Preliminary Evaluation of Real-time Steering Entropy for Monitoring Driver State

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Problem

Both distraction and fatigue have been found to be contributing factors in vehicle crashes. As individual crashes, these are a safety issue, but the levels of fatalities and injuries that are occurring in crashes where these contributing factors are present also make this a social issue. Many driver state monitors (DSMs) are being proposed and researched to potentially address this issue (Ghimire et al., 2015). Camera-based systems are the most common type of DSM, however, they have various challenges and limitations. Sensor fusion approaches are also being proposed for DSM applications (Melnicuk, V., Birrell, S., Crundall, E., 2016). Monitoring the steering inputs of drivers in real-time appears to be a promising source of input to DMSs. A Real-time Steering Entropy (RSE) method that analyzes steering behavior has been proposed as a method to monitor drivers, and has been demonstrated to detect various forms of driver distraction (Kondoh, et al. (1) and Kondoh, et al. (2), 2015). In the present work, the RSE performance in identifying periods of reduced alertness in long-duration driving situations and at different times during the day was investigated.

Method

RSE quantifies the nature of a driver's corrective steering with an index of relative entropy (*RHp*) from information theory. *RHp* values increase when the driver's workload is high. Through video review, previous work (Kondoh, et al. (1), 2015) found that when *RHp* was high, drivers were often observed to be dialing, talking on the cell phone, looking away from the forward roadway, or appeared to have generally reduced alertness.

The RSE method was applied to a naturalistic driving database gathered from 18 drivers in the United States as part of a joint research project between the Virginia Tech Transportation Institute (VTTI) and Nissan Motor Company. The naturalistic driving database in this study contained over 2,300 trips, 39,000 km, and 730 hours. RSE computation requires an initial 20 minutes of driving to initialize or "learn" the driver's baseline steering behavior. To accommodate this requirement, only trips that were 20 minutes or longer were used. Consequently, a subset of 263 trips (encompassing 10,500 km and 190 hours) was used for testing. The *RHp* was calculated in an offline simulation. After processing the data, 222 cases where the driver's state indicated higher *RHp* were reviewed using video.

Results

Figure 1 shows the categorization of observed driver's state from the video review. Figure 1 illustrates the distribution of the observed behaviors and driver states that were observed during video review.

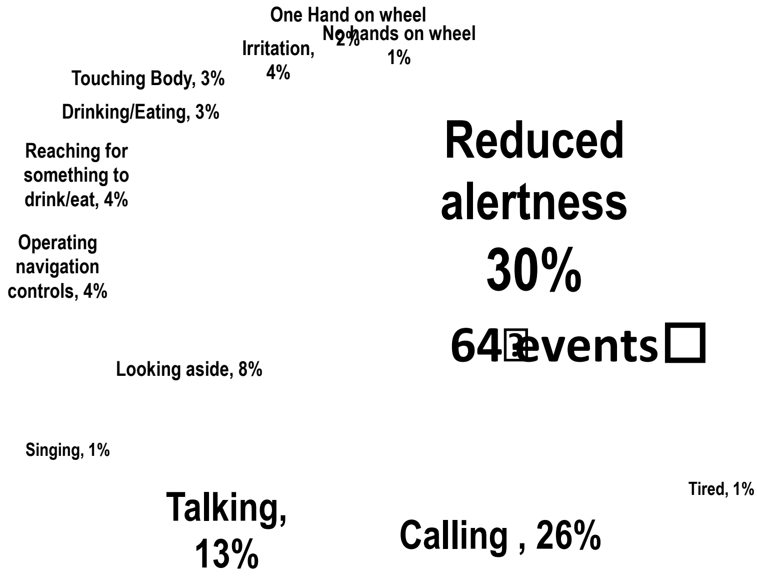

Figure 1. Distribution of driving behaviors and states in the naturalistic driving data

As shown on Figure 1, a total of 64 high-RHp events that could be regarded as reduced alertness were observed. The elapsed time from trip start to the event occurrence for these 64 events was calculated. Figure 2 shows the percentage of trips exhibiting high-RHp events across the driving time (blue line) and within these, the percentage of those high-RHp events that were due to reduced alertness (red line). The percentage of high-RHp reduced alertness observations tended to increase as driving time increased, even though the percentage of high-RHp remained relatively steady. In the previous study, reduced alertness was present in approximately 30% of all RHp detections. In the present study, which examined longer driving periods, the RHp level appeared to be much higher for the driving time beyond 2.5 hours when compared to the time before 2.5 hours. Some increased variability is also present, probably related to a reduction in the number of observations available; only 16 events were observed after 2.5 hours because there were not many trips of that length in the data.

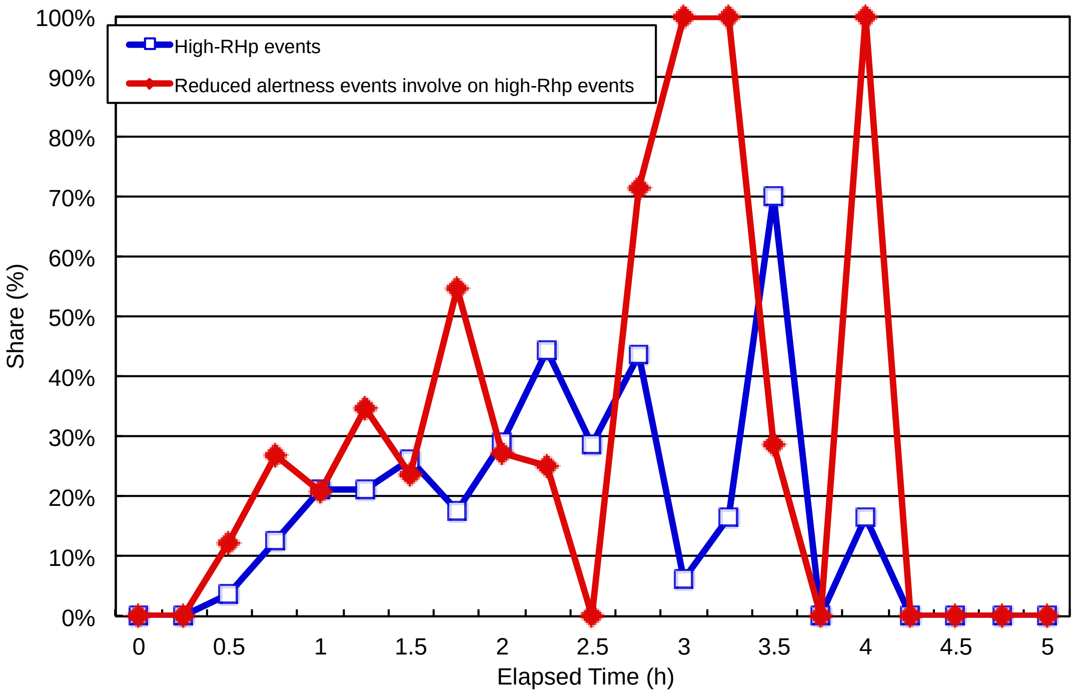

Figure 2. Relationship between percentage of trips with high-RHp events and percentage of high-RHp events where reduced-alertness was observed as a function of elapsed trip time

Figure 3 shows the relationship between percentage of trips with high-*RHp* events (blue), the percentage of high-RHp events where reduced alertness was observed (red), and time of day. The peaks (local maxima) in the percentage of high-RHp events with reduced alertness generally occurred every few hours although the percentage trips with high *RHp* events was generally constant (~10%).

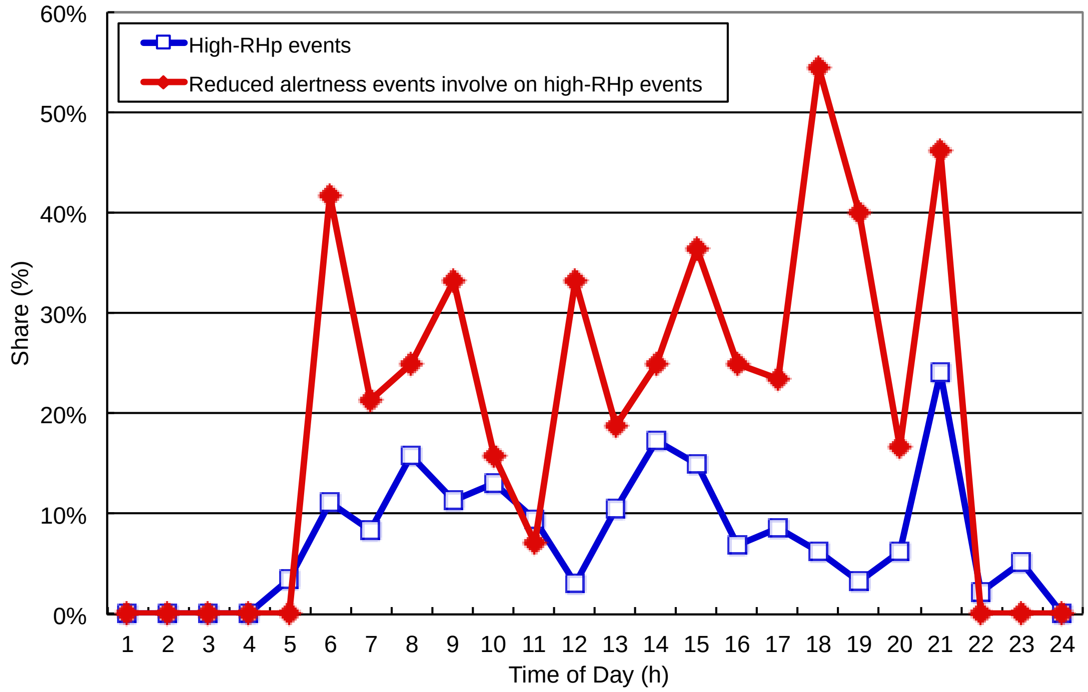

Figure 3. Relationship between percentage of trips with high-RHp events and percentage of high-RHp events where reduced-alertness was observed as a function of time-of-day

Discussion

The relationship between driving time and the rate of *RHp* events coinciding with reduced alertness was investigated using naturalistic driving data. As would be expected, longer periods of driving correspond with more frequent periods of reduced alertness.

When examined relative to the time of day in which the events occurred, the peaks in percentage of high-RHp events where reduced alertness was observed were found to be approximately three hours apart. The ultradian rhythm is known as the 90–120 minute cycle between drowsiness and alert states. Taxi drivers and/or bus drivers tend to feel sleepiness in intervals of 120 minutes, as reported in Maruyama (1982). Preliminarily, it seems that such a cycle may also be present in these data.

In this study, the detection performance of *RHp* has been considered in long-duration naturalistic driving. Previous work has demonstrated that the RSE method can accurately detect various conditions in which the driver encounters high workload while driving. In Kondoh, et al. (2) (2015), the performance of *RHp* relative to cellphone use and driving with reduced alertness was demonstrated. RSE appeared to have the potential to, via inclusion in Advanced Driver Assistance Systems for example, reduce the prevalence of crashes associated with these two driver states. In this study, a higher prevalence of reduced-alertness events was observed as trip durations increased, stressing the potential for the RSE approach to reliably detect higher-risk driving conditions where interventions on the driver may be useful.

While the initial findings of the current work appear promising, testing with larger driving datasets is an appropriate next step. Additionally, the exploration of a fatigue monitor over extended driving illustrates a benefit of NDS in that it supports analysis of long stretches of driving and sub-circadian cycles. This makes NDS data a valuable tool to for understanding subtle longitudinal factors in driving behavior.

Summary [150 words]

The real-time steering entropy (RSE) method has been proposed as an index for quantifying driving workload in real-time when drivers perform secondary tasks. This study explored the application of RSE to detection of reduced alertness or fatigue. The RSE method was applied to naturalistic driving data in an offline simulation using data from 18 participants. Reduced alertness cases were detected by RHp.

Two practical findings appear to confirm that reduced alertness tends to increase as the length of a driving period increases. The findings also appear to indicate a cyclical level of alertness, similar to the ultradian rhythm. These findings further indicate the utility of RSE method over previous work and the need for investigation and potential refinement of this approach with larger naturalistic driving data sets.

Reference

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