to complete post-experiment questionnaires regarding their acceptance of and trust in each ADS design. The participants were asked to mark their answers on a 10 cm line ranged between zero (not at all) and ten (absolutely).

Results

Table 2 presents descriptive statistics of the first control input by the drivers when encountering the traffic congestion for each ADS design. The system triggered HMI-3 to the driver’s first reaction (hands on the steering wheel, decision button, or none). The system status was calculated as the time elapsed from the system triggered HMI-3 to the driver’s first reaction (hands on, decision button, or none).

Table 2. Statistical data of the first control input by the drivers when encountering the traffic congestion for each ADS design. The purpose of the table is to understand the combined effects of the driver’s demographic factors (gender, age, experience, and practice) on driver behavior toward the system. Yes: drivers previously practiced automated driving; No: drivers presented with automated driving for the first time.

| Gender | Age and driving experience | Practice | Hands-on the steering wheel | Decision Button | None | Lane change maneuvers |
|--------|-----------------------------|----------|----------------------------|-----------------|------|----------------------|
|        |                             | ADS-1    | ADS-2                       | ADS-3           | ADS-4 | Manual               | Automatic |
| Male   | Younger                     | Yes*     | 5/5                         | 5/5             | 0/5   | 5/5                  | 2/5        | 0/5 | 0/5 | 0/5 | 3/5 | 11/20 | 8/20 |
|        | No*                         | 3/5      | 4/5                         | 0/5             | 1/5   | 4/5                  | 3/5        | 2/5 | 1/5 | 1/5 | 1/5 | 11/20 | 5/20 |
|        | Older                       | Yes      | 5/5                         | 4/5             | 0/5   | 1/5                  | 5/5        | 0/5 | 0/5 | 0/5 | 0/5 | 10/20 | 9/20 |
|        | No                          | 4/5      | 5/5                         | 0/5             | 1/5   | 4/5                  | 0/5        | 0/5 | 0/5 | 0/5 | 0/5 | 12/20 | 7/20 |
| Female | Younger                     | Yes      | 4/5                         | 5/5             | 0/5   | 5/5                  | 0/5        | 0/5 | 0/5 | 0/5 | 0/5 | 10/20 | 9/20 |
|        | No                          | 5/5      | 4/5                         | 0/5             | 0/5   | 5/5                  | 2/5        | 0/5 | 1/5 | 0/5 | 3/5 | 11/20 | 5/20 |
|        | Older                       | Yes      | 4/5                         | 5/5             | 1/5   | 1/5                  | 5/5        | 0/5 | 0/5 | 0/5 | 0/5 | 10/20 | 9/20 |
|        | No                          | 4/5      | 5/5                         | 0/5             | 0/5   | 5/5                  | 0/5        | 1/5 | 0/5 | 0/5 | 0/5 | 11/20 | 5/20 |
| Total  |                             | 34/40    | 37/40                       | 2/40            | 6/40  | 36/40                 | 9/40       | 6/40 | 3/40 | 2/40 | 25/40 | 10/20 | 10/20 |

(2) ADS-2: the system displayed HMI-4 requesting the driver to take over the vehicle control and change lanes. However, the driver could respond to the system’s request to intervene or ignore the request and let the system continue automated driving at 20 km/h.

(3) ADS-3: the system displayed HMI-4 requesting the driver’s permission to execute the lane-change maneuver automatically. The driver could approve the automatic lane change by pushing a button (Fig. 1, top-right) or ignore the request and let the system continue automated driving at 20 km/h.

(4) ADS-4: the system displayed HMI-4 informing the driver that an automatic lane-change maneuver will start in 6 s. The driver could disapprove of the lane change execution by pushing a button (Fig. 1, right) within the 6 s period; otherwise, the system proceeds with the maneuver.

ADS-1 did not support drivers’ decisions or actions when encountering traffic congestion, approximately 85% of the participants took over the vehicle control and manually changed lanes. For ADS-2, 92% of the participants responded to the system’s optional request to resume manual control and overtake the traffic congestion. While both ADS-3 and ADS-4 were able to perform lane change automatically, 90% of the participants pushed the decision button to permit ADS-3 automatic lane-change maneuver, approximately 40% of the participants pushed the decision button to interrupt ADS-4 automatic lane-change maneuver. In general, there was no significant effect of the demographic factors on drivers’ first reaction and choice. However, the design of the system and HMI strategies affected driver’s behavior toward each system more compared to demographic factors.
the wheel, foot on the pedal, or push the decision button) in response to the change in traffic condition. Statistically significant effects were identified for ADS design, gender, age and driving experience as well as practice (F (3, 156) = 4.32, F (1, 38) = 32.46, F (1, 38) = 27.03, F (1, 38) = 36.10 respectively, \( p < 0.01 \)). The analysis also indicate significant interactions occurred between ADS design and gender groups (F (3, 144) = 7.33, \( p < 0.05 \)), ADS design and age and driving experience groups (F (3, 144) = 9.18, \( p < 0.01 \)), and ADS design and previous practice (F (3, 144) = 11.12, \( p < 0.01 \)). In general, the driver’s reaction time results were comparable between the ADS-2 and ADS-3 conditions, but both were shorter than the ADS-1 and ADS-4 conditions. Supporting driver’s decision-making under ADS-2 and ADS-3 might reduce the time spent by the drivers to understand the ADS behavior and traffic condition, which could improve driver’s risk field and perceived risk31.

For each demographic factor, multiple comparisons with Tukey HSD indicated that drivers’ reaction time was comparable. Overall, the highest mean level was recorded under the ADS-1 condition (M = 10.83) by the younger male drivers with a first-time practice of automated driving, while the minor mean level was recorded under the ADS-2 condition (M = 4.66) by the older female drivers with the previous practice of automated driving. For ADS-1, the practiced younger female drivers reacted faster than the non-practiced younger male drivers (\( p < 0.05 \)). For ADS-2, the non-practiced younger male drivers reacted faster than the non-practiced older female drivers (\( p < 0.05 \)). The analysis indicated a significant difference between practiced younger female drivers and older female drivers under the ADS-3 condition (\( p < 0.05 \)) and between the practiced younger males and females (\( p < 0.01 \)) under the ADS-4 condition. These results indicate that while the effects of driver demographic factors may not be significant when considered separately, the combined effects of drivers’ gender, age, experience, and practice are more noticeable. They are consistent with our anticipation that the combined effect of driver demographic factors would be more than the separated effect of each factor.

Drivers’ acceptance of each ADS was evaluated based on their willingness to use the system in the real world. The question was administrated to the participants after completing all driving tests. Figure 3 compares drivers’ rating of their acceptance of each ADS design between groups and subgroups. In general, ADS-1 and ADS-2 were more accepted than ADS-3 and ADS-4. These results support the first hypothesis that the more the system
requires drivers’ decisions and control, the less the drivers accept the system. Each demographic factor resulted in differences between groups for each ADS design. These differences became significant when all factors, i.e., gender, age, experience, and practice, are considered collectively. The practiced older male drivers recorded the highest acceptance rate under the ADS-1 condition, and the non-practiced older male drivers recorded the lowest acceptance rate under the ADS-4 condition.

Wilcoxon Rank Sum test was applied to examine the differences between groups and subgroups within and between systems. The practiced older male drivers significantly more accepted ADS-1 than the non-practiced older female drivers ($Z = -2.03, p < 0.05$). However, comparisons of the acceptance of ADS-2 and ADS-3 did not reveal any significant difference between groups and subgroups. ADS-4 was significantly less accepted by the practiced younger male drivers and non-practiced older male drivers than the practiced younger female drivers ($Z = -3.57, p < 0.01$) and practiced older female drivers ($Z = -2.89, p < 0.05$) respectively.

The subjective assessment of the participants’ trust in the system was collected under each ADS design, as shown in Fig. 4. The question was to what extent they think the system is trustworthy. Although the participants’ rating of all systems was above the mid-value of the scale, ADS-4 was rated lower than other systems. When the participants were asked about the reason, they reported that it was difficult to trust a system that gives a short time (6 s) to decide whether they have to cancel its action or not in the presence of other vehicles passing at a higher speed on the adjacent lane.

The data in Fig. 4 shows that while the non-practiced younger female drivers recorded the highest trust rate under ADS-1, the practiced younger male drivers recorded the lowest trust rate under ADS-4. Wilcoxon Rank Sum test indicated that the practiced younger female drivers significantly more trusted ADS-4 than the practiced younger male drivers ($Z = -1.99, p < 0.05$). However, comparisons of the trust in ADS-1, ADS-2, and ADS-3 did not reveal any significant difference between groups and subgroups. These results indicate that ADS-1, ADS-2, and ADS-3 are affected by the demographic factors to a lesser extent than ADS-4, in which the system has a higher capability of decision making and action implementation without driver's intervention. Given that the majority of the drivers preferred to change lanes, the finding of ADS-4 condition is contrary to previous studies which have suggested that the more an automated system seems to have human-like behavior, the more human is expected to trust it$^{32,33}$.

Figure 3. Subjective assessment of drivers’ acceptance of ADS considers participants’ gender, age, experience, and practice.
Discussions

This driving simulator study investigated the effects of drivers’ gender, age, experience, and practice on their decision-making and control during low-speed conditional automated driving on a highway. The interaction between the investigated demographic factors and different ADS designs and capabilities resulted in a significant difference in drivers’ decision-making, reaction time, acceptance, and trust. When the drivers encountered traffic congestions during automated driving, they preferred to change lanes more than continue automated driving in the slow lane. Depending on ADS capabilities, the drivers resumed the vehicle control and changed lanes manually or provided an appropriate intervention to let the system changes lanes automatically.

Results of the type of the first control input by the drivers showed that the younger drivers were less likely to interrupt the automated driving compared to the older drivers. There was no significant difference in drivers’ reaction time associated with gender, but drivers who practiced automated driving before reacted faster to the HMI and traffic changes than first-time-practicing drivers. The results showed that the standard deviation of the drivers’ reaction time under the ADS-1 condition is larger than the ADS-2 condition, and the latter is larger than the ADS-3 and ADS-4 conditions. With ADS-1, the drivers had to perceive the traffic change and decide what to do without system support. ADS-2 supports drivers’ decision-making reduced the time spend by the drivers to reach a decision and act31. Further reduction in the standard deviation of drivers’ reaction time was achieved when the system supported drivers’ control with a time limitation to decide. These results support the second hypothesis that the drivers would rather use the automated driving functions of the system when available than intervening in the automated process of the system.

The overall drivers’ subjective assessments of their acceptance of and trust in the systems were above the mean. While the human demographic factors revealed significant differences under the ADS-1 and ADS-4 conditions, they did not reveal significant differences under the ADS-2 and ADS-3 conditions. The likely cause for such variance is related to the extent to which the design of each system is compatible with the concept of human-centered automation (see34,35 for more details). ADS-1 and ADS-4 did not support human decision-making when the automated process changed in response to an external change in the surrounding environment. It was difficult for the drivers to understand the automated process of ADS-4, which could lead to automation surprises and reduce human trust and acceptance. Although ADS-2 and ADS-3 differed in terms of systems capabilities, both systems are designed to support human decision-making and support drivers’ understanding of the automated process and the surrounding environment. These findings warrant future research on the influence of human and individual characteristics on user-ADS interaction and the design of automated vehicles.

Figure 4. Subjective assessment of drivers’ trust in ADS considers participants’ gender, age, experience, and practice.
Conclusions
Although the investigated scenarios were not time-critical, drivers’ decision-making was safety–critical as they had to scan the adjacent lane before deciding to proceed with lane change initiation. The investigation of the interaction between demographic factors and system design in such time-critical conditions has shown that the drivers tend to accept and trust systems with less intervention requirement than systems requiring driver intervention. This study has gone some way toward enhancing our understanding of how driver gender, age, experience, and practice will influence the potential effects of automated vehicles on traffic flow and safety. It also shows that cooperative ADS designs (e.g., ADS-2 and ADS-3) would compromise the influence of demographic factors. Though limited in terms of the small sample size and the investigated scenarios, these findings can be used to develop ADS interventions, particularly during the penetration of automated vehicles in real traffic and the potential conflict with the manually (human) controlled vehicles.

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**Author contributions**
M.I., funded, supervised, and guided the study; H.M. conceived the study and formulated the model; H.M., C.K.L. piloted the experiment and collected the data; H.M. conceived the analysis, analyzed the results, and prepared the figures; H.M. wrote the paper; J.A.M., N.U., M.I. reviewed and edited the paper.

**Competing interests**
The authors declare no competing interests.

**Additional information**

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