Implementation of an integrated model for understanding the impact of task complexity and coping capacity on crash risk

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Abstract

Background

The driving task can be characterised as the 'dynamic control task in which the driver has to select relevant information from a vast array of mainly visual inputs to make decisions and execute appropriate control responses' and 'drivers execute planned actions which are shaped by their expectations of the unfolding road, pedestrian and traffic scenarios in front of them and the reality that they actually observe'.

Task complexity is related to the current status of the real-world context in which a vehicle is being operated. Task complexity is determined by goals that have to be reached by performance. The driving task is partly determined by the demands of the road environment, traffic layout, weather conditions and time of the day or location.

Coping capacity refers to the ability of drivers and road systems to manage and respond effectively to various challenges and stressful situations encountered while driving. This includes the resources, skills and strategies that drivers, vehicles and infrastructure employ to ensure safe and efficient travel. This concept is dependent upon two underlying factors and it consists of several aspects of both vehicle and driver state.

Within the above framework, Safety Tolerance Zone (STZ) refers to a context-sensitive and dynamic zone in which the driver is within acceptable boundaries of safe operation and thus not in immediate risk of a crash. The calculation of this zone happens on a continuous real-time assessment by monitoring the driver, vehicle and environment, taking into account both task complexity and coping capacity indicators.

Methods

The aim of this work was to develop an integrated model for understanding the impact of task complexity and coping capacity on crash risk. The fundamental challenge within this research was to identify how explanatory variables of task complexity (e.g. time of the day, weather conditions) and coping capacity (e.g. fuel type, vehicle age, speeding, harsh events) are correlated with the dependent variable of risk in order to predict STZ levels.

Towards that end, a naturalistic driving experiment was conducted, involving a total of 135 drivers aged 20-65 and a large database of 31,954 trips was collected and analysed. The experimental design was divided into four consecutive phases. Phase 1 served as a reference period where driving behaviour was monitored without any interventions. Phase 2 involved a period of monitoring where only real-time warnings from Advanced Driver Assistance Systems were provided inside the vehicle. In phase 3, these in-vehicle warnings were supplemented with feedback delivered via a smartphone app, while phase 4 introduced gamification features in the app, supported by a web dashboard.

In order to achieve these objectives, Generalized Linear Models (GLM) were implemented to examine the key correlations among observed metrics. GLMs are appropriate, as they provide a flexible framework for modelling relationships between multiple explanatory variables and driving performance outcomes.

Additionally, Structural Equation Models (SEM) were performed to identify the impact between latent and observable variables of task complexity and coping capacity with complex relationships (i.e. crash risk). SEM constitutes the key component of this study as it can be used to explore how the model variables are inter-related, allowing for both direct and indirect relationships to be modelled.

Results

Through the application of SEM model, the analysis revealed that task complexity was positively correlated with risk, which means that as task complexity increases, the crash risk increases. Firstly, crucial indicators such as the time of day and weather conditions significantly affect crash risk. Driving during night-time or in adverse weather conditions can exacerbate the challenges posed by complex tasks, further increasing the likelihood of crashes. Secondly, drivers could become overwhelmed by the demands of complex tasks, leading to reduced attention to the road and other traffic participants.

On the other hand, coping capacity was negatively correlated with risk, which means that as coping capacity increases, the crash risk decreases. This relationship can be explained by the fact that drivers with higher coping capacity are better equipped to handle complex and challenging driving situations. They can manage stress, make quicker and more accurate decisions and maintain better control over their vehicles, all of which contribute to safer driving. Consequently, their enhanced ability to cope with driving demands reduces the likelihood of crashes and other risky incidents, leading to a lower overall risk. Conversely, drivers with limited coping capacity may struggle to effectively manage complex tasks, leading to higher crash risk.

The latent analyses also demonstrated a positive correlation of task complexity and coping capacity which implied that drivers' coping capacity increased as the complexity of driving task increases. It was revealed that when drivers encountered complex tasks, they were compelled to engage more deeply with the driving process and tended to regulate well their capacity to react to potential difficulties, while driving. Lastly, younger or less experienced drivers faced more challenges compared to older and more experienced ones.

The respective path diagram of the SEM for headway is presented in Figure 1.

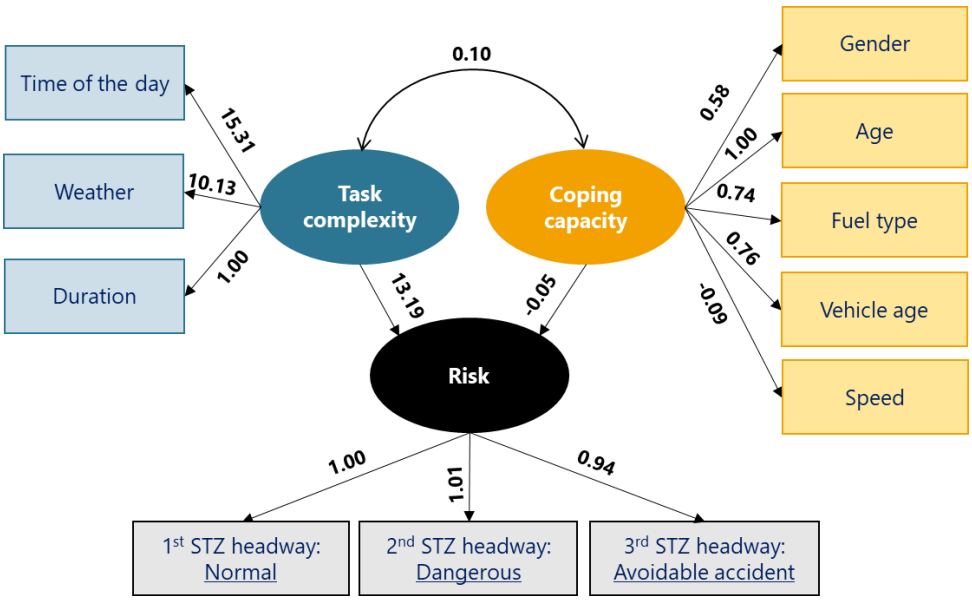

Figure 1: SEM results of task complexity and coping capacity on risk

Discussion and Conclusion

The inter-relationship between task complexity and coping capacity significantly impacts driver's ability to remain within the STZ level. High task complexity, such as navigating through heavy traffic, adverse weather conditions or unfamiliar routes, demands increased cognitive resources, quick decision-making and heightened alertness. When drivers have a high coping capacity, they can manage these challenges more effectively, maintaining their actions within a safe tolerance zone. However, if the coping capacity is low, the driver may struggle to handle these complexities, leading to elevated stress and tension levels that push their actions outside the STZ. Thus, the balance between task complexity and coping capacity is crucial in determining overall safety. High task complexity combined with low coping capacity results in significantly higher risks, as the driver is more likely to operate outside the STZ, potentially compromising driving performance and safety.

Safety interventions were evaluated in terms of their effectiveness in keeping the driver within safe boundaries (i.e. STZ) by monitoring and collecting data on driving behaviour. Findings from the work revealed that both real-time and post-trip interventions positively influenced risk compensation, increased drivers' coping capacity and reduced dangerous driving behaviour. When safety interventions were introduced during different phases of the experiments, drivers improved their performance, became more aware, which led to greater headways and fewer harsh events.

The study's findings support policy recommendations for implementing personalised feedback and targeted interventions for high-risk groups to enhance coping capacity and reduce crash risk in real-world driving.

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