Automation, Collaboration, & E-Services

Vincent G. Duffy
Steven J. Landry
John D. Lee
Neville Stanton *Editors*

Human-Automation Interaction

Transportation

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Shimon Y. Nof, PRISM Center, Grissom Hall, Purdue University,
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The Automation, Collaboration, & E-Services series (ACES) publishes new developments and advances in the fields of Automation, collaboration and e-services; rapidly and informally but with a high quality. It captures the scientific and engineering theories and techniques addressing challenges of the megatrends of automation, and collaboration. These trends, defining the scope of the ACES Series, are evident with wireless communication, Internetworking, multi-agent systems, sensor networks, cyber-physical collaborative systems, interactive-collaborative devices, and social robotics – all enabled by collaborative e-Services. Within the scope of the series are monographs, lecture notes, selected contributions from specialized conferences and workshops.

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ACES Series Editor Foreword

Our Springer ACES Series is delighted to welcome the unique three-book excellent collection of editors, chapter co-authors and contributors on *Human-Automation Interaction.* This collection includes:

- Human-Automation Interaction: Mobile Computing
- Human-Automation Interaction: Transportation
- Human-Automation Interaction: Manufacturing, Services, and UX.

When we consider collaboration today, during the age of cyber-collaborative world and society, we cannot limit it any longer to human–human collaboration, the foundation and future of any human civilization. At the same time, we cannot ignore the fact that automation, while invented and implemented by humans, is made solely for the sake of humans. Hence, we have an essential need to understand and explore the science, engineering and management of HAI, *Human-Automation Interaction*. After all, the purpose of interaction is collaboration. That is the theme defined by the committee for the Gavriel Salvendy International Symposium for Emerging Frontiers in Industrial Engineering. (The committee includes Robert Proctor, Chair; Vincent Duffy, Shimon Nof and Yeuhwern Yih.) While during the pandemic years it could not be held in person, it was possible to engage many colleagues worldwide, who are the participants in this three-book important, collaborative endeavor.

Thanks again to all the participants and contributors, all of us who for many years have been inspired and learned from the leadership of Prof. Gavriel Salvendy. Thanks also to the Springer team, who supported the publication of these books. We would like to welcome and invite many readers of various academic backgrounds to enjoy these exciting articles as part of their exploration of HAI.

West Lafayette, IN, USA
June 2022

Shimon Y. Nof
Editor, Springer ACES Series

Preface (HAI: Mobile Computing)

Human-Automation Interaction (HAI) has become present and design considerations are now important in so many aspects of our lives. The themes of the three books are *Transportation*, *Mobile Computing and Manufacturing* and *Services and User Experience* (UX). This initiative is intended as a look toward the future and a tribute to our esteemed colleague, Gavriel Salvendy, who contributed to research literature and the infrastructure development in engineering, human factors and ergonomics over the past six decades.

We celebrate Prof. Salvendy's birthday this year with a compilation of articles in three main themes of *Human-Automation Interaction.* He reviewed and expressed interest in very many of the articles contributed this year. Over the past 40 years, he has been an editor of handbooks and journals in areas of overlapping research interest with most of our contributing authors. Dr. Salvendy is a founding chair of *Human–Computer Interaction International* (HCII) and *Applied Human Factors and Ergonomics International* (AHFE) conferences.

As co-editors, we invited and appreciated the opportunity to interact with the authors that contributed chapters within the HAI theme of their interest. We look forward to sharing these articles with a general audience that has an interest in human factors and ergonomics. We greatly appreciated the opportunity to celebrate international collaborations and contributors through this initiative. We are grateful to those who contributed to this special compilation of articles.

Papers from these volumes were included for publication after a minimum of one single-blind review from among the co-editors within the thematic areas. I would again like to thank the co-editors for their contributions, cooperation, support and efforts throughout. Eighty-six contributing authors from 11 countries contributed 30 articles to the book. Authors and editors in this book are representing China, Germany, India, Japan, Korea, Malaysia, Nigeria, Portugal, Switzerland, the UK and the USA.

The co-editors are Martina Ziefle, Patrick P. P. L. Rau and Mitchell M. Tseng. The main parts for the HAI Mobile Computing book are shown below:

Section A: Health, Care and Assistive Service
Section B: Usability, User Experience and Design
Section C: Virtual Learning, Training and Collaboration
Section D: Ergonomics in Work, Automation and Production
Section E: Interaction with Data and User Modeling in Special Applications.

On behalf of the co-editors

West Lafayette, IN, USA

Vincent G. Duffy

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Interaction with Vehicle Automation

The Shorter Takeover Request Time the Better? Car-Driver Handover Control in Highly Automated Vehicles

Hsiang-Chun Wang, Zhi Guo, and Pei-Luen Patrick Rau

Abstract The future development of fully automated vehicle cannot be predicted yet. Car-driver handover control need be existed in a certain period, but it is not well understood. The present study is to gain deeper insight into car-driver handover control in the highly automated vehicle by investigating the effects of mode transition, the time of transition to takeover request (TTR-time) and take over request time (TOR-time). Two experiments were conducted via driving simulator. Experiment 1 invited twenty participants to analyze the influence of TOR-time when resuming control. Experiment 2 recruited forty participants to further explore the effects of mode transition, TTR-time and TOR-time with a 2 * 2 * 2 mixed design. The shorter TOR-time resulted in less takeover reaction time but worse quality. Six seconds was the balance point between less takeover reaction time and higher handover control quality. In addition, the shorter TTR-time aggravated the significant difference of takeover reaction time caused by TOR-time, but the longer TTR-time abridged the significant difference and improved the attitude towards TOR-time during transition from level 3 to level 2 of automation. If the TOR-time is needed to be reduced in the design for acute threats, no less than six seconds would be better. If the future autonomous vehicle involves the mode transition of automation levels, designer and engineer also should take the time of mode transition to takeover request into account. These findings provide practical implications for the takeover control design of highly automated vehicles.

Keywords Autonomous driving · Levels of automation · Driver behavior · Human-automation interaction · Vehicle design

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1 Introduction and Background

Autonomous driving is widely assumed to be beneficial for road safety due to the operations of safety driving, like no speeding, no emotional driving, et cetera. But automated vehicles may also have negative effects on road safety [1–5]. For instance, crashes may happen when drivers have to resume the control while they are out of the loop and when the system fails to deal with the unpredictable behaviors of other road users, bad weather and complex urban traffic situations. The future development of fully automated vehicle cannot be predicted yet due to technology limitation. A mixture of vehicles with different automation levels will gradually change into a mixture of vehicles with higher automation levels to deal with these issues in the near future [4]. National Highway Traffic Safety Administration (NHTSA) in USA and internationally the Society of Automotive Engineers (SAE) have defined various levels of vehicle automation in order to differentiate the responsibilities between the driver and an automated driving system [6, 7]. The definitions indicate drivers also need to resume the driving control even in the highly automated vehicles. But the driver's responsibilities during autonomous driving between partial automation and high automation is hard to understand and will be an unfamiliar aspect of autonomous driving for novice drivers faced such systems. For example, the studies on highly automated systems showed that the operator's manual skills could be inhibited or even deteriorated in the presence of long periods of automation [8]. Given the problem, researcher and developer proposed adaptive automation in highly automated systems, like several complex automation modes (e.g. level 2 and 3 of automation) may be used in one vehicle [8, 9]. Therefore, it is a critical research topic to understand car-driver handover control.

In the past, studies on handover control in highly automated vehicles have focused on the effects of trust, traffic density, takeover scenarios, the secondary task and take-over request time (TOR-time) on take-over performance [10–20]. But studies on TOR-time are very limited to establish a well-understood foundation about how long it will take to get the driver back into the loop. Damböck et al. [21] found drivers were capable of taking over control within a time budget of 4–8 s, depending on the complexity of the situation. Gold et al. [14] found driver had the less take over reaction time with the shorter TOR-time by the comparison of 5 s and 7 s in a highly automated driving scenario with a secondary task and acute threats. But Walch et al. [10] found there was no difference of takeover reaction time between 4 and 6 s in a highly automated driving scenario with fog and hazards. Merat et al. [11] stated that it took drivers around 10–15 s to take over the car and 35–40 s to stabilize the lateral control of the vehicle in a highly automated driving scenario without hazards.

The previous works of TOR-time mainly focused on inattentive drivers in an autonomous driving with level 3 of automation defined by NHTSA, which did not consider the human-machine coordination with different automation levels. The transition among different automation levels would be better for driver to take over when confront the acute threats because the transition provides gradually change of monitoring levels. So what will happen for driver in the condition of mode transition

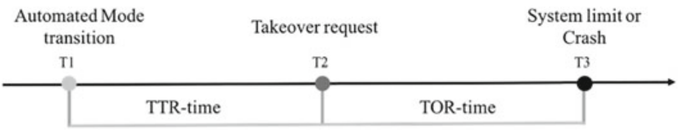

Fig. 1 The definitions of TTR-time and TOR-time

when taking over the automated vehicle? In addition, these studies concerned about different TOR-times and different scenarios, resulting in lack of comparison among the findings. Most studies concerned about tactical level [10, 14], like gaze behavior before the resuming control. Only one study was about the resumption of control on the operational level like lateral and vertical control after drivers resumed the driving [11]. In fact, both tactical and operational levels play important roles during the transition of control. In order to well understand the effects of TOR-time during take-over control, these issues should be taken into account.

Therefore, the present study focus on the operation level of driving task of attentive drivers within the situation of acute threats to (1) examine the specific influence of TOR-time in the same driving scenario via four levels occurred in previous studies [10, 14], and (2) investigate the effects of mode transition between level 2 and level 3 of automation, the time of transition to takeover request (TTR-time) and take over request time (TOR-time).

2 The Effects of Different Levels of TOR-Time

2.1 Objectives

Literature review shows that 4–8 s are the time budgets for most takeover driving studies. The time budget for take over request increase 1 s, the driver's takeover time will increase 0.33 s, and the takeover quality decrease [22]. But most comparative study of time budget apply more than 1 s as the interval. There is no study investigating which ranging from 4 to 8 s would be a balance point for TOR-time design with a 1 s interval. Therefore, the present experiment would examine the difference of time budget of 4, 5, 6, and 7 s in takeover driving.

2.2 Methods

Participants. Twenty participants (11 males, 9 females) took part in this experiment. Their average age was 27.16 years (*SD* = 2.80). All of them had a driving license for 4.76 years on average ($SD = 2.36$), and drove totally at least 5000 km before participating in this experiment. All participants had a normal vision and hearing.

Experimental Design. The experiment used a single-factor (TOR-time: 4, 5, 6 and 7 s) within-subject design. The order of the TOR-time conditions was random.

TOR-time is the time budget of takeover request, namely the time between the onset of takeover request and colliding or reaching the system limits if driver would not intervene.

The dependent variables included takeover performance [10, 14], driving performance within one minute after takeover [11] involving operational level of driving, and subjective experience ratings. The takeover performance was assessed using take-over reaction time and the number of collision within 100 m after driver's take over. Take-over time was defined as the time between the onset of take-over request and the moment when the participants starts to take over manual control of the automated car. Driving performance after take over was mainly assessed by lateral control indexes, namely the maximum steering angle, the maximum lateral acceleration and the standard deviation of steering angle which evaluates the driving stability, as the present study focus on the driver's steering behavior after resuming the car control.

Subjective experience ratings were assessed by the workload, satisfaction and attitudes towards TOR-time. The workload was measured by NASA-TLX [23]. The satisfaction was measured on a 7-point Likert scale by After-Scenario Questionnaire with three items, respectively the satisfaction with the ease, the time and the support information of finishing task [24]. The attitudes towards TOR-time were measure on a 7-point Likert scale by Semantic Differential Scale, including "urgent-non-urgent", "able to react-unable to react", and "safe-dangerous" for TOR-time, in which 1 represents the closest to the meaning of the left side and 7 represents the closest to the meaning of the right side [25].

Scenarios and Apparatus. The automated vehicle drive at a speed of 100 km/h on the right lane of a two-lane highway with a hard shoulder in a driving simulator. There are no other vehicles in the front of automated vehicle. On the left lane, other vehicles are driving at 90 km/h and driving distances were random (see Fig. 2a). Three acute threatening take-over scenarios occurred on the right lane were designed to explore the effect of time budget of takeover request (TOR-time) on driver's takeover performance and feelings during hand-over control. They were respectively the scenario of blocked road by sudden road construction without cues, the scenario of the sudden braking of the leading vehicle, and the scenario of illegally parking of a stranded vehicle ahead between the right lane and the road shoulder without cues (see Fig. 2). For all scenarios, when the emergency occurs, there are no vehicles on the corresponding and front part of the left lane and other vehicles driving at 90 km/h behind the left part of the automated driving vehicle. It provide an opportunity for the driver to take over the control and change lane.

The experiment was conducted in a six DOF (degree of freedom) driving simulator with a 270-degree field of view in Department of Automotive Engineering, Tsinghua University (see Fig. 3). Participants drove in the simulated car and were able to steer,

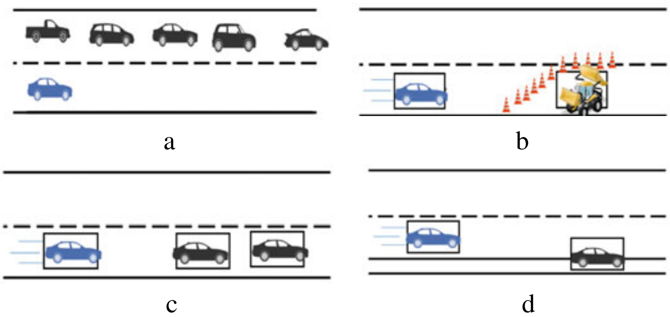

Fig. 2 The basic driving scene (**a**) and the scenarios of blocked road (**b**), sudden braking of leading vehicle (**c**), and illegally parking of a leading vehicle (**d**)

brake, accelerate and observe the real-time information about the driving on the dashboard, such as speed, tachometer and so on. The simulator could also automatically control longitudinal and lateral motion via the automatic system using programming. The sound effects of the engine, passing vehicles, audio signals and road environment were provided via audio simulating system of the driving cabin. The vehicle data were recorded in detail by the simulator. The road environment of the driving scene was a two-lane highway with a hard shoulder, and the speed was limited at 120 km/h in accordance with the speed traffic regulation in China.

Procedure. Participants drove freely 5 min to be familiar with the manipulation and presentation of TOR-time of driving simulator after the brief introduction of the experiment and the signature of informed consent. And then participants were required to finish three scenarios at each level of TOR-time. The three scenarios were displayed in a random order. All participants need to fill questionnaires of subjective ratings after each level of time budget.

The study was approved by ethics committee. All participants were provided with informed consent and obtained monetary compensation for their participation.

Fig. 3 The six DOF driving simulator used in the experiment

2.3 Results

For each dependent variable, the one-way repeated measures analysis of variance (ANOVA) was used to examine the effect of TOR-time. Multiple comparison test with bonferroni corrections were conducted to identify specific significant differences among means.

Take-over performance. The ANOVA result revealed a significant effect of TOR-time ($F(1, 19) = 11.92$, $p < 0.001$). According to the findings in the previous studies [10, 14], the comparisons between 4 and 5 s, 5 and 6 s, 6 and 7 s, 4 and 6 s, and 5 and 7 s were planned to be analyzed. Paired sample test showed there was a significant difference between 5 and 6 s ($M_{\text{TOR-5 s}}$: 1.58 ± 0.051, $M_{\text{TOR-6 s}}$: 1.87 ± 0.073, $p < 0.01$), between 4 and 6 s ($M_{\text{TOR-4 s}}$: 1.46 ± 0.061, $M_{\text{TOR-6 s}}$: 1.87 ± 0.073, $p < 0.01$), and between 5 and 7 s ($M_{\text{TOR-5 s}}$: 1.58 ± 0.051, $M_{\text{TOR-7 s}}$: 1.97 ± 0.121, $p < 0.01$); but the differences between 4 and 5 s ($M_{\text{TOR-4 s}}$: 1.46 ± 0.061, $M_{\text{TOR-5 s}}$: 1.58 ± 0.051, $p = 0.706$) and between 6 and 7 s ($M_{\text{TOR-6 s}}$: 1.87 ± 0.073, $M_{\text{TOR-7 s}}$: 1.97 ± 0.121, $p = 1.000$) were not significant, which was depicted in Fig. 4. In addition, the collisions of 4 s, 5 s, 6 s and 7 s were respectively 5, 2, 2, 1, but it was not examined because the expected values of over 20% cells were less than 5.

Driving performance. The driving performance was evaluated by lateral control indexes, including the maximum steering angle, the maximum lateral acceleration and the standard deviation of steering angle. The ANOVA results indicated the effect of TOR-time was significant for both the maximum steering angle ($F(1, 19) = 12.00$, $p < 0.001$) and the standard deviation of steering angle ($F(1, 19) = 13.54$, $p < 0.001$), and the effect of TOR-time on the maximum lateral acceleration was marginally significant ($F(1, 19) = 2.77$, $p = 0.078$). The descriptive statistic showed that the shorter TOR-time accompanied by larger maximum steering angle, larger standard deviation of steering angle and larger maximum lateral acceleration. But the significant difference occurred only in the pair of 5 s and 7 s, and the pair of 4 s and 7 s for both maximum steering angle ($M_{\text{TOR-5 s}} = 28.18 \pm 2.890$ vs. $M_{\text{TOR-7 s}} = 17.24 \pm 1.347$, marginally significant $p = 0.012 > 0.008$; $M_{\text{TOR-4 s}} = 35.17 \pm 3.576$ vs. $M_{\text{TOR-7 s}} = 17.24 \pm 1.347$, $p < 0.001$) and standard deviation of steering

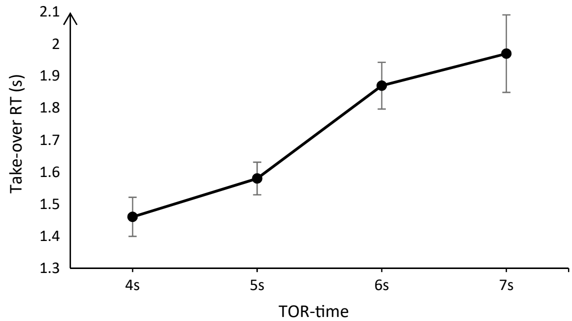

Fig. 4 The influence of TOR-time on take-over reaction time

angle ($M_{\text{TOR-5 s}} = 14.17 \pm 1.359$ vs. $M_{\text{TOR-7 s}} = 8.59 \pm 0.606$, $p < 0.008$; $M_{\text{TOR-4 s}} = 17.22 \pm 1.604$ vs. $M_{\text{TOR-7 s}} = 8.59 \pm 0.606$, $p < 0.001$). Although TOR-time had a marginally significant effect on the maximum lateral acceleration, the differences of each two levels of TOR-time were not significant according to the paired sample test with bonferroni corrections (all $p > 0.008$).

Workload and satisfaction. The ANOVA analysis showed the effect of TOR-time was significant for both subjective workload ($F(1, 19) = 4.25$, $p < 0.05$) and satisfaction related to the task ($F(1, 19) = 5.23$, $p < 0.05$). According to the descriptive statistic, there was a slight decrease of workload and an increase of satisfaction with the increase of TOR-time. Further analysis of multiple comparison indicated the difference between 4 and 7 s was marginally significant for workload ($M_{\text{TOR-4 s}} = 2.75 \pm 0.123$ vs. $M_{\text{TOR-7 s}} = 2.36 \pm 0.108$, $p = 0.01 > 0.008$) and significant for satisfaction ($M_{\text{TOR-4 s}} = 4.62 \pm 0.214$ vs. $M_{\text{TOR-7 s}} = 5.72 \pm 0.213$, $p = 0.004 < 0.008$).

Attitude towards TOR-time. "urgent-non-urgent", "able to react-unable to react", and "safe-dangerous" were used to assess the attitude towards TOR-time. A significant effect of TOR-time was observed for "urgent-non-urgent" ($F(1, 19) = 5.82$, $p < 0.01$), "able to react-unable to react" ($F(1, 19) = 4.04$, $p < 0.05$), and "safe-dangerous" ($F(1, 19) = 5.85$, $p < 0.01$). The descriptive statistic indicated that participants reported TOR-time they perceived was less likely to be "urgent" and more likely to be "able to react" and "safe" with the increase of TOR-time. Further analysis of multiple comparison indicated the differences between 4 and 7 s and between 4 and 6 s were significant for "urgent" ($M_{\text{TOR-4 s}} = 2.65 \pm 0.254$ vs. $M_{\text{TOR-7 s}} = 4.05 \pm 0.359$, $p < 0.008$; $M_{\text{TOR-4 s}} = 2.65 \pm 0.254$ vs. $M_{\text{TOR-6 s}} = 3.70 \pm 0.363$, p < 0.008) and "safe" ($M_{\text{TOR-4 s}} = 4.24 \pm 0.315$ vs. $M_{\text{TOR-7 s}} = 2.65 \pm 0.296$, $p < 0.008$; $M_{\text{TOR-4 s}} = 4.24 \pm 0.315$ vs. $M_{\text{TOR-6 s}} = 2.71 \pm 0.268$, $p < 0.008$). The differences between 4 and 7 s and between 5 and 7 s were significant for "able to react" ($M_{\text{TOR-4 s}} = 3.18 \pm 0.300$ vs. $M_{\text{TOR-7 s}} = 2.18 \pm 0.231$, $p < 0.008$; $M_{\text{TOR-5 s}} = 2.82 \pm 0.324$ vs. $M_{\text{TOR-7 s}} = 2.18 \pm 0.231$, $p < 0.008$).

3 The Effects of Mode Transition, TTR-Time, and TOR-Time

3.1 Objectives

As fully automated vehicles are not predictable in the future due to its technology restrictions, a mixture of vehicles with different levels of automation will be existed [4]. A human factors research on transitions in automated driving [26] shows that driving states are different between various levels of automation. Take level 2 and level 3 of automation as an example to illustrate the driving state. Level 2 of automation, partial automation driving (PAD), is that the automation system are responsible for the longitudinal and lateral controls, driver's control are both off, and the driver need to monitor permanently to be able to resume the control anytime needed. Level 3 of automation, conditional automation driving (CAD) or high automation driving (HAD), is that both longitudinal and lateral controls are done by automated system and drivers are out of control, but drivers are not monitoring permanently, ranging from monitoring permanently and not monitoring at all. But what drivers and system should do is not equal to what these driver and the system actually do. In real situation, drivers and automation system need to jointly conduct the driving task and adjust dynamically their weight according to the momentary situation. It is shared control [27]. It means both level 2 and 3 of automation would be appeared in one vehicle. The previous studies about taking-over control mainly focus on partial automation driving and high automation driving [22]. In shared control situation, it might be existed switch from level 2 to level 3 or from level 3 to level 2. Therefore, it is necessary to explore the effect of mode transition and the time between mode transition and take over request on driver's resuming control when facing system failures. As for the time of transition to takeover request (TTR-time) and take over request time (TOR-time), most previous studies on hand-over control examine the difference of 5 and 7 s [22], and the first experiment in the present study show 6 s was a balance point, so we also choose the two time levels of 5 and 7 s for the TTR-time and the two time levels of 4 and 6 s for TOR-time.

3.2 Methods

Participants. Forty subjects (22 males, 18 females) took part in the experiment. Their average age was 26.62 years ($SD = 3.75$). All of them had a driving license for 4.81 years on average ($SD = 2.32$), and drove more than 5000 miles per year. The participants had a normal vision and hearing, and were randomly divided into two groups. One group went through the transition of automation level from level 3 to level 2 (11 males and 9 females, average age = 26.91 ± 3.68, average driving experience = 4.66 ± 2.31 years), and the other group went through the transition from level 2 to level 3 (11 males and 9 females, average age = 26.33 ± 3.81, average driving experience = 4.95 ± 2.34 years). None of those participants attended the first experiment.

Experimental Design. The experiment used a 2 (Mode transition: L3-L2, L2-L3) * 2(Transition-takeover request time: 5, 7 s) * 2(Take-over request time: 4, 6 s) mixed within/between factorial design. Mode was a between-subject variable, and transition-takeover request time (TTR-time) and take-over request time (TOR-time) were within-subject variables. Four combinations of time were formed based on two levels of each of the two within-subject variable, and the corresponding four driving conditions were conducted in a counterbalanced order. Figure 1 demonstrates the definitions of TTR-time and TOR-time. Mode transition described the switch among different levels of automation at two levels: the switch from level 3 to level 2 and its reverse transition. According to the definition of automation levels by NHTSA and SAE [4, 28], level 2 in the experiment was defined as the situation in which participants were asked to keep their hands on the wheel and system could control lateral and longitudinal movements; level 3 in the experiment referred to as the situation that participants were required to just pay their attention to the road center ahead of the vehicle without putting their hands on the wheel and system automatically control the driving. When the transition from one automation level to another one occurs, the cue information about what the participant need to do in the current automation level would be presented visually and audibly in the front of drivers.

The dependent variables included takeover performance [10, 14], driving performance within one minute after takeover [11], and subjective experience ratings. The takeover performance was assessed using take-over reaction time and the number of collision within 100 m after driver's take over. Take-over time was defined as the time between the onset of take-over request and the moment when the participants starts to take over manual control of the automated car. Driving performance after take over was mainly assessed by lateral control indexes, namely the maximum steering angle, the maximum lateral acceleration and the standard deviation of steering angle which evaluates the driving stability.

Subjective experience ratings were assessed by the workload, satisfaction and attitudes towards TTR-time and TOR-time. The workload was measured by NASA-TLX [23]. The satisfaction was measured on a 7-point Likert scale by After-Scenario Questionnaire with three items, respectively the satisfaction with the ease, the time and the support information of finishing task [24]. The attitudes towards TTR-time and TOR-time were measure on a 7-point Likert scale by Semantic Differential Scale, including "sufficient-insufficient", "urgent-non-urgent", and "able to react-unable to react" for TTR-time, and "urgent-non-urgent", "able to react-unable to react", and "safe-dangerous" for TOR-time, in which 1 represents the closest to the meaning of the left side and 7 represents the closest to the meaning of the right side [25].

Scenarios and Apparatus. The scenario and apparatus are the same as those in the first experiment.

Procedure. Participants drove freely 5 min to be familiar with the manipulation and presentation of mode transition, TTR-time and TOR-time of driving simulator after the brief introduction of the experiment and the signature of informed consent. In the formal driving task, one half of the participants went through the transition from level 3 to level 2, and the other half went through the transition from level 2 to level 3. After a certain period of time (TTR-time), the system suffered from the acute threatening driving scenarios and reached its boundary, take over request (TOR) was prompted to remind driver of resuming manual control to avoid the potential accident. All participants had to drive 3 trials for each combination of two time within-subject variables and filled questionnaires of subjective ratings after each combination. The whole experiment took approximately an hour.

The study was approved by ethics committee. All participants were provided with informed consent and obtained monetary compensation for their participation.

3.3 Results

For each dependent variable, a 2 * 2 * 2 mixed-model repeated measures analysis of variance (ANOVA) was used to examine the main and interaction effects. In addition, multiple comparison test with bonferroni corrections was conducted to identify specific significant differences among means.

Take-over performance. The control shift from automated system to the driver was executed as soon as participants firstly manipulated the steering wheel two degrees or hit ten percent braking pedal position after the takeover request was prompted [14]. Therefore, take-over reaction time was the time between the onset of take-over request and the moment of the participants' first conscious input of control shift. The ANOVA results revealed a significant main effect of TOR-time ($F(1, 38) = 48.32$, $p < 0.001$), and a significant interaction effect of TTR-time and TOR-time on take-over reaction time ($F(1, 38) = 4.83$, $p < 0.05$), but there were no significant main effects of mode transition and TTR-time and any other significant interaction effects. The results apparently showed a decrease reaction time with a shorter TOR-time in general ($M_{\text{TOR-4 s}}$: 1.46 ± 0.053, $M_{\text{TOR-6 s}}$: 1.94 ± 0.099). The results indicated the shorter TTR-time aggravated the significant difference caused by TOR-time ($M_{\text{diff in 5 s}} = 0.61 \pm 0.102$, $p < 0.001$), but the longer TTR-time abridged the difference ($M_{\text{diff in 7 s}} = 0.36 \pm 0.076$, $p < 0.001$), see Fig. 5.

Furthermore, a TOR-time of 4 s resulted in significantly more collisions (11.7%) within 100 m after driver's takeover than TOR-time of 6 s (5.8%), $\chi^2 = 5.11$, $p < 0.05$. But there were no significant differences of collision for mode transition (10.4% for L2-L3, 7.1% for L3-L2, $\chi^2 = 1.67$, $p > 0.05$) and TTR-time (7.9% for 5 s, 9.6% for 7 s, $\chi^2 = 0.42$, $p > 0.05$). The interaction effects of TTR-time and TOR-time or mode transition and TOR-time were not examined because the expected values of over 20% cells were less than 5.

Driving performance. Participants were more likely to resume manual control to avoid accidents by changing lane. Therefore, the driving performance was evaluated by lateral control indexes, including the maximum steering angle, the maximum lateral acceleration and the standard deviation of steering angle. For the 2 * 2 * 2

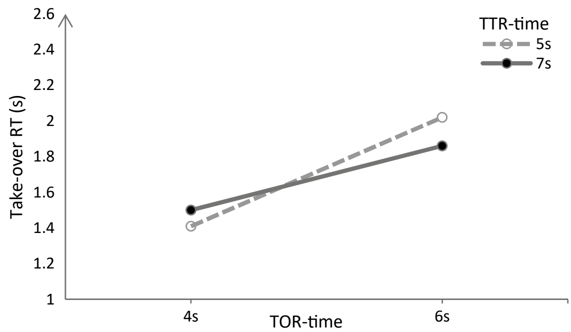

Fig. 5 The influence of TTR-time on the effect of TOR-time on take-over reaction time

ANOVA analysis of each of the three dependent variables, only the main effect of TOR-time was significant (the maximum steering angle, $F(1, 38) = 52.37, p < 0.001$; the maximum lateral acceleration, $F(1, 38) = 62.78, p < 0.001$; the standard deviation of steering angle, $F(1, 38) = 6.39, p < 0.05$). A shorter TOR-time resulted in larger maximum steering angle ($M_{\text{TOR-4 s}} = 30.40 \pm 1.678$ vs. $M_{\text{TOR-6 s}} = 20.89 \pm 1.159$), larger standard deviation of steering angle ($M_{\text{TOR-4 s}} = 15.38 \pm 0.803$ vs. $M_{\text{TOR-6 s}} = 10.07 \pm 0.534$), and larger maximum lateral acceleration ($M_{\text{TOR-4 s}} = 5.59 \pm 0.363$ vs. $M_{\text{TOR-6 s}} = 4.31 \pm 0.375$), which indicates higher risk of lane change.

Workload and satisfaction. As is known to all, highly automated driving was developed to reduce the workload of driver. Therefore, workload should be taken into account to evaluate the effects. The ANOVA analysis showed that only the main effect of TOR-time was significant ($F(1, 38) = 8.78, p < 0.01$). The results revealed participants with the TOR-time of 4 s (2.88 ± 0.111) had a higher workload during fully resuming control compared to those with 6 s (2.61 ± 0.104). In addition, only the significant main effect of TOR-time was also observed for satisfaction measured by items involved the ease, the time and support information of finishing task ($F(1, 38) = 20.60, p < 0.001$). The shorter TOR-time was, the less satisfaction participants had ($M_{\text{TOR-4 s}} = 5.02 \pm 0.189$ vs. $M_{\text{TOR-6 s}} = 5.64 \pm 0.184$).

Attitude towards TTR-time. "sufficient-insufficient", "urgent-non-urgent", and "able to react-unable to react" were used to assess the attitude towards TTR-time. A significant main effect of TOR-time and a significant interaction effect of mode transition and TTR-time were observed for "urgent-non urgent" ($F(1, 38) = 4.38, p < 0.05$; $F(1, 38) = 5.01, p < 0.05$) and "able to react-unable to react" ($F(1, 38) = 7.48, p < 0.01$; $F(1, 38) = 4.59$, $p < 0.05$). Only a significant main effect to TOR-time was observed for "sufficient-insufficient" ($F(1, 38) = 14.77, p < 0.001$). Participants within a TOR-time of 4 s reported TTR-time they perceived was less sufficient ($M_{\text{TOR-4 s}} = 3.73 \pm 0.263$ vs. $M_{\text{TOR-6 s}} = 2.71 \pm 0.239$), more urgent ($M_{\text{TOR-4 s}} = 3.24 \pm 0.227$ vs. $M_{\text{TOR-6 s}} = 3.75 \pm 0.208$) and less likely to able to react ($M_{\text{TOR-4 s}} = 2.93 \pm 0.196$ vs. $M_{\text{TOR-6 s}} = 2.43 \pm 0.181$) compared to those with 6 s. Participants with TTR-7 s reported less urgent compared to TTR-5 s ($M_{\text{TTR-5 s}} = 3.40 \pm 0.261$ vs. $M_{\text{TTR-7 s}} = 3.90 \pm 0.309$, marginally significant $p = 0.06$) when they went through the mode transition from level 3 to level 2, but there was no significant effect of TTR-time on subjective attitudes towards TTR-time ($M_{\text{TTR-5 s}} = 3.50 \pm 0.261$ vs. $M_{\text{TTR-7 s}} = 3.18 \pm 0.309$, $p = 0.22 > 0.05$) when they went through the mode transition from level 2 to level 3. However, the longer TTR-time was, the higher the possibility of the reaction participants perceived was, which occurred only in the condition of mode transition from level 2 to level 3 ($M_{\text{TTR-5 s}} = 2.93 \pm 0.230$ vs. $M_{\text{TTR-7 s}} = 2.50 \pm 0.276, p < 0.05$).

Attitude towards TOR-time. "urgent-non-urgent", "able to react-unable to react", and "safe-dangerous" were used to assess the attitude towards TOR-time. A significant main effect of TOR-time and a significant interaction effect of mode transition and TTR-time were observed for "urgent-non urgent" ($F(1, 38) = 29.31, p < 0.001$; $F(1, 38) = 5.14, p < 0.05$). Only a significant main effect to TOR-time was observed for "able to react-unable to react" ($F(1, 38) = 16.02, p < 0.001$) and "safe-dangerous" ($F(1, 38) = 29.15$, $p < 0.001$). Participants with TOR-4 s reported TOR-time they perceived was more urgent ($M_{\text{TOR-4 s}} = 2.25 \pm 0.189$ vs. $M_{\text{TOR-6 s}} = 3.38 \pm 0.211$), less likely to able to react ($M_{\text{TOR-4 s}} = 3.36 \pm 0.226$ vs. $M_{\text{TOR-6 s}} = 2.61 \pm 0.190$) and more likely to be dangerous ($M_{\text{TOR-4 s}} = 4.41 \pm 0.257$ vs. $M_{\text{TOR-6 s}} = 3.19 \pm 0.214$) compared to those with 6 s. Participants with TTR-7 s reported TOR-time they perceived was less urgent compared to TTR-5 s ($M_{\text{TTR-5 s}} = 2.58 \pm 0.253$ vs. $M_{\text{TTR-7 s}} = 3.13 \pm 0.294$, $p < 0.05$) when they went through the mode transition from level 3 to level 2, but there was no significant effect of TTR-time on subjective attitudes towards TOR-time ($M_{\text{TTR-5 s}} = 3.00 \pm 0.253$ vs. $M_{\text{TTR-7 s}} = 2.90 \pm 0.294$, $p = 0.63$) when they went through the mode transition from level 2 to level 3.

4 General Discussion

The goal of the study is to explore the effects of mode transition, TTR-time and TOR-time on the takeover control of driver in autonomous driving. The results showed TOR-time was a critical factor influencing takeover time and quality and subjective feelings. The first experiment was further conducted to examine the specific influence of TOR-time via four levels based on previous study findings.

Both experiments showed the trend: the shorter TOR-time resulted in less takeover reaction time, more collision and more unstable lateral control, and made drivers perceive more workload, less satisfaction and more urgent and less safe perceived TOR-time which was also felt to be less likely to be able to react. If the driver has not enough time to maneuver control or enough situation awareness, the driving behaviors generally belong to operational level involving immediate control of vehicle and reactionary driving based on events that have happened [29, 30]. When the driver has no experience of the situation, it is hard for he/she to deal with the event [30].

The results of the first experiment provided more specific findings. Starting off at 7 s of TOR-time, 5 s started to reduce significantly in the takeover reaction time and the stability of lateral control, but significant decrease of satisfaction and attitudes towards TOR-time and significant increase of workload began almost at 4 s. The finding indicated the effect of TOR-time was more sensitive to objective performance than to subjective feelings or attitudes. Overall, a preliminary recommendation for designer or engineer of autonomous vehicles is that no less than six seconds would be better when the TOR-time need to be reduced in design for acute threats. The results about the difference between 5 and 7 s of TOR-time is the same as the findings of Gold et al. [14]. But the results about the difference between 4 and 6 s of TOR-time is not the same as the findings of Walch et al. [10]. One possible explanation for this finding is that the fog scenario in the Walch's study was easy to provide the anticipation for driver ahead compared to the sudden driving scenarios in the present study. The anticipation could undermine the effect of TOR-time on takeover control. Another important distinction between the present study and previous work is that the current study asked participants to monitor the environment but not to play a secondary driving task. The attention driver paid to the driving task in previous work was less than the present study, thus the difference of 4 and 6 s did not be revealed. Future research should be conducted in this aspect via more driving scenarios to figure out the general conclusion.

When a highly automated vehicle involves mode transition among different levels of automation, the second experiment found TTR-time modulated the effects of TOR-time on takeover control. The shorter time of mode transition to takeover request (TTR-time) aggravated the significant difference of takeover reaction time caused by TOR-time, but the longer TTR-time abridged the significant difference. It confirmed the speculation according to SOA theories about dual-task interference [31, 32]. Therefore, whatever the task before takeover request is the secondary task or mode transition of automation levels, the time from the previous task to takeover request should be taken into account when designing for car-driver handover control interface, or the practice about car-driver take over should be considered when autonomous driving is promoted. In addition, mode transition modulated the effect of TTR-time on driver's attitudes towards TOR-time and TTR-time. Participants perceived the TOR-time and TTR-time to be less urgent with the longer TTR time when they went through the mode transition from level 3 to level 2, but they perceived the possibility of the reaction about TTR-time to be higher with the longer TTR-time when they were in the mode transition from level 2 to level 3. It implies different level of monitoring would influence the perception of TOR-time and TTR-time. In order to provide best user experience, designer and engineer also should take the interaction of mode transition and the time of mode transition to takeover request into account in the future.

5 Conclusion

To gain deeper insight into car-driver handover control in highly automated vehicle, the specific influences of take over request time were examined via four levels, and the effects of mode transition, the time of transition to takeover request and take over request time were investigated. Overall, both experiments confirmed that the shorter takeover request time resulted in less takeover reaction time but worse quality. If the take-over request time is needed to be reduced in the design for acute threats, a preliminary recommendation for designer or engineer is that no less than six seconds would be better. Also, if the future autonomous vehicle involves the mode transition of automation levels, designer and engineer also should take the time of mode transition to takeover request into account due to its effects on takeover reaction time and attitudes towards TOR-time when designing the interaction of car-driver handover control. Therefore, these findings provide practical implications for the takeover control design of vehicles with different levels of autonomy. Additional research is also needed before adopting these results, given the limited driving scenario and traffic situation in the study.

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Personalized Risk Calculations with a Generative Bayesian Model: Am I Fast Enough to React in Time?

Claus Moebus

Abstract We present a Bayesian modeling and decision procedure to answer the question of whether the reaction speed of a single individual is slower and thus more risky than the speed of a randomly selected individual in a reference population. The behavioral domain under investigation is simple reaction times (SRTs). To do this, we need to consider aspects of Bayesian cognitive modeling, psychometric measurement, person-centered risk calculation, and coding with the experimental, Turing-complete, functional, probabilistic programming language WebPPL. We pursue several goals: *First*, we lean on the new and paradoxical *metaphor of a cautious gunslinger*. We think that a whole range of risky situations can be embedded into this metaphor. *Second*, the above described *gunslinger metaphor* can be mapped to the framework of *Bayesian decision strategies*. We want to show by way of example that within this framework the research question '*transfer the locus of longitudinal control*' in Partial Autonomous Driver Assistant Systems (PADAS) can be tackled. *Third*, *evidence-based* priors for our generative Bayesian models are obtained by reuse of meta-analytical results. For demonstration purposes we reuse reaction-time interval estimates of Card, Moran, and Newell's (CMN's) meta-analysis, the Model Human Processor (MHP). *Fourth*, the modification of priors to posterior probability distributions is weighted by a likelihood function, which is used to consider the SRT data from a single subject as evidence and to measure how plausibly alternative prior hypotheses generate these data. *Fifth*, we want to demonstrate the expressiveness and usefulness of WebPPL in computing posterior distributions and personal probabilities of risk.

Keywords Personal Bayesian risk calculation · Context-dependent risk potential of an individual subject · Single-case diagnostics · Cognitive engineering model · Reuse of meta-analyses as Bayesian priors · Generative Bayesian model · Model human processor · Single subject response time · Probabilistic programming language WebPPL · Bayesian decision strategy · Transfer the locus of longitudinal control · Partial autonomous driver assistant system · PADAS

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1 Introduction

1.1 Motivation

This is a study in the development of a *Bayesian cognitive engineering model* and *Bayesian psychometric decision procedure*. It is accompanied by the reuse and integration of psychological *meta-analysis data*. All computations are supported by *code* written in the *Turing-complete functional* probabilistic programming language *WebPPL*.

We feel being in the tradition of Westmeyer [34], Bessiere et al. [2], Pearl [26], Lee and Wagenmakers [15], Goodman et al. [10], and Levy and Mislevy [17]. We pursue several goals:

First, we lean on the new and paradoxical metaphor of a *cautious gunslinger*. We think that a whole range of risky situations (e.g. [16]) can be embedded into this metaphor. The agent has to answer himself three increasing complex *counterfactual and metaphoric questions*: (1) *Can I draw my revolver fast enough, if my opponent needs only τ_c milliseconds to do so?*, (2) *Can I draw my revolver as fast as a randomly selected person of a (younger) reference population, if my opponent needs only τ_c milliseconds to do so?*, (3) *Is the probability that I can draw my revolver as fast as a randomly selected person of a (younger) reference population less than $p = 0.05$, if my opponent needs only τ_c milliseconds to do so?*.

Second, the above described *gunslinger metaphor* can be mapped to the framework of *Bayesian decision strategies*. We want to show by way of example that within this framework the research question '*transfer the locus of longitudinal control*' in Partial Autonomous Driver Assistant Systems (PADAS) can be tackled.

Third, *evidence-based* priors for our generative Bayesian models are obtained by reuse of meta-analytical results. For demonstration purposes we reuse reaction-time interval estimates of Card, Moran, and Newell's (CMN's) meta-analysis, the Model Human Processor (MHP). According to the MHP total simple reaction times (SRTs) of an arbitrary computer user are composed from three latent time components related to perception, cognition, and motor processes.

Fourth, the modification of priors to posterior probability distributions is weighted by a *likelihood function*, which is used to consider the SRT data from a single subject as evidence and to measure how plausibly alternative prior hypotheses generate these data. Posteriors are obtained by runs of the Metropolis-Hastings Markov-Chain-Monte-Carlo *(MH-MCMC)* algorithm provided in Turing-complete, functional WebPPL.

Fifth, we want to demonstrate the expressiveness and usefulness of the experimental *WebPPL* in computing posterior distributions and personal probabilities of risk. When SRT-specific values-at-risk ([7, 18], p. 114ff; [29], p. 178) are externally provided prior risk probabilities can be compared to posterior risk probabilities. It can be checked whether there is a substantial or even striking increase, which we call *risk-excess*. This way it is possible to answer the above mentioned questions. So, *hazardous scenarios* (e.g. traffic scenarios) with only a few behavioral data of a