Drivers' mental state detection: Behavioral and machine-learning-based investigation.

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Summary

Vehicle increases the extent of individual mobility, but it also causes problems, such as, road accidents. Drivers' error, that accounts for 45-75 percent of the cause of roadway crashes, is considered as a major contributing factor of crashes. Drivers' error is known to critically depend on drivers' mental state. The advanced driver assistance systems (ADASs) have a potential to significantly reduce road accidents, if they can effectively monitor drivers' mental states. However, currently, the method to monitor driver's mental state does not fully develop. In this thesis, I explore the possibility to monitor drivers' mental state without using any special sensors to measure it.

Driving a car continuously requires drivers to keep their attention focusing on relevant stimuli surrounding environment and to take appropriate actions, if they are necessary. Drivers' performance on driving situations largely depends on drivers' mental states. Especially, when drivers come to a state of high workload, distraction, fatigue, drowsiness or mind wandering, the risk of car accident would increase because of deliberate attentional concentration is prevented by them. However, so far, no study systematically examined a relationship among drivers' mental states and a relationship between them and driving behavior.

First, in order to get a full view of driver mental states from psychological perspective, the Chapter 2 reviewed psychological theories related to mental workload, distraction, fatigue, drowsiness and mind wandering, and discussed internal relationship among those

concepts based on previous psychological, brain function and human factor studies. I argued that mental workload, which is an important factor affecting driving and traditionally examined in human factor studies on aircraft pilots, is multidimensional and multifaceted. There are two situations that produce high workload, which may deprive attentional resources utilized for driving: Over-load which occurs in a task with relatively high demands and under-load which occurs in a task with relatively low demands. Over-load state appears when the task demand exceeds capacity-limit of processing resource, while under-load state would be due to the monotony of the task, in which drivers have to keep concentration under boring task situation. In addition, I argued that distraction is a special factor that can yield over-load. The high workload state sometimes accompanies with fatigue, which is a subjective state experienced under performing a task. The 'active fatigue' associates with over-load, and 'passive fatigue' derives from under-load. It is considered that fatigue is a cause of drowsiness, which is a transitional state between wakefulness and sleepiness. Mind wandering, in which task-unrelated thoughts unintentionally come up with in mind, is a very frequent and ubiquitous phenomenon during daily tasks, such as driving, and is considered to be an early state of drowsiness. Under this framework of mental states, I discussed that the detecting states of mind wandering is the key issue to monitor drivers' mental state, because it can be a precursor of drowsiness, which leads to serious car accident, and it can be a natural consequence of high mental workload. However, so far, no studies explored the relationship of mental workload and mind wandering. Therefore, in following sections of this thesis, I investigated the relationship of them in different approaches in the context of car driving.

In Chapter 3, the relationship between mental workload and mind wandering during driving was experimentally investigated. An experiment on driving simulator was designed. Participants (n=40) were asked to perform a car following task in a simple road course and to report mind wandering state after hearing a brief thought probe tone randomly given during driving. After the task, participants filled a questionnaire of mental workload. The results of the experiment demonstrated the relationship between workload and mind wandering from both the individual difference perspective and the temporal perspective. In the individual difference perspective, there was a negative correlation between workload and mind wandering (r = -0.459, p < 0.01) for different individuals. Participants who experienced higher workload reported fewer instances of mind wandering. In the temporal perspective, both workload and mind wandering increased along with task performing time and were positively correlated. This result is explained under the framework proposed in Chapter 2. Workload and mental fatigue can increase simultaneously as a function of the work period. Under fatigue, executive control is compromised. When executive control is deficient, mind wandering is more likely. This time-depending variation was also found in some aspects of driving behavior (e.g., in the standard deviation of lateral car positions on the road). As a result, an increase in mental workload with time can result in decrease of executive control capability and an increase in spontaneous mind wandering, and they affect on driving behavior. Importantly, since behavioral data show the correlation with mind wandering state, on a practical level, mind wandering may be a reliable indicator of workload. Drivers' workload might be estimated by questioning them about their mind wandering status during driving.

Some previous studies have already tried to estimate workload level and monitor distraction, fatigue and drowsiness in driving. However, mind wandering is more covert than those other states, and would result in a high accident risk when induced in driving situation. Chapter 3 showed the possibility that mind wandering state can be detected using driving performance data. In Chapter 4, the possibility to automatically detect mind wandering was investigated using driving behavior data obtained in the driving experiment of Chapter 3. The machine learning methods were applied to classify whether a participant would experience mind wandering or not (that is on- versus off-task) using only driving behavior data, from both driver-independent and driver-dependent modelling perspectives. Both the global features and local features are extracted from a driving behavior log. Global features, which were calculated based on whole driving data, indicate the different characteristics between individuals, and local features, which were calculated with certain moving time windows (e.g., 15 seconds) while driving, show each participant's behavior varying on time. In the driver-independent modeling, although a unique model was not built were built for all participants or participants only with medium mind wandering proportion (MWP), a model was built in participants only with high or low mind wandering MWP. For participants with high or low MWP, an optimal model was built with global-only features (kappa = 0.384), which suggested the possibility that the participants who have high or low mind wandering percentage can be detected with global features. In the driver-dependent modeling, models were built for each participant with the medium MWP. The best models of some participants were effective. That is temporal state of mind wandering can be detected using driving data obtained 5-15 seconds of the time window. This chapter shows the possibility that driving behavior data are effective in automatically detecting mind wandering during driving. In addition, the limitations of current approach are also apparent. For example, the grand truth of mind wandering state only relies on drivers' subject reports. This may lead to ineffective model built in some drivers. It is essential that both inter-individual and intra-individual differences should be taken into consideration for mind wandering detection in order to apply this methodology to all types of drivers.

In the last chapter, the future work is mainly discussed. The development of driving state detection in ADASs that are reliable for any individuals, any vehicles, and any environments is expected in future. Needs for monitoring driving states in easy sensor settings may increase even in autonomous cars. This study provides a step to minimize the negative impacts of mindless driving. The modeling approach taken in this study should also benefit other fields of psychological research.