Drivers' recovery performance in a critical run-off-road scenario – A driving simulator study

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ABSTRACT

Single vehicle accidents are commonly caused by fatigue and distraction and resulting in severe casualties and high economic costs. In order to evaluate driver recovery from run-off-road accidents, comprising of 80% of fatal crashes on rural roads, a simulator study in an advanced full-motion driving simulator was carried out. Drivers were given a secondary task to perform at six positions down the road (to simulate distraction), and an artificial yaw deviation was added to the vehicle to induce a run-off-road accident whilst the driver was distracted. The results show that the severity of the recovery manoeuvre was larger than similar events caused by the failure of automated lane keeping systems, leading to lane departures. Furthermore, significant learning effects was found, providing recommendations for further studies into run-off-road experiments.

Keywords: run-off-road, crash scenario, driver behaviour, driver recovery, vehicle recovery.

1 INTRODUCTION

Single vehicle accidents are commonly caused by fatigue and distraction and lead to severe casualties and high economic costs. In fact, 80% of fatal crashes in the US (between 1991-2007) on rural roads were run-off-road (ROR) accidents, and rural roads are more likely to be the scene of ROR crashes than urban roads (Liu & Subramanian, 2009). Additionally, driver distraction seems to be a significant contributor to ROR accidents, as a driver is 67.1% more likely to experience a fatal ROR accident out of all types of on-road crashes (Liu & Subramanian, 2009). An analysis of 70 critical, but non-accident, run-off-road situations showed that about 70% of the drivers had been engaged in a secondary task that involves both a visual and a manual component, typically leading to situations where the driver has the left hand on the steering wheel while looking and grasping after something with the right hand (Petersson, Svanberg, & Johansson, 2013; Sandin, Augusto, Johansson, Svanberg, & Petersson, 2015). As ROR accidents are notoriously difficult to replicate, and manouvisual distraction tend to be a substantial contributor to such accidents, a simulator study was conducted to assess how drivers handle an artificially induced ROR scenario with a strong manouvisual distraction component. The experiment was carried out in a driving simulator as driver behaviour in critical ROR situations can safely be studied in advanced moving-base driving simulators. It is anticipated that the insights generated in this study may contribute to the development of advanced driver assistance systems to reduce the impact and severity of such incidents.

2 Method

2.1 Participants

12 participants (75% male, age: 33.8 ±8.9) partook in this study. All participants provided their informed consent and the study complied with the American Psychology Association's ethics guidelines.

2.2 Apparatus

The study was conducted in the VTI simulator IV, a high-fidelity, full-motion driving simulator located in Gothenburg, Sweden. The driving simulator uses the front half of a Volvo XC60, running a validated vehicle model from a Volvo V60 and has movement in 8 degrees of freedom and 180 degree field of view. As part of this experiment drivers also had to engage in a secondary task which consisted of a small touchscreen display located to the right of the centre stack. The task was initiated by a computer-generated voice stating 'läs siffrorna nu' (read the numbers now, in Swedish) in the vehicle cabin, and upon hearing the sound, the participant had to place, and hold their finger on the display to display 6 numbers in quick succession and read them out loud (thus simulating a distracting event involving a visual and manual component). Each number was displayed for 200-milliseconds with a 200-millisecond interval, for a total of 2.2 seconds.

2.3 Dependent measures

The following dependent measures were used to assess driver behaviour in the critical ROR scenario:

- Lateral position in meters which provides an indication of vehicle control and indicates whether the vehicle has left the roadway or not.
- Steering wheel angle [rad] indicating controllability, and whether compensatory actions are taken by the driver prior to the distraction task.
- Vehicle heading [degrees] indicating the severity of the ROR event and recovery.
- Lateral Jerk [m/s^3] indicating the severity of the recovery manoeuvre.
- Reaction time [seconds] indicating how long drivers took to make the first manoeuvre in the recovery of the vehicle.

2.4 Analysis

The data was analysed using the Manhattan-plot technique introduced by (Gibson, 2010) and used in the human factors literature by (Eriksson et al., Accepted; Eriksson & Stanton, 2017; Petermeijer, Cieler, & de Winter, 2017)

2.5 Scenario

The participant drove a 20-minute highway scenario whilst engaging in the secondary task for a total of 6 times. On two occasions, a yaw deviation was applied to the vehicle whilst the driver was engaged in the secondary task, provoking a ROR scenario. The yaw deviation was introduced on the fourth and sixth event respectively. The yaw deviation was initiated when the driver engaged in a visoumanual secondary task on a screen. The driver had to hold their right index finger on the screen to activate the secondary task which activated an added clockwise yaw deviation, intended to create the ROR scenario. The artificial yaw deviation was included to assure that a ROR event would occur as these events are unlikely to occur in the short amount of time a driver spends in the simulator. The added yaw deviation was presented visually when the participant engaged in the additional task but was not represented in the vehicle dynamics or the lateral acceleration of the simulator's motion system. This was done to ensure that the participant would not notice the deviation until the vehicle had left the roadway and received the associated kinematic feedback.

2.5.1 Yaw deviation

The manoeuvre consisted of a rotation and displacement of the world in order to promote a set of vehicle states that lead to a run of road situation. Said manoeuvre was triggered when the driver activated the distraction task by pressing on the touch screen. The motion of the vehicle was characterized as a 5th polynomial describing its lateral displacement on the road. The manoeuvre was performed in open loop, i.e., the terms of the polynomial were computed when the manoeuvre initiated and remained constant until the end. The vehicle longitudinal speed was assumed to be constant and equal to the speed at the beginning of the deviation at the moment the polynomial terms are computed.

2.5.2 2.1 Manoeuvre parameters

The manoeuvre parameters were:

- v_x = variable : Vehicle longitudinal speed. Measured at the time the polynomic terms were computed. Assumed constant during the manoeuvre, i.e, $v_x = v_{xi} = v_{xf}$.
- ψi = variable : Initial yaw angle towards the road edge.
- ψf = -3.0deg : Final yaw angle towards the road edge.
- a_{yf} = 0 : Final lateral acceleration of the vehicle relatively to the road edge.
- a_{yi} = variable : Initial lateral acceleration of the vehicle relatively to the road edge.
- $v_{yf} = \tan(\psi f)\, v_x$: Final lateral velocity of the vehicle relatively to the road edge.
- $v_{yi} = \tan(\psi i)\, v_x$: Initial lateral velocity of the vehicle relatively to the road edge.
- y_t = variable : Total lateral displacement of the vehicle relatively to the road edge. Represented by the distance between the right from wheel and the road markings.
- d_t = 2.0sec : Total duration of the artificial deviation.

Taking the displacement, position and acceleration, it was possible to compute the terms of the polynomial which characterized the vehicle lateral displacement for the duration of the manoeuvre.

3 Results

Preliminary analysis showed that all participants went off road in the first run-off road scenario. It took drivers approximately 2.78±0.34 seconds from engaging with the secondary task until peak-counter steering to bring the vehicle back onto the road (combination of reaction time, and initial correction time as per SAE J2944, 2015). It was found that the maximum lateral jerk experienced when bringing the vehicle back onto the road was 15,97 ±7,98 m/s^3 when first experiencing the run off road scenario, and 9,91±6,68 m/s^3 when experienced for the second time, resulting in a significant difference ($t(11)=3.04$, $p<0.05$).

3.1 Learning effects

As the study entailed two ROR scenarios, learning effects were assessed. The significant difference in lateral jerk indicated a learning effect, which, combined with the significantly different lateral positioning (Figure 1) before the distraction task indicates that drivers adopted a strategy to reduce the likelihood of leaving the roadway when engaging in the secondary task by steering the vehicle slightly to the left when prompted to engage in the secondary task. This is also reflected in a reduction of vehicle heading (Figure 2) for the second ROR event, which also yielded smaller steering wheel angles (Figure 3) than the first run -off-road event.

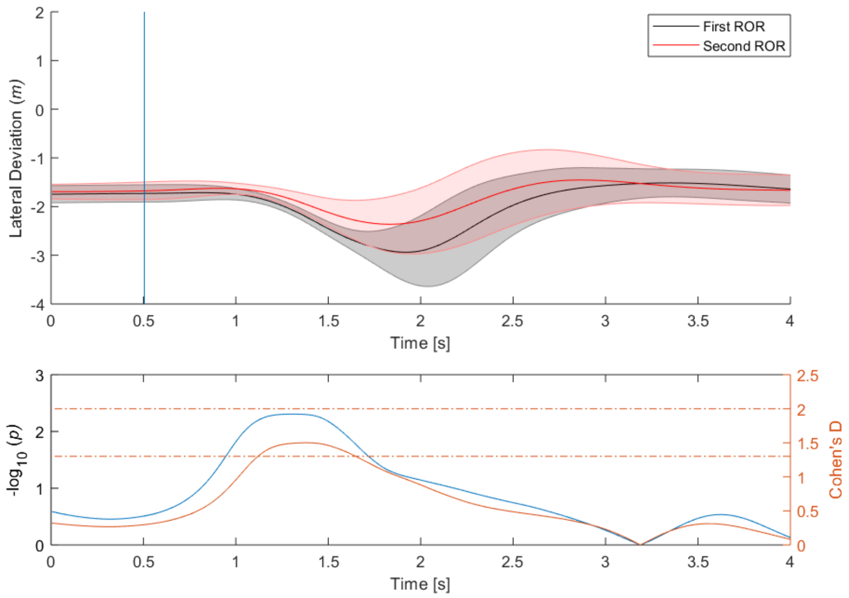

Figure 1. Lateral deviation (m) for the two ROR scenarios. The bottom graph shows paired T-tests and effect size comparing the two events over time. The blue vertical line indicates the start of the secondary task, and the two horizontal lines in the bottom graph indicate alpha values of 0.05 and 0.01 respectively.

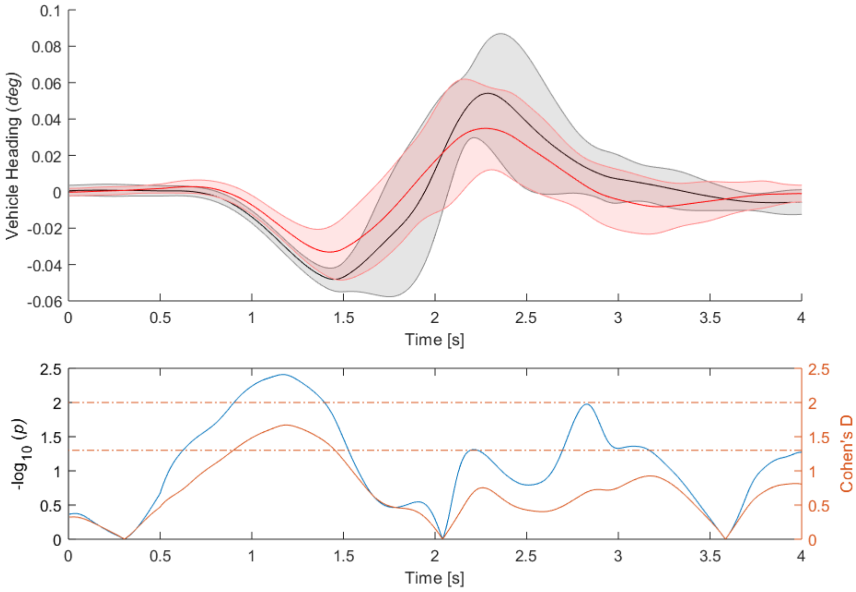

Figure 2. Vehicle heading in the two ROR scenarios.

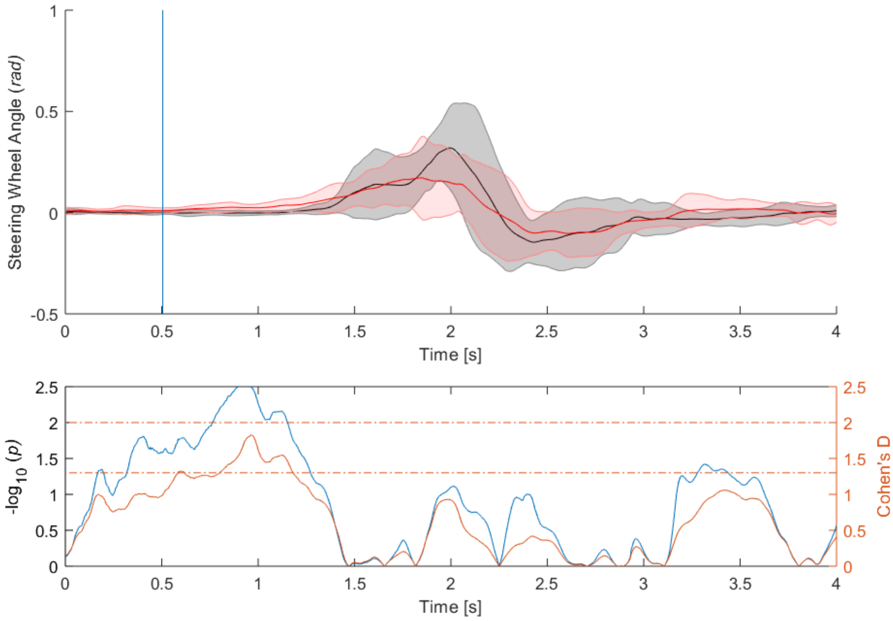

Figure 3. Steering wheel angle for the two ROR events.

4 Conclusion

This manuscript assessed how drivers handle a critical ROR scenario whilst being distracted in a full motion driving simulator. When comparing the lateral jerk values in this study with a similar event by Wörns (2018), also in VTI Simulator IV, where an active steering system failed in a left curve, the recorded maximum lateral jerk value was 6.55-14.37m/s^3 depending on whether the participants were fast responders or not, indicating that the participants in this study exhibited a harsher response caused by the kinematics associated with going off-road in the moving base simulator. The results presented in this manuscript serves as a baseline source of information on how drivers recover from a run off road scenario. A proposed measure to reduce the likelihood of ROR accidents could be an automatic steering-wheel intervention that in emergency situations prevents the vehicle from leaving the lane. However, previous studies have shown that the drivers are likely to counteract such interventions so that lower level torque overlays have little effect, and higher-level overlays lead to controllability issues. Therefore, it is recommended that further studies explore the impact of active interventions. It is also concluded that experiments assessing ROR situations should be carried out in a between-group design as there is substantial learning effects resulting in compensatory strategies to avoid or reduce the criticality of such an event.

5 Impact

The scenario and the results from this study will be used as a baseline for future evaluations of safety functions that prevents the vehicle from leaving the road. Additionally, the results may be used to create driver models for how drivers handle ROR events.

6 Acknowledgement

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