



INCORPORATING PHYSIOLOGICAL STRESS MEASURES INTO ASSESSMENT OF DRIVER PERFORMANCE: IMPLICATIONS FOR METHODOLOGY AND DESIGN

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Abstract: Despite the evidence suggesting that physiological stress can compromise cognitive functioning and decision-making, there is a paucity of literature on the effects of physiological stress on driver behaviour and performance. This paper reviews the literature on physiological stress and decision-making, prior research on physiological stress and driving, and methodological considerations for effectively incorporating physiological data with driving performance. In particular, we will highlight implications and recommendations for future studies on driver stress and performance. These recommendations include selecting driver behaviours and experimental manipulations to improve ecological validity. As well, we discuss the benefits of incorporating physiological stress measures into experimental driving research to capture human factors related to driver decision-making. Finally, we include as an example the preliminary results of a study incorporating physiological stress into a model exploring peer passenger effects on young driver performance. We measured physiological stress via wearable biopotential recording sensors while male and female participants, ages 16 to 25 years, completed tasks either alone or with a peer, before driving. We use these preliminary findings to describe how to select stressors appropriate for the population and stress measurement tools appropriate to the methodological design. **Keywords** – Physiological stress; driver stress; driver performance; human factors

1 Introduction

Driver performance may be affected by a number of external variables, including the behaviour of other drivers on the road, road conditions, and visibility. However, a significant body of research supports the inclusion of internally-oriented variables when assessing driver performance. Specifically, the effects of physiological stress on decision-making suggest that stress should be a key variable of consideration when exploring driving outcomes sensitive to human error. Mather and Lighthall (2012) proposed the *stress triggers anticipated reward salience* (STARS) model of how physiological stress affects decision-making. The STARS model argues that stress sensitizes individuals to anticipated rewards and minimizes attention to, or learning of, possible negative outcomes. In the context of driving behaviour, stress may precipitate dangerous driving due to the various perceived rewards the driver might access. This might include, for example, speeding up to get to a destination faster, despite the higher likelihood of a collision due to speeding.

This paper reviews the relationship between physiological stress and decision-making and prior research on physiological stress and driving outcomes. We make specific methodological recommendations for future research on driver performance. Specifically, we note that driving outcomes, types of stress, and

the unique context of the population being sampled are key variables for further consideration when designing studies examining stress effects on driver performance.

2 Literature Review

2.1 Physiological stress and decision-making

The “stress response” to an event is underpinned by physiological, endocrinal, cognitive, and affective changes that help the body respond effectively. Stress-inducing events can be acute (an immediate, sudden stressor such as an accident) or chronic (a long-term or repeated stressor, such as abuse). In the face of a stressor, the brain activates the “fight-or-flight” response to help the body respond by ‘fleeing’ (removal from the stressor) or ‘fighting’ (adapting to the stressor). Sterling and Eyer (1988) referred to the process through which the body adapts to acute, daily stressors and maintains homeostasis as *allostasis*. When individuals do not adapt to a repeated stressor or manage their responses to repeated stressors, their allostatic load increases, creating conditions for adverse health outcomes and behavioural consequences of repeated, chronic stress (e.g. poor cardiovascular health, poor diet; McEwan, 2008).

A major side effect of both chronic and acute stress is impaired decision-making. Chronic stress has been found to result in habit-based, rather than goal-oriented, decision-making (Dias-Ferreria et al., 2009). That is, when under chronic stress, choosing the less cognitively taxing option is more appealing, even when it makes goal-directed behaviour more challenging. Radenbach et al. (2015) found that a history of chronic stress compounded the effect of acute stress on decision-making, such that individuals with longer histories of stressors made less adaptive decisions after acute stressors. Wemm and Wulfert (2017) also found evidence for a reward bias after an acute stressor, whereby young adults were more likely to make risky choices after experiencing a social stressor. This effect of stress on decision-making is also particularly pronounced for women. Chronically stressed adults took more risks on an in-laboratory risk task after an acute stressor, and this was especially true for women (Ceccato, Kudielka, & Schwieren, 2016). Similarly, Lighthall et al. (2012) found that acute stressors are sensitive to gender. After a cold stressor (where individuals place their hands in ice-cold water), stress hormones measured in salivary cortisol increased and affected adaptive decision-making for female participants on a subsequent gambling task (Lighthall et al., 2012).

2.2 Prior studies of physiological stress and driving

A recent meta-analysis conceptualizing chronic exposure to driving as a stressor revealed mixed results (Antoun, Edwards, Sweeting, & Ding, 2017). Antoun et al. (2017) reviewed 7 studies of both on-road and simulated driving for their effects on cortisol and cardiovascular stress responses. Some studies found no evidence for driving as a stressor while others did; however, no particular pattern (i.e. between type of driver, on-road or simulated) emerged for the conditions under which driving increased physiological stress. A major limitation of this meta-analysis is the small sample size of participants ($N = 162$) and the lack of inclusion of variables relevant to physiological stress in driving contexts, such as emotional arousal.

For example, driver aggression, anger, and anxiety are linked to increased physiological stress and dangerous driving after sudden external stressors and internal perceived stressors. Morris and Pilcher (2016) had drivers complete a simulated drive while exposed to cold inside the car cabin to simulate winter weather conditions. Despite participants reporting that they felt cold but not uncomfortable, the cold stressor was still associated with slower braking time, harder braking, and giving less headway between cars, indicating a more aggressive driving style. Barnard and Chapman (2016) further propose that fear and anxiety about driving can increase physiological stress, negatively affecting hazard detection. Specifically, fear and anxiety may create a U-shaped relationship between physiological stress and hazard detection, such that at very low and very high levels of fear and anxiety, hazard detection is improved via deceleration of physiological responses to allow for effective visual scanning of the road. However, moderate levels of fear and anxiety can compromise hazard detection by increasing the physiological stress response to hazards on the road (Barnard & Chapman, 2016).

Perceived stress due to work- and personal-life stressors also predict driver errors and traffic violations. Ge, Qu, Jiang, Du, Sun, and Zhang (2014) found that individuals who perceived more stress (any type) in their lives also tended to drive more dangerously on the road, and this effect was compounded by higher reported levels of anger. Rowden, Matthews, Watson, and Biggs (2011) report that both work- and personal life-related stressors were associated with increased collision risk, but that driver traits (i.e. anger) interacted with stressors to increase or decrease the relationship between stress and driving outcomes. More daily hassles (i.e. minor acute stressors but chronic exposure) in particular were also predictive of both driver errors and traffic violations (Rowden et al., 2011). Ge et al. (2014) propose that working memory is limited, and that stress and its associated emotional consequences may limit one's capabilities to attend to changing road conditions.

3 Methodological Implications

Similar to Ge et al. (2014), Antoun et al. (2017) suggest that the effects of stress on driving outcomes may be due to the cognitive load of managing distractions while driving. Further, the type of stressor experienced and its relationship to driving outcomes may also be driver- and context-specific (Antoun et al., 2017). Similar to the transactional model of stress, which states that individual sensitivity to stress predicts responses to stressors, individual differences in how much a driver likes driving, feels comfortable on the road, or has traits associated with aggressive driving will intersect with how they perform as a driver and their response to driving situations (Rowden et al., 2011).

For this reason, research that incorporates stress physiology into driver assessment must consider the contributing roles of emotional arousal and the context of the driver sample. While *emotional arousal* can refer to any emotion that may affect behaviour, anger, anxiety, and fear can have independent and additive effects on driving outcomes and physiological stress due to their effects on individuals' ability to self-regulate. Other cars preventing a driver's intended behaviour or making them wait can elicit anger, possibly due to drivers feeling less in control of their travel, thereby resulting in changes to acceleration and speed (Roidl, Frehse, & Hoger, 2014). Further, higher levels of self-reported anxiety and fear around driving are associated with higher speed and acceleration, as well as faster braking (Barnard & Chapman, 2016; Roidl et al., 2014).

The context of the driver sample can also influence the types of stressors that will elicit stress responses. Professional drivers, such as taxi drivers or bus drivers, face particular occupational stressors that in turn affect driver performance. In long-haul truck drivers, the quality of relationship between employees' dispatchers and an occupational culture of support for safe driving ("psychological safety") was associated with fewer hard braking incidents and more safe driving behaviour (Zohar, Huang, Lee, & Robertson, 2014). A poor safety climate around professional drivers is also associated with higher occupational stress and more fatigue-related near misses while driving. That is, poor safety culture increases drivers' occupational stress, translating into fatigue and more dangerous driving (Strahan, Watson, & Lennon, 2008).

The need to consider individual differences in stress responses and the context of the driver sample means that methodological decisions should be made with ecological validity in mind. This means that the experimental design should reflect the real conditions drivers experience as closely as possible to effectively measure their physiological stress in response to driving stressors. As Antoun et al. (2017) found, the mixed results for driving as a stressor suggests that, in and of itself, driving may not always induce physiological stress, but that experimentally manipulated stressors sensitive to the sample do. Professional drivers, for example, face unique stressors that impact dangerous driving. Bus drivers have a combination of high-demand, low-control occupational strains, which in turn affects risky driving behaviour (Useche, Gomez Ortiz, & Cendales, 2017). This effect is compounded by fatigue (Useche et al., 2017). In non-professional drivers, a high degree of self-reported distress after a collision is associated with more anxious driving behaviours (hard braking, slower speed) for individuals with a longer history of stressful life events (Clapp et al., 2011). A longer history of stressful life events also distinguishes between individuals with histories of collisions who experience driving anxiety and those who do not. That is, sensitivity to stressors via chronic life stress increases the effect a previous collision has on future driving behaviour (Clapp et al., 2011). In practice, this means that the ability of a sudden

hazard in the road to elicit physiological stress would depend on whether bus drivers', for example, were tested after a long shift, which would prime their fatigue (Useche et al., 2017). Alternatively, physiological stress may not appear to occur after a sudden hazard in a sample with a history of collisions, unless they are also asked about distress, anxiety, and chronic life stressors (Clapp et al., 2011).

4 Incorporating stress into a model of adolescent risky driving: an example study and 'lessons learned'

As an example of some of the above considerations, we describe below how sample-specific stressors were incorporated into an experimental study exploring mechanisms of peer passenger influence on young drivers. Peer passengers increase the likelihood of driver distraction, errors, and fatal accidents for adolescent drivers (Ouimet, Pradhan, Brooks-Russell, Ehsani, Berbiche, & Simons-Morton, 2015; Curry, Mirman, Kallan, Winston, & Durbin, 2012; Simons-Morton et al., 2011; Simons-Morton, Lerner, & Singer, 2005). Peer presence can induce physiological stress via elevated heart rate, pulse, and sweat production in non-driving contexts (Stroud et al., 2009; van den Bos, de Rooji, Miers, Bokhorst, & Michiel Westenberg, 2014), but physiological stress has not been explored for its effects on adolescent risky driving in the presence of a passenger. We conducted a driving simulator experiment as an initial effort to test these relationships. The simulation scenarios consisted of a 5-kilometre drive where we measured drivers' speed, lateral displacement, and acceleration through straight driving segments and intersections, including a left turn into oncoming traffic. We measured physiological stress via wearable biopotential recording sensors (BIOPAC, Goleta, CA) throughout the entire study, which transmit wirelessly to recording software. Participants were 75 young men and women between the ages of 17-25 completing tasks alone or with a peer before the driving scenarios. We measured heart rate via a three-lead electrocardiogram (ECG) and respiration rate via a respiration band worn around the chest.

Evidence suggests that peer presence is physiologically stressful among adolescents because they are especially sensitive to social evaluation and strongly desire social acceptance (Somerville, Jones, Ruberry, Dyke, Glover, & Casey, 2013). To use this as an ecologically valid stressor, we manipulated whether the participant was socially accepted or socially rejected by the peer passenger, as played by a research confederate who followed an acceptance or rejection script. We referred to this manipulation as a 'social stressor,' reflecting a type of stressor to which adolescents are particularly sensitive. We anticipated that social rejection would be especially stressful for young people desiring acceptance, and that this type of social stressor would serve as a distraction from the road and increase risky driving. Our results supported previous findings that peer presence increased physiological stress and affected driving behaviours relative to control participants who drove with no passenger. However, social acceptance, not rejection, seems to have a stronger effect on participants' stress and driving, particularly for young women (for the full study, see Sutherland, Hasein, Easa, & Day, 2018). This may be due to the fact that young women find social cohesion particularly rewarding, which enhances their physiological response to the presence of an accepting peer, as demonstrated in previous research (Voroboyev, Kwon, Moe, Parkkola, & Hämäläinen, 2015).

This initial test of physiological stress as having a role in young drivers' risky driving revealed several 'lessons learned.' During the pilot phase of data collection, we measured sweat production (skin conductance) and pulse in addition to heart rate and respiration. However, we had to alter our physiological data collection in response to the limits of these particular physiological measures within a driving simulator. Sweat production (as measured by skin conductance) and pulse are measured via sensors placed on the non-dominant fingers. It was possible to collect sweat and pulse data during study components prior to driving, but sensors had to be removed because the steering wheel interfered significantly with data collection. Given that we could not collect stress physiology data from these measures during variables of interest (the drives), we omitted them after piloting five participants.

However, physiological measures worn on the torso did not interfere with participants' ability to drive. The ECG leads reliably produced clean, analyzable data for almost all participants and was not affected by movement of the participant. The respiration band was particularly sensitive to anatomical differences in participants, such as chest depth and width, which required us to place the band above the breastbone for some participants and over the diaphragm for others. Since our experimental methodology had

participants moving around at certain times (e.g. turning to face in different directions, getting in and out of the car), the respiration band would occasionally drop the signal, typically when a participant slouched in the seat. Unlike the ECG sensors, respiration bands may be most effective when study methodologies require minimal movement and participants can stay stationary in proper posture. Finally, participants putting on a seatbelt similarly interfered with the respiration band and ECG leads. Despite our interest in tracking whether or not participants put on their seatbelts, we amended our study script to instruct the participant not to put on the simulator's seatbelt because it interfered with the physiological data collection. Based on our experiences, wireless ECG apparatuses may be most effective for measuring physiological stress in a driving simulator when participants are also completing other tasks as part of the study, with respiration bands being similarly effective when the study is primarily stationary.

5 Conclusions

In summary, the key methodological consideration when designing experimental studies that measure driver stress is ensuring ecological validity of the selected stressor (e.g. passenger presence, concerns about safety climate) and measuring co-occurring variables, such as drivers' fear, anxiety, and history of chronic stress. It is likely that different populations of drivers experience varying degrees of stress while driving depending on the stressors they have been exposed to. Additionally, the measurement devices used to capture physiological stress must be carefully selected to minimize their impact on drivers while they complete study (e.g. avoidance of measurement sensors on the hands or fingers) and be adaptable to the driving environment (e.g. mobile, wirelessly recorded).

Our review of the literature indicates that physiological stress and individual sensitivities to stressors have significant effects on driver performance. Individual differences, such as anger or anxiety, and individual group differences, such as professional and non-professional drivers, have their own unique contributors to not only the stress response, but also to the effect on driver performance. Future research on driver performance and human factors related to driving should consider incorporating stress physiology as a unique contributor when measuring driver errors and violations. Using a machine learning approach, recent research suggests that driver behaviour during certain road conditions and road shape may predict upcoming physiological stress reactions while driving (Munoz-Organero & Corcoba-Magana, 2017). While preliminary, this indicates that physiological stress may be one human factors component that could be integrated into collision or hazard avoidance systems, and inform road and research designs to minimize the effect of physiological stress on driver performance.

The broader implication of measuring driver stress is that physiological stress is a modifiable risk factor for collisions and driver injury. Recent evidence suggests that young drivers respond positively to receiving feedback on their driving (i.e. being told when they are speeding) and adjust their driving behaviour accordingly (Paaver, Eensoo, Kaasik, Vaht, Maestu, & Harro, 2013). Further, event-triggered driving feedback (i.e. being video recorded when certain risky driving behaviours occur) also resulted in subsequent reduced rates of risky driving amongst newly licensed drivers (Carney, McGehee, Lee, Reyes, & Raby, 2010). These findings suggest that populations at higher risk for physiological stress while driving, such as young or professional drivers, may reduce the likelihood of stress interfering with their decision-making if biofeedback (i.e. information about their physiological stress) was incorporated into driver training. It is also possible that collision or hazard avoidance systems could be designed to measure drivers' physiological state via sensors in the steering wheel and/or driver's seat and integrate this data with traffic and road conditions to more cohesively warn drivers of possible threats (Munoz-Organero & Corcoba-Magana, 2017). Future research on human factors implicated in driver injury and collision risk should consider developing and testing driver training interventions and biofeedback systems to determine the optimal methods of identifying and modifying physiological arousal while driving.

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