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Contents

Summary

Sudden sickness in drivers is a common cause of fatal crashes and accounts for about 10% of road traffic fatalities in Sweden. The risk could be mitigated with a driver monitor system capable of detecting critical medical conditions. Vehicle integrated and wearable sensor technologies for monitoring physiological and behavioral signs have been rapidly developed in recent years. Those technologies have the potential to detect critical medical conditions, even in an early phase. However, limited studies have approached this application. In order to fill the knowledge gap, in this project, workshops and literature review were conducted to investigate: 1) what are the most relevant medical conditions that cause crashes and fatalities, 2) physiological and behavior signs before or during those conditions, 3) technologies to sensing those signs in vehicle, 4) challenges and approaches to move forward.

Syncope - Unresponsive Driver & Sudden Illness Detection

1 Background

Sudden illness in drivers is a common cause of fatal crashes and accounts for about 10% of road traffic fatalities in Sweden. Similar to fatigue and distraction, the risk could be mitigated with a driver monitor system capable of detecting critical medical conditions, in combination with minimum risk maneuvers executed by automated driving systems. Such developments are being incorporated into the Euro NCAP roadmap and EU's General Safety Regulations (GSR) for motor vehicles. Monitoring technologies have been rapidly developed in recent years and many physiological and behavioral signs can be measured with vehicle integrated sensors and wearable sensors. In-vehicle measures have a great potential to detect critical medical conditions, even in an early phase. However, there is a knowledge gap regarding detailed detection criteria for a variety of conditions. As a result, early-stage Euro NCAP assessment protocols for sudden illness focus on detection of unresponsive drivers, not detection of the medical condition per se. An unresponsive driver is determined as a driver who either does not return their gaze to the forward road view within 3 seconds of an inattention warning being issued or a driver whose gaze has been away from the forward road view or has been eyes closed for ≥ 6 seconds. This approach means that the detection has a time delay, and it could be problematic in high level automation when the driver's gaze may not be forward. Utilizing other physiological and behavioral information could potentially provide better assessment for sudden sickness conditions.

2 Project set up

2.1 Purpose

The purpose of the study was to fill the knowledge gap regarding in-vehicle sudden illness detection by gathering people with background in traffic safety, biomedical engineering, medical science and transportation authority in a collaborative project. As a first step, we are aiming to perform a background review for in-vehicle sudden illness and incapacitation detection. The results will create knowledge for guiding future research and development as well as policy making.

2.2 Objectives

The objectives of the study were:

1. Identify the most common illnesses and medical conditions that lead to driver impairment and crashes.

2. Review state-of-the-art sensing technologies for monitoring physiological and behavioral signs of illness in the vehicle environment.

3. Explore the feasibility of using those physiological and behavioral measures to have an early detection of critical conditions that can lead to severe driving impairment, or identify different types of medical conditions.

4. Formulate future research directions for coming research calls.

2.3 Project period

2022-09-01 – 2023-02-28

2.4 Partners

- Chalmers E2
- VTI
- Autoliv
- Volvo Cars
- Trafikverket
- VGR/SU

3 Method and activities

The study was conducted through literature studies and a series of workshops.

Literature studies are focusing on the following aspects: 1. Identifying the most frequent medical conditions that cause traffic accidents. 2. Physiological and behavior signs associated with those conditions. 3. Sensing technologies for physiological measurements in vehicles.

Three workshops with internal and external stakeholders were performed. The purpose was to collect input from different perspectives. The first workshop was held with clinicians to discuss what the signs and symptoms of sudden illness onset are and how these can be measured. The second workshop focused on the industry perspective. Here, both internal and external stakeholders in the automotive industry were invited. This workshop focused on opportunities and challenges with in-vehicle monitoring. The third workshop was held with traffic safety experts that provided insights into the severity of the problem with sickness related traffic fatalities.

Project results and implications were also discussed in internal project meetings.

4 Results and Deliverables

4.1 Results from workshops

Summaries of the discussions during the workshops are presented below.

4.1.1 Clinical workshop

Clinicians with extensive experience in cardiology and trauma care participated in the workshop. In the emergency department, cardiovascular problems are the most common critical conditions encountered. Looking at sudden severe sickness onset in general, cardiac events are the most common, and should likely be the most common among drivers. This was confirmed by a representative from Trafikverket.

A cardiac event such as a myocardial infarction can be detected in the clinical setting using for instance electrocardiography (ECG). In hospital wards, vital parameters are continuously monitored, and warning systems are activated based on bedside physiological measurements using blood pressure, heart rate, respiratory rate, etc. These physiological measurements can show a deterioration of the patient's condition. Similar strategies could be adopted in vehicles, but the equipment for vital parameter monitoring needs to be less intrusive than in the clinical setting. Heart rate was concluded to be an important vital sign to monitor for detection of cardiac events.

Although cardiovascular problems are the most common, it is important not to exclude other diseases. Breathing problems, seizures, stroke, diabetic reactions etc. are also critical if they occur in a driving situation. Some of these conditions may also cause sudden changes in the heart rate and could possibly be detected through heart rate measurements whereas other conditions would require different vital sign monitoring. Change in breathing patterns is another parameter that can provide information about a patient's status. When it comes to conditions like diabetes, many patients have automatic blood sugar sensors, and one future possibility could be to connect these to sudden sickness detection systems.

4.1.2 Industry workshop

Several stakeholders from the automotive industry were invited to participate in the workshop. Representatives from four external companies participated in addition to the project partners. The Questions discussed in the workshop were:

- What type of (sudden illness) monitoring do you think will be feasible?
- Challenges with in-vehicle physiological monitoring?
- What are the technical limitations?
- Privacy and security issues with occupant monitoring
- Do wearables have a role, or will only vehicle mounted sensors be possible?
- Who should be monitored? Other road users and vehicle occupants?

It was foreseen that future vehicles should be able to identify medical conditions before a critical event happens. Camera based driver monitoring systems can possibly be used to detect heart rate (variability), respiratory rate and other vital signs. Machine vision may be able to determine unresponsive/unconscious driver, but physiological measurements will be needed to give more clues as to whether there is a medical issue, or the driver is just sleeping. One thought was that the real task is not to define sudden sickness per se but rather to reduce the list of sudden events and teach the future systems to predict these kinds of events beforehand. Especially those that directly impact one’s ability to stop the vehicle, e.g., heart attack or sudden drop of blood pressure, to avoid a crash. It was stressed that it is important that the sensors are non-intrusive and that it is perceived as an added value by the driver. One important application is to support the emergency responders with more information about the event. Long term monitoring to look for trends, e.g., slow deterioration of a condition over time could be an application.

Being able to detect a specific state at a specific point in time was seen as one of the main challenges with driver monitoring in general. A major challenge for sudden sickness detection is also to get data to test the systems. Medical emergencies are rare events, and they cannot be experimentally manipulated for validation of the systems as done for example when testing fatigue detection systems. Therefore, testing will rely on historical or synthetic data. It is very important to have good accuracy and minimize false positives as well as false negatives, especially automatic minimal risk (stopping) maneuvers should not be activated unless there is a real emergency. Other foreseen challenges were related to regulatory processes. Diagnostic tools are considered medical devices and the regulations around medical devices need to be handled. If the in-vehicle system should be allowed to actually make a decision on whether you are in a medical emergency situation, the device needs to be tested and approved as a medical device.

Technical limitations include concerns whether we can measure the needed physiological parameters with high enough precision. There is generally a tradeoff between availability, non-intrusiveness, and precision. Several sensors are already available in the vehicles, cameras, radar for occupant detection etc. It could therefore be a challenge to fit in additional sensors, but also an opportunity to use sensors already available.

Health monitoring would also involve storing sensitive personal data. Therefore, all data will probably need to be processed locally in the vehicle to avoid/mitigate risk of exposing (sensitive) personal data. The possibility to opt-in could be a solution to privacy issues. Privacy issues become even more sensitive in commercial vehicles where there is employer – employee dependency issues.

Wearables were discussed as a possible add-on on top of sensors in the vehicle. However, it was seen as unlikely it would be part of a regulation unless some agreed-upon interface/communication interface comes in place. There is a wealth of information available out there from such devices, but it was not seen as realistic to use a device not part of the vehicle for real-time detection of 'incapacitated' and 'unresponsive'. For crash avoidance, monitoring the driver is the main objective. Monitoring and assessment of other occupants' state would, however, be relevant for post-crash assessment and communication to care and rescue services.

Some of the discussion revolved around whether it is necessary to know the cause of unresponsiveness. On the one hand, it was argued that if a vehicle can handle any type of unresponsive driver, that is enough to prevent crashes due to driver incapacitation. On the other hand, being able to measure the type of unresponsiveness can provide valuable information about sickness to emergency responders. In manual driving, the timing is also crucial, and a few seconds of incapacitation can have much more severe consequences than in automated or piloted driving. Being able to detect the early signs of sickness could enable mitigation strategies such as escalating warnings or minimum risk maneuvers before the driver gets into a state of unresponsiveness. An unresponsive driver is not going to respond to escalation in the HMI, regardless of how much it is escalated, but detecting the onset of sickness before the driver is completely incapacitated could provide the opportunity to handle the medical emergency in an early stage. In relation to this, it was also stressed that it is important to determine what information is actually needed and valuable to care and rescue services, in relation to what is feasible to measure.

4.1.3 Traffic safety workshop

The participants in this workshop were, in addition to the project group, the team appointed by Trafikverket to investigate road traffic fatalities caused by illness. In the official statistics from Trafikanalys, about 10% of the road traffic fatalities are due to illness. In many of these cases, the person would have died from the illness irrespective of whether the onset was during driving or while doing some other activity. Often, the driver has run off the road or stopped in traffic without involving other vehicles in a crash. In other cases, the crash load was the cause of death and the reason for crashing was likely a sudden sickness onset. There are probably also cases where a crash has been caused by a sudden sickness, but it has not been determined and documented. In these cases, the person killed in the crash might not be the driver that had a sudden sickness event. Thus, the total number of sickness related fatalities is most likely an underestimation. This type of statistics is also only available for fatal crashes in Sweden. We are therefore not able to estimate the total number of non-fatal crashes caused by sudden sickness. Further analyses of traffic fatalities due to sudden sickness are planned by the team at Trafikverket. Preliminary data confirms that cardiovascular events, such as sudden cardiac arrest and myocardial infarction are the most common conditions reported in sickness-related crashes.

4.2 Results from literature studies

4.2.1 Medical conditions and traffic safety

Through a literature search, eight studies have been identified that investigate medical conditions that causes road crashes or death after 1990 (see Table 1). (Please note the differences among studies in ways for coding the conditions and methods for data collection)

Six studies investigated medical conditions as the cause for death in vehicle (Ahlm et al., 2001; Antecol & Roberts, 1990; Büttner et al., 1999; Cheng & Whittington, 1998; Halinen & Jaussi, 1994; Tervo et al., 2008). They show that medical conditions can be the direct cause for 3-10% of all deaths on the road or in vehicles. In addition, one study shows that 3% of the deaths in crashes caused by medical conditions were because of the crash impact itself (Tervo et al., 2008). In those studies, cardiovascular related conditions are the dominating cause (53-97%). And stroke is the second common cause for death (5.4%-27%). For those conditons, fast and appropriate medical care can significantly increase the survival rate. In addition, studies show that less than half of the drivers managed to stop the car by themself under these conditions (Büttner et al., 1999; Tervo et al., 2008).

Two studies investigated medical conditions causing crashes (Lindsay & Baldock, 2008; National Highway Traffic Safety Administration, 2010). Those studies show medical conditions are causing 1.3-13% casualty crashes where emergency services departed. Major causing conditions include both life threating conditions and conditions that cause transient loss of consciousness, where cardiac related conditions, seizure, syncope, diabetic reaction, psychosis-related episodes are the most frequent causes.

Table I. List of studies that investigated medical conditions that causes road crash or death after 1990.

Study, Place and Period	Data	Cases	Medical conditions	Other findings
(National Highway Traffic Safety Administration, 2010) U.S. July 2005, to December 2007	Nationwide survey of crashes NMVCCS. Crashes involving light passenger vehicles to which EMS had been dispatched. Medical conditions are coded if they are major and had the potential for influencing the performance of the driving task.	49,868 drivers (had crashes precipitated by medical emergencies) 1.3% of all crashes	35% Seizure 29% Blackout 20% Diabetic reaction 11% Heart attack 3% Stroke 4% Other	
(Lindsay & Baldock, 2008) Adelaide, Australia April 2002 and October 2005	At-scene investigation of road crashes in which an ambulance was called.	298 road crashes 39 crashes with medical conditions as a direct causal factor, 25 car drivers, 14 pedestrians	28% Cardiac-related event 20% Epileptic event 8% Schizophrenia-related episode 8% Hypoglycaemic event 4% Other psychosis-related episode 4% Dementia 4% Asthma-related event 4% Complications related to end stage Conn's disease 4% Loss of consciousness related to pregnancy 4% Chronic sleep deprivation with severe and chronic pain 4% Cumulative effects of multiple medical conditions 8% Loss of consciousness with cause yet to be determined	
(Tervo et al., 2008) Finland January 2003 to December 2004	All autopsy reports from fatal motor vehicle accidents during the years 2003 and 2004.	522 accidents in total 10.3% (54/522) accidents immediately caused of disease attack 9% of deaths, 5.1% by disease attack, 3.7% by crash injuries	70% Cardiovascular 13% Cerebral circulatory 7% Spontaneous aortic rupture 11% Others	The major part of crashes secondary to a DA were single accidents (32/54, 59%) or crashes against a non-moving object (9/54, 17%). Typical of these crashes was a relatively low velocity; 27 (66%) less than 50 km/h and 36 (88%) less than 80 km/h. Twelve (22%) accidents were collisions with another vehicle.
(Ahlm et al., 2001) Sweden 1999		580 deaths in road traffic 50 nature deaths	69% Ischemic heart disease 9% Cerebral hemorrhage 9% Ruptured aortic aneurysm 6% Cardiac enlargement 3% Cerebral infarction 3% Epilepsy	

(Büttner et al., 1999) Files from Ludwig-Maximilians University, Munich, Germany 1982-1996	Retrospectively reviewed: (a) sudden death at the wheel when driving; (b) found dead in a car on the driver's seat; and (c) traffic accident	147 drivers of motor vehicles were found out of 34 554 cases	76.9% Ischemic heart disease 4.1% Aortic aneurysm 5.4% Cerebrovascular disease 1.3% Epilepsy 1.3% Diabetes mellitus 4.8% Bronchial asthma 1.3% Pulmonary embolism 1.3% Esophageal varices 2.7% Bronchopneumonia 0.7% Colloid cyst	I. Found dead in a vehicle 43 Sudden natural death at the wheel: II. Driver was able to stop the vehicle 28 III. Vehicle stopped by a passenger 1 IV. No collision / property damage 8 V. Collision with A. Other vehicle 26 B. Property 27 C. Pedestrian 2 No further information 12
(Cheng & Whittington, 1998) Birmingham and Solihull UK 1984-1988	Cases reported to the coroner. Data were obtained from reports provided by the police, witnesses, coroner's officers and pathologists. In 75 cases, autopsy was carried out and in 84 instances the matter was dealt with without an inquest.	86 cases of sudden natural, nontraumatic deaths of motor vehicle drivers	93% Cardiovascular disease Others: Respiratory failure Pneumonia Subarachnoid haemorrhage Cerebral infarction Ruptured abdominal aortic aneurysm Gastrointestinal haemorrhage	Frontal collision accounted for 46 (92%) cases, side impact for three (6%), and rear collision for one (2%) case. Only 36 (42%) drivers had managed to stop the vehicle or come safely to a halt without damage.
(Halinen & Jaussi, 1994) Finland 1984-1989	All who die in traffic accidents have an autopsy taken by a forensic scientist using standard methods. A police questionnaire includes information on driver's health, medication and possible new symptoms before the accident. Possible illness as a cause of accidents is judged and classified by medical advisors. The database classification does not include the specific diagnosis of the illness which caused the accident.	48 accidents caused by sudden illness. 1.5% accident, 3.9% drivers' death	57-68% Cardiac arrest 9% Epileptic fit 9% intracerebral hemorrhage	

(Halinen & Jaussi, 1994) Canton de Vaud, Switzerland 1986-1989	All the police records of accidents were registered in the data bank as attributable to the key word 'malaise'. Final diagnoses of the causes of accidents were based on (1) records, which always included a detailed description of the mechanisms of the accident, of the drivers' condition supplied by themselves and/or the police and/or witnesses and frequently medical follow-up information; (2) the medical records collected by the Public Health office of the canton in all cases; (3) the autopsy findings in about half of the fatalities.	157 accidents with unclassified fit or sudden unconsciousness, 0.4% all accidents, 3.4% of all traffic death	53-79% cardiac arrest 27% Intracerebral hemorrhage	
(Antecol & Roberts, 1990) U.S	Case study of hearts from 30 persons died from nature cause on driver's seat of four-wheeled motorized vehicles	30 cases	97% cardiovascular conditions 80% coronary artery disease	33% died in parked vehicle 67% died while driving 35% no collision 50% damage to other people

4.2.2 Sensing technologies and detection

Measurable signs and symptoms of medical conditions

Physiological and behavior signs pre and during the most frequent medical conditions connected to road crashes or death were investigated. Several medical conditions can be accompanied by changes in vital signs. Heart rate and blood pressure change are often present with the conditions that influence blood supply to the brain. For conditions caused by heart functionality, signs in the heart electrical activity can be captured. Motor deficits caused by illness could be reflected by behaviors.

Sudden cardiac death is mostly connected to cardiac arrhythmias where ventricular tachycardia and ventricular fibrillation is responsible for more than 75% of the cases (Margulescu & Anderson, 2019). Acute ST elevation, myocardial infarction, and arrythmias that lead to syncope and sudden cardiac arrest can be identified with electrocardiogram (ECG). Recent studies show that a good recognition of such events could still be achieved using a single lead ECG recording rather than the standard 12 lead ECG (Gibson et al., 2022; Hannun et al., 2019). Abnormal vital signs are prevalent hours before the cardiac arrest in patients treated in hospital wards and severe deterioration can be found before the failure of the circulatory system (Andersen et al., 2016; Churpek et al., 2012; Gilhooley et al., 2019; Kang et al., 2016; Oh et al., 2016). Survival is possible

with fast, appropriate medical care. Early detection could thus save lives and prevent crashes.

Heart rate and blood pressure deviations are also seen in other conditions. Increased heart rate can be observed with 64-100% seizure cases. (Leutmezer et al., 2003; Lotufo et al., 2012). For neurally mediated syncope, a reflex response causes vasodilation, bradycardia, and systemic hypotension leading to decreased cerebral blood flow (Gauer, 2011), the change in heart and blood pressure can be observed tens of seconds before the loss of consciousness. Abrupt blood pressure rise is the most common clinical symptom of acute ischemic stroke (McManus & Liebeskind, 2016).

Video analysis that identifies limb motor deficits, facial weakness, gaze deviation, eye blinking, etc. could be used for automatic detection of stroke and seizure symptoms. (Bat-Erdene & Saver, 2021; Hou et al., 2022)

Using continuous glucose monitor (CGM), hypoglycemia and hyperglycemia conditions can be detected or even prevented at an early stage.

Sensing technologies

Technologies that could provide unobtrusive physiological measurements in the vehicle are summarized.

Inside the vehicle, ECG could be acquired by contact or noncontact electrodes. Dry contact electrodes can be integrated into the steering wheel where ECG can be measured when the driver has both hands on. Compared to clinical standard ECG, this measurement can provide only one lead and with higher noise level caused by nonoptimized contact and motion artifacts. The continuity of the measurement is dependent on the driving style about hands on wheel. Capacitive electrodes allow ECG measurement without direct contact. Those electrodes can be imbedded into the seat or seatbelt. Due to motion artifacts, the technology may not deliver good continuous measurement while driving on bumpy roads (Leicht et al., 2022).

In addition to ECG, several other technologies can be used for HR measurement. Those technologies are detecting the body surface displacement or superficial perfusion caused by the pulse (Leonhardt et al., 2018; Sidikova et al., 2020). Body surface displacement can be measured through technologies like seismocardiography (SCG) and ballistocardiograph (BCG). Reflecting the mechanical properties of the circulation, those measures also have the potential to detect conditions like cardiac arrest that cause failure in circulation (Kern et al., 2023; Lee et al., 2021). In a vehicle, BCG and SCG measurement can be achieved in one way with pressure or strain-gauge sensors integrated in the seat or seatbelt, or in another way through radar integrated in the steering wheel, seat, dashboard etc. The motion artifacts remain the major challenge for those technologies. Superficial perfusion can be captured by contacting photoplethysmography (PPG) or

noncontracting PPG through visible lights or infrared camera. In vehicle, it can be achieved by integrating contacting PPG sensor in the steering wheel (Nguyen et al., 2017) or with camera (Liu et al., 2022).

Respiration can also be detected with body surface displacement with a larger amplitude compared to displacement caused by heartbeat. SCG or BCG sensors for heart rate can be used for respiration monitoring at the same time (Leonhardt et al., 2018). In addition, the temperature difference between inspiration and expiration can be captured through thermal image analysis (Ebrahimian et al., 2018).

Cuffless blood pressure (BP) measurement techniques have been recentely developed with many devices on the market currently. Cuffless blood pressure measurement can be based on pulse transit time or pulse wave analysis (Stergiou et al., 2022). In vehicle pulse transit time could be estimated with PPG measurement from multiple sites or simultaneous ECG and PPG measurement (Futatsuyama et al., 2014). With the purpose of managing hypertension, most technologies were developed and evaluated with single measurement over multiple subjects. Limited published studies were on intra-individual BP change monitoring. As pulse transient time is correlated to the blood pressure change (Block et al., 2020), the technology has the potential to track change under critical conditions without the need of calibration.

Camera beased soulutions have been continuesly developed for various driver monitoring applicaitons. Analysis of gaze, facial expression, posture for head, trunk and limb can be achieved through 2D or 3D videos in the vehicle (Wang et al., 2019). Therefore certain symtons of motor imparement caused by medical conditon could be identified.

5 Conclusions, Lessons Learnt and Next Steps

Sudden medical conditions are the cause of 3-10% of road deaths directly. They are also the cause of an additional 3% of the deaths caused by the crash impact. The majority are due to cardiovascular problems. Less than half of the drivers experiencing a sudden illness episode managed to stop their car. Medical conditions are also causing 1.3-13% casualty crashes, where most frequent conditions are cardiac related conditions, epileptic events, diabetic reaction, and syncope. Various types of impairment can be caused by those medical conditions including vision, motor, and cognitive impairment. Not all the impairments are reflected by gaze, as the drivers can become unconscious with their eyes open. Monitoring based on other signs can potentially provide faster detection and better coverage of conditions.

Among the most frequent conditions, some have the potential to be directly identified with physiological measurements. For example, cardiac arrest condition can be detected

with electrocardiography. In addition, abnormities in vital signs, including heart rate, blood pressure and breath rate, are associated with several related conditions. Higher degree of abnormality can indicate a higher risk at the time or in the near future. Risk scoring systems based on those measures are developed and have been used in clinical practices. How to use those measures in driving scenarios needs to be investigated in future studies where balance of sensitivity and specificity under driving conditions need to be considered.

Substantial development with in-vehicle physiological measurement technologies have been carried out with promising results. Sensors for detection sudden illness conditions can be shared with other safety functionality including hands on wheel detection, fool-proof seat belt, occupants positioning for airbag deployment and children presence detection, and sleepiness and inattention detection. However, most of the technologies are suffering with compromised measurement quality in real life driving due to movement from the human and vehicle or varying light conditions. Sensor fusion is one of the potential methods to mitigate this challenge. At the same time, with the trend of connecting mobile devices with vehicles, measurements from consumer wearables such as smart watches and heart rate belts can also become the source of measurement. In this case a real time interface for data communication needs to be established.

One major challenge for sensor and algorithm development and evaluation is the rarity of data under medical conditions while driving. Early phase development may need to rely on established criteria, data measured under other conditions or simulated data. Concerns with privacy for health data and regulatory issues have been raised in the study but not been explicitily explored within current project scope.

6 Dissemination and Publications

The results are presented mainly in this report. The project results will also be presented in a SAFER seminar.

References

Ahlm, K., Eriksson, A., Lekander, T., & Björnstig, U. (2001). [All traffic related deaths are not “fatalities”--analysis of the official Swedish statistics of traffic accident fatalities in 1999]. *Lakartidningen*, *98*(17), 2016–2022. http://www.ncbi.nlm.nih.gov/pubmed/11374230

Andersen, L. W., Kim, W. Y., Chase, M., Berg, K.--> M., Mortensen, S. J., Moskowitz, A., Novack, V., Cocchi, M. N., & Donnino, M. W. (2016). The prevalence and significance of abnormal vital signs prior to in-hospital cardiac arrest. *Resuscitation*, *98*, 112–117. https://doi.org/10.1016/j.resuscitation.2015.08.016

Antecol, D. H., & Roberts, W. C. (1990). Sudden death behind the wheel from natural disease in drivers of four-wheeled motorized vehicles. *The American Journal of Cardiology*, *66*(19), 1329–1335. https://doi.org/10.1016/0002-9149(90)91163-Z

Bat-Erdene, B. O., & Saver, J. L. (2021). Automatic Acute Stroke Symptom Detection and Emergency Medical Systems Alerting by Mobile Health Technologies: A Review. *Journal of Stroke and Cerebrovascular Diseases*, *30*(7), 105826. https://doi.org/10.1016/J.JSTROKECEREBROVASDIS.2021.105826

Block, R. C., Yavarimanesh, M., Natarajan, K., Carek, A., Mousavi, A., Chandrasekhar, A., Kim, C. S., Zhu, J., Schifitto, G., Mestha, L. K., Inan, O. T., Hahn, J. O., & Mukkamala, R. (2020). Conventional pulse transit times as markers of blood pressure changes in humans. *Scientific Reports 2020 10:1*, *10*(1), 1–9. https://doi.org/10.1038/s41598-020-73143-8

Büttner, A., Heimpel, M., & Eisenmenger, W. (1999). Sudden natural death ‘at the wheel’: a retrospective study over a 15-year time period (1982–1996). *Forensic Science International*, *103*(2), 101–112. https://doi.org/10.1016/S0379-0738(99)00063-8

Cheng, L. H., & Whittington, R. M. (1998). Natural deaths while driving: would screening for risk be ethically justified? *Journal of Medical Ethics*, *24*(4), 248–251. https://doi.org/10.1136/jme.24.4.248

Churpek, M. M., Yuen, T. C., Park, S. Y., Meltzer, D. O., Hall, J. B., & Edelson, D. P. (2012). Derivation of a cardiac arrest prediction model using ward vital signs*. *Critical Care Medicine*, *40*(7), 2102–2108. https://doi.org/10.1097/CCM.0b013e318250aa5a

Ebrahimian, S., Kiashari, H., Nahvi, A., Homayounfard, A., & Bakhoda, H. (2018). Monitoring the Variation in Driver Respiration Rate from Wakefulness to Drowsiness: A Non-Intrusive Method for Drowsiness Detection Using Thermal

Imaging. *Journal of Sleep Sciences*, *3*(1–2), 1–9. https://jss.tums.ac.ir/index.php/jss/article/view/110

Futatsuyama, K., Kawachi, T., & Nakagawa, T. (2014). Cuffless Blood Pressure Monitoring using Steering Wheel Sensor System. 生体医工学, *52*(Supplement), OS-67. https://doi.org/10.11239/JSMBE.52.OS-67

Gauer, R. L. (2011). Evaluation of syncope. *American Family Physician*, *84*(6), 640–650.

Gibson, C. M., Mehta, S., Ceschim, M. R. S., Frauenfelder, A., Vieira, D., Botelho, R., Fernandez, F., Villagran, C., Niklitschek, S., Matheus, C. I., Pinto, G., Vallenilla, I., Lopez, C., Acosta, M. I., Munguia, A., Fitzgerald, C., Mazzini, J., Pisana, L., & Quintero, S. (2022). Evolution of single-lead ECG for STEMI detection using a deep learning approach. *International Journal of Cardiology*, *346*, 47–52. https://doi.org/10.1016/j.ijcard.2021.11.039

Gilhooley, C., Burnhill, G., Gardiner, D., Vyas, H., & Davies, P. (2019). Oxygen saturation and haemodynamic changes prior to circulatory arrest: Implications for transplantation and resuscitation. *Journal of the Intensive Care Society*, *20*(1), 27–33. https://doi.org/10.1177/1751143718764541

Halinen, M. O., & Jaussi, A. (1994). Fatal road accidents caused by sudden death of the driver in Finland and Vaud, Switzerland. *European Heart Journal*, *15*(7), 888–894. https://doi.org/10.1093/oxfordjournals.eurheartj.a060606

Hannun, A. Y., Rajpurkar, P., Haghpanahi, M., Tison, G. H., Bourn, C., Turakhia, M. P., & Ng, A. Y. (2019). Cardiologist-level arrhythmia detection and classification in ambulatory electrocardiograms using a deep neural network. *Nature Medicine*, *25*(1), 65–69. https://doi.org/10.1038/s41591-018-0268-3

Hou, J. C., Thonnat, M., Bartolomei, F., & McGonigal, A. (2022). Automated video analysis of emotion and dystonia in epileptic seizures. *Epilepsy Research*, *184*, 106953. https://doi.org/10.1016/J.EPLEPSYRES.2022.106953

Kang, M. A., Churpek, M. M., Zadravecz, F. J., Adhikari, R., Twu, N. M., & Edelson, D. P. (2016). Real-Time Risk Prediction on the Wards. *Critical Care Medicine*, *44*(8), 1468–1473. https://doi.org/10.1097/CCM.0000000000001716

Kern, W. J., Orlob, S., Bohn, A., Toller, W., Wnent, J., Graesner, J. T., & Holler, M. (2023). Accelerometry-based classification of circulatory states during out-of-hospital cardiac arrest. *IEEE Transactions on Biomedical Engineering*. https://doi.org/10.1109/TBME.2023.3242717

Lee, H. Y., Jung, Y. H., Jeung, K. W., Lee, D. H., Lee, B. K., Jang, G. Y., Oh, T. I., Mamadjonov, N., & Heo, T. (2021). Discrimination between the presence and absence of spontaneous circulation using smartphone seismocardiography: A preliminary investigation. *Resuscitation*, *166*, 66–73. https://doi.org/10.1016/J.RESUSCITATION.2021.07.009

Leicht, L., Walter, M., Mathissen, M., Antink, C. H., Teichmann, D., & Leonhardt, S. (2022). Unobtrusive Measurement of Physiological Features Under Simulated and Real Driving Conditions. *IEEE Transactions on Intelligent Transportation Systems*, *23*(5), 4767–4777. https://doi.org/10.1109/TITS.2022.3143004

Leonhardt, S., Leicht, L., & Teichmann, D. (2018). Unobtrusive Vital Sign Monitoring in Automotive Environments—A Review. *Sensors*, *18*(9), 3080. https://doi.org/10.3390/s18093080

Leutmezer, F., Schernthaner, C., Lurger, S., Pötzelberger, K., & Baumgartner, C. (2003). Electrocardiographic Changes at the Onset of Epileptic Seizures. *Epilepsia*, *44*(3), 348–354. https://doi.org/10.1046/j.1528-1157.2003.34702.x

Lindsay, V. L. A., & Baldock, M. R. J. (2008). Medical conditions as a contributing factor in crash causation. *Australasian Road Safety Research, Policing and Education Conference*, *November*, 610–622.

Liu, S., Koch, K., Zhou, Z., Maritsch, M., He, X., Fleisch, E., & Wortmann, F. (2022). Toward Nonintrusive Camera-Based Heart Rate Variability Estimation in the Car under Naturalistic Condition. *IEEE Internet of Things Journal*, *9*(14), 11699–11711. https://doi.org/10.1109/JIOT.2021.3131742

Lotufo, P. A., Valiengo, L., Benseñor, I. M., & Brunoni, A. R. (2012). A systematic review and meta-analysis of heart rate variability in epilepsy and antiepileptic drugs. *Epilepsia*, *53*(2), 272–282. https://doi.org/10.1111/j.1528-1167.2011.03361.x

Margulescu, A. D., & Anderson, M. H. (2019). A Review of Driving Restrictions in Patients at Risk of Syncope and Cardiac Arrhythmias Associated with Sudden Incapacity: Differing Global Approaches to Regulation and Risk. *Arrhythmia & Electrophysiology Review*, *8*(2), 90–98. https://doi.org/10.15420/aer.2019.13.2

McManus, M., & Liebeskind, D. S. (2016). Blood Pressure in Acute Ischemic Stroke. *Journal of Clinical Neurology*, *12*(2), 137. https://doi.org/10.3988/jcn.2016.12.2.137

National Highway Traffic Safety Administration. (2010). The contribution of medical conditions to passenger vehicle crashes. *Annals of Emergency Medicine*, *55*(6), 563–564. https://doi.org/10.1016/j.annemergmed.2010.03.026

Nguyen, T. T., Takahashi, I., Tanaka, T., Takeuchi, E., Kato, S., Suzuki, T., Kanamori, H., Ninomiya, Y., & Aoki, H. (2017). Development of an automated vehicle stop system for cardiac emergencies. *Advances in Science, Technology and Engineering Systems*, *2*(3), 669–673. https://doi.org/10.25046/AJ020385

Oh, H., Lee, K., & Seo, W. (2016). Temporal patterns of change in vital signs and Cardiac Arrest Risk Triage scores over the 48 hours preceding fatal in-hospital cardiac arrest. *Journal of Advanced Nursing*, *72*(5), 1122–1133. https://doi.org/10.1111/jan.12897

Sidikova, M., Martinek, R., Kawala-Sterniuk, A., Ladrova, M., Jaros, R., Danys, L., & Simonik, P. (2020). Vital Sign Monitoring in Car Seats Based on Electrocardiography, Ballistocardiography and Seismocardiography: A Review. *Sensors 2020, Vol. 20, Page 5699*, *20*(19), 5699. https://doi.org/10.3390/S20195699

Stergiou, G. S., Mukkamala, R., Avolio, A., Kyriakoulis, K. G., Mieke, S., Murray, A., Parati, G., Schutte, A. E., Sharman, J. E., Asmar, R., McManus, R. J., Asayama, K., De La Sierra, A., Head, G., Kario, K., Kollias, A., Myers, M., Niiranen, T., Ohkubo, T., … Palatini, P. (2022). Cuffless blood pressure measuring devices: review and statement by the European Society of Hypertension Working Group on Blood Pressure Monitoring and Cardiovascular Variability. *Journal of Hypertension*, *40*(8), 1449–1460. https://doi.org/10.1097/HJH.0000000000003224

Tervo, T. M. T., Neira, W., Kivioja, A., Sulander, P., Parkkari, K., & Holopainen, J. M. (2008). Observational Failures/Distraction and Disease Attack/Incapacity as Cause(s) of Fatal Road Crashes in Finland. *Traffic Injury Prevention*, *9*(3), 211–216. https://doi.org/10.1080/15389580802040303

Wang, H. Y., Zhao, M. M., Beurier, G., & Wang, X. G. (2019). Automobile Driver Posture Monitoring Systems: A Review. *Zhongguo Gonglu Xuebao/China Journal of Highway and Transport*, *32*(2), 1–18.