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Moving Between Automated and Manual Driving: Mental Workload and Performance Implications

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Abstract. Automated driving has been predicted to take-over from manual vehicle control in the near future. The driver's role may then change from active operator to passive observer. Such technology offers the tantalising promise of improving driving safety. However, many studies have presented findings suggesting potentially adverse effects from automated driving systems, e.g., reduced situation awareness. Mental workload is also a key issue of concern for researchers in this area. Excessive mental workload has repeatedly been shown to be associated with degraded driving performance. Previously, most traffic psychology studies on mental workload have focused the manual driving task. However, a shift to (and from) highly automated driving will impose differing cognitive demands on the driver. For example, mental workload levels are likely to shift from underload to overload and visa-versa. Rapid resumption of manual control from a highly automated observation role seems inevitable on the basis of equipment failure or adverse conditions. Consequently, how driving performance will be effected; how it will effect driver mental workload; and how to protect road users from such system failures, are the interesting questions of concern. The aims of this experimental study are to determine the effects of control state changes (automated to manual, and manual to automated) on driver mental workload and driving performance. Participants will perform several counterbalanced driving transition scenarios (shifting between manual driving, highly automated driving and fully automated driving) in driving simulator. Dependent variables will include subjective mental workload measures, eye tracking, driving performance measures and performance on a secondary loading task. The results of this study are anticipated to provide insight into the human-machine interaction system with respect to mental workload and driving performance. Findings will contribute to our understanding of the implications of control state changes in automated driving scenarios. For example, shifting into or out of, automated driving modes. More generally, we anticipate findings could support vehicle designers by improving their understanding of the limitations of automated driving systems with respect to driver mental workload.

Keyword: Mental Workload; Automated Driving; Driving Performance; Driver Mental Workload

1 Introduction

Automated driving has been designed to take over driver's role from active operator to passive observer. 'Anti-lock Braking System, Collision Warning System, Adaptive Cruise Control (ACC) and Lane Keeping Assistance (LKA)' are the examples of developed automated driving [4]. These technologies offer the tantalising promise of improving driving safety. However, many studies have presented findings suggesting potentially adverse effects from automated driving systems, 'out-of-loop problems' e.g., complacency, degradation of skill, loss of situation awareness, vigilance decrements [1-5]. Mental workload is also a key issue of concern for researchers in this area [1, 5]. It was predicted that drivers' mental workload in electronic aids driving will be a hot topic in the near future [9]. Excessive mental workload has repeatedly been shown to be associated with degraded driving performance. For example, Merat [6] described, based on Malleable Attentional Resource Theory (MART), automation can causes a temporary reduction in attentional resources as a result performance degradation. Mental underload is the result of highly automation, and has been found associated with performance degradation [11]. Previously, most traffic psychology studies on mental workload have focused the manual driving task and static states of automated driving task. However, a shift to (and from) highly automated driving will impose differing cognitive demands on the driver. Term of 'transition driving control' was defined as a process during the driver and automation system change from one driving state to another driving state [4-5]. Automation Initiates transition, and Driver in Control after (AIDC) transition is an example of low-workload changing to high-workload, and should be concerned in safety situation [5]. Driver Initiates transition, and Automation in Control after (DIAC) and Automation Initiates transition, and Driver in Control (AIDC) were defined a 'passive transition' due to after control transitions are forced to take over control from the another agent [4]. Rapid resumption of manual control from a highly automated observation role seems inevitable on the basis of equipment failure or adverse conditions [5]. Consequently, how driving performance will be effected; how it will effect driver mental workload; and how to protect road users from such system failures, are the interesting questions of concern. The aims of this experimental study are to determine the effects of control state changes (automated to manual, and manual to automated) on driver mental workload and driving performance.

2. Methods

2.1 Participants

160 drivers (at least one year of experience in car driving) will be chosen to participate in this study. The participants will be divided equally into two group. First group, they will be required driving in approaching a junction road situation and another group driving in sudden manoeuvre by another vehicle situation (Table 1).

Table 1. The number of participants by transition event

Transition Event	Driving State		Participants
	Before Transition	After Transition	
Approaching a junction road	Manual	Manual	5
		ACC	5
		AS	5
		ACC+AS	5
	ACC	Manual	5
		ACC	5
		AS	5
		ACC+AS	5
	AS	Manual	5
		ACC	5
		AS	5
		ACC+AS	5
	ACC+AS	Manual	5
		ACC	5
		AS	5
		ACC+AS	5
Sudden manoeuvre by another vehicle			
	Manual	Manual	5
		ACC	5
		AS	5
		ACC+AS	5
	ACC	Manual	5
		ACC	5
		AS	5
		ACC+AS	5
	AS	Manual	5
		ACC	5
		AS	5
		ACC+AS	5
	ACC+AS	Manual	5
		ACC	5
		AS	5
		ACC+AS	5
Total			**160**

2.2 Driving simulator

The experiments will be conducted in the STI stimulator room in Heriot-Watt University, Edinburgh, the United Kingdom. Inside the room, a modified car cabin car and a big screen projector which located in front of car cabin will be served as testing environment. A special camera and eye tracker will be used to record drivers' control activity and drivers' eye tracking. All scenarios base upon two lane rural road only. The room will be controlled temperature at 18° C for comfortable reason.

2.3 Automated driving system

Four levels of automated driving will be modified and observed the effects from transition event between each other. 1) Adaptive Cruise Control (ACC) = Speed and headway are automatically controlled. 2) AS (Active Steering) = Lane keeping is automatically controlled. 3) ACC+ AS = Speed, headway and Lane keeping are automatically controlled. 4) Manual driving = longitudinal and lateral are controlled by drivers manually.

2.4 Transition Event

Two transition situations, which based upon real world driving (approaching a junction road and sudden manoeuvre by another vehicle) will be created for investigating the effects of resume control from one stage of driving to another stage. Each situation, the participants will be required to resume control from initiate transition to after transition. There are all 16 scenarios which will be observed in each transition event.

2.5 Test procedure

Before the test drive, participants will be introduced the objectives and information of driving scenario. However, the participants will be not receive information about take over control events. Then, they will be required to sign an inform consent and filled out a socio-demographic questionnaire. The participants will be give 15 min to practice before running the experiments. In the experiments, all drivers will be asked to drive with speed limit (70 mph). Every participants will be required to resume control between different states of transition randomly (4 situations) (Table 1) with responding visual stimulus. After transition event, experiments will be pause to ask the participants response a Rating Scale Mental Effort (RSME) form. When all four trials are completed, all participants should be thanked. Each experiment should spend approximately 60 min.

3. Dependent Measures

3.1 Primary task performance

Speed instability (mph), distance headway instability (m), lateral position (m) from road centreline, lane excursion, time spent out of lane will be recorded by STI Stimulator software. It has been suggested that speed (time) and accuracy (errors) during performing primary task are the most frequently employ of primary task measures for assessing workload [8]. Speed has found to decrease while workload increase, it is a sensitive measure [7].

3.2 Secondary task performance

Visual-spatial additional task will be used as a secondary subsidiary task. Participants will be required to response visual stimulus which will be appear on projector screen during the transferring between driving state. Correct response and time response will be recorded and analysed. Attentional ratio (AR = STcr/STt) where AR= Attention Ratio, ST= Secondary Task, cr = correct response and t= time, will be analysed to refer spare capacity of drivers. AR ratio is appropriate for autonomous vehicle study [11].

3.3 Physiology

Eye tracking (eye blink rate, blink duration) will be recorded by specific camera during the participants taking control with each transition driving situations. Decreased eye blinks and blink duration relate to increasing visual workload [7].

3.4 Subjective rating

Rating Scale Mental Effort (RSME), developed by Zijlatra in 1993, will be used to indicate participants' opinion after each scenarios. This unidimensional rating has been recommended and wildly accepted to report effort feeling of participants [1].

3.5 Data analysis

All dependent valuables will be compared between driving states and also compared between transition events.

4. Conclusion and implication

The results of this study are anticipated to provide insight into the human-machine interaction system with respect to mental workload and driving performance [5, 8]. Findings will contribute to our understanding of the implications of control state changes in automated driving scenarios. For example, moving into or out of, automated driving modes. More generally, we expect findings could support vehicle designers by improving their understanding of the limitations of automated driving systems with respect to driver mental workload.

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