



Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.

Contents lists available at [ScienceDirect](https://www.sciencedirect.com)

## Journal of Transport &amp; Health

journal homepage: [www.elsevier.com/locate/jth](http://www.elsevier.com/locate/jth)

# Impact of Post-Covid-19 on driver behaviour: A perspective towards pandemic-sustained transportation

Shahzeb Ansari<sup>a,\*</sup>, Haiping Du<sup>a</sup>, Fazel Naghdy<sup>a</sup>, Abdul Sattar<sup>b</sup>

<sup>a</sup> School of Electrical, Computer and Telecommunication Engineering (SECTE), Faculty of Engineering and Information Sciences (EIS), University of Wollongong, New South Wales, Australia

<sup>b</sup> School of Engineering, RMIT University, Victoria, Australia

## ARTICLE INFO

## Keywords:

Driver behaviour  
Post-Covid-19  
Vaccinated drivers  
Driver health vitals  
Driver psychology  
Pandemic-sustained transportation

## ABSTRACT

**Introduction:** With the announcement of novel Coronavirus disease 2019 (Covid-19) as a pandemic by World Health Organization (WHO) in March 2020, the whole world went into a lockdown that heavily affected human economic and social life. Since December 2020, with the discovery of effective vaccines, the world is now returning to some normality, particularly for those who are vaccinated. The multimodal transportation has resumed with majority of vaccinated drivers being back on road, driving to their work, and providing transport services. However, there are still several long-term Post-Covid-19 factors, affecting driver health and psychology.

**Methods:** The study deployed a systematic search strategy and selected 62 research publications after rigorous evaluation of the literature. The review was based on (1) forming the inclusion and exclusion criteria, (2) selecting the appropriate keywords, and (3) searching of relevant publications and assessing the eligible articles.

**Results:** A broad perspective study is carried out to gauge the impact of Post-Covid-19 scenarios on the driver physical health and mindset in the context of road safety and pandemic-sustained transportation. It was found that the Post-Covid-19 factors such as wearing face-mask during driving, taking oral anti-viral drugs, and fear of contracting disease, significantly impact the driver's performance and situation awareness skills. The analysis suggested that driver's health vitals and psychological driving awareness can be precisely detected through hybrid driver state monitoring methods.

**Conclusions:** The paper conducts a comprehensive review of the published work and provides unique research opportunities to counteract the challenges involved in precise monitoring of driver behaviour under the effects of different Post-Covid-19 factors. The perspective suggested the possible solutions to live with the pandemic in the context of pandemic-sustained transportation.

## 1. Introduction

Covid-19 has heavily impacted the world economy, human life, healthcare system, life psychology, and transportation (Cusack, 2021; Lemke et al., 2020; Liu et al., 2022). As of January 2022, particularly due to Omicron variant of Covid-19, more than 370 million

\* Corresponding author.

E-mail addresses: [shahzeb@uow.edu.au](mailto:shahzeb@uow.edu.au) (S. Ansari), [hdu@uow.edu.au](mailto:hdu@uow.edu.au) (H. Du), [fazel@uow.edu.au](mailto:fazel@uow.edu.au) (F. Naghdy), [abdul.sattar@rmit.edu.au](mailto:abdul.sattar@rmit.edu.au) (A. Sattar).

<https://doi.org/10.1016/j.jth.2022.101563>

Received 11 February 2022; Received in revised form 1 December 2022; Accepted 31 December 2022

Available online 3 January 2023

2214-1405/© 2023 Elsevier Ltd. All rights reserved.

**Table 1**  
Main research questions related to the Post-Covid19 problems, and potential hypothesis.

Research Questions	Hypothesis
What impact will be imposed on the driver life in Post-Covid-19?	The restrictions will be imposed for vaccinated positive Covid-19 drivers. Particularly, if having low to mild symptoms, then they may have to self-isolate at home, or provide services by wearing facemask.
What will be the main factors affecting the driver behaviour during driving in contrast to Post-Covid-19?	The main factors would include wearing the facemask, adopting defensive style, and taking Covid-19 anti-viral drugs during driving particularly for ride share, bus and taxi drivers.
How the effects of Post-Covid-19 will be impacted on driver health and psychology?	The restrictions of Post-Covid-19 would impact the driver performance by inducing driver fatigue and sleepiness, if the facemask is worn for long hour of driving, as well as a stress could also be tempted because driver will need to remain more cautious and active for limiting the spread of disease despite the granted freedom.
What measures need to be taken to provide assistance to the driver when affected by Post-Covid-19 factors?	The smart detection algorithms can be deployed for real-time tracking of driver health, and adaptive shared control strategies can be devised to provide assistance to the drivers during driving.

people have been affected by the disease, resulting in more than 5.65 million deaths worldwide. In the period of more than two years since December 2019, the daily life of entire world is intensively transformed to online education, working from home, and social distancing interaction (Dwivedi et al., 2020). Particularly, due to the enforcement of various types of lockdowns (such as, partial, herd, and complete), people were directed to stay at home with no visitors allowed (Saba et al., 2021). This resulted in low multimodal transportation, reduced traffic collisions, and radical change in driver behaviour (Katrakazas et al., 2020).

In the early stage of Covid-19 pandemic over the period of March 2020 to December 2020, the lockdowns and grounding of vehicles and airplanes had severe impact (Qureshi et al., 2020; Di Domenico et al., 2020). Studies reported in the literature indicate that during the lockdowns, the mobility of transportation was reduced by 74%, resulting in 62% decrease in crashes and fatality rate in various parts of the world compared to Pre-Covid-19 scenarios (Gupta et al., 2021). In Spain, the mobility of transportation was significantly reduced by 65%, resulting in 62% decrease in fatalities (Katrakazas et al., 2020). A similar situation was also observed in the United States, Canada, Kingdom of Saudi Arabia, and Greece (Vanlaar et al., 2021; Sekadakis et al., 2021). While, the mode of active transportation (cycling, walking) increased from 9% to 18% (Shaer and Haghshenas, 2021). The ride-share services such as taxi drivers reduced their shifts because of low work and fear of contracting the disease (Wang et al., 2021; James et al., 2021a). At the same time, common adult and specifically adolescent drivers remained non-vigilant and made common driving mistakes on quiet roads (Inada et al., 2021; Yasin et al., 2021; James et al., 2021b; Stavrinou et al., 2020). The studies conducted showed a significant increase in driving mistakes, including 10% in speeding, 4.2% in distracted driving, 42% in mobile phone usage during driving, and 26.3% in use of alcohol and drugs (Katrakazas et al., 2020; Gupta et al., 2021; Tucker and Marsh, 2021). However, these variations in the driver behaviour can be considered as short-term impacts on transportation and can be prevented by imposing fines and demerit points (Kim, 2021). As the restrictions eased and lockdown was lifted, the transportation mobility was increased, the phone usage and speeding was decreased (Truelove et al., 2021).

With the breakthrough in Covid-19 vaccines since December 2020, the world is now gradually returning to some normality, though not quite the same as the Pre-Covid-19 routine life (Li and Giabbanelli, 2021). The countries such as Singapore, United Arab Emirates, and Australia have achieved more than 90% double vaccination target, and are encouraging people to receive the third dose (booster) as soon as possible after three months of the second dosage of Covid-19 vaccine to prevent the deadly consequences of Delta and Omicron variants (RACGP, 2022). The citizens are granted freedoms to travel overseas, move around the country, and live life like close to Pre-Covid-19. People now can visit the friends and family, drive to their offices for work, and can socially interact. However, there are still several factors of Covid-19 that will keep affecting the transportation particularly driver behaviour despite incredible rate of vaccinations and are assumed to continue for several years.

This study explores the Post-Covid-19 factors that can impact driving and revolutionize the conventional way of monitoring and compensating for the driver behaviour using available technologies. According to the literature, most of the studies conducted on the relationship between Covid-19 lockdown and driving, were focused on the speed of the driving as well as the driver's eating and drinking habits during this period, the distance travelled every day, and the usage of alcohol (Katrakazas et al., 2021). The main aim of the paper is to determine the influence of Post-Covid-19 factors affecting the driver behaviour psychology and health vital condition relating to various research questions presented in Table 1. A comprehensive analysis of published papers in the context of Covid-19 sustained transportation as well as road safety is conducted. This can provide unique research opportunities in the deployment of innovative technologies to accurately detect driver behaviour impacted by Post-Covid-19 factors. More specifically, the paper investigates current trends and challenges associated with detecting exact state of driver while wearing face mask, examination of hurdles involved in precise estimation of driver situation awareness level under the psychological stress, and possible new research directions in approximating the fear of contracting the disease induced during driving, as well as conducive methodologies proposed for monitoring the effects of Covid-19 medicines on driving performance. Such factors can contribute to study and simulation of the driver fatigue and sleepy conditions represented through frequent yawning and distractions (Ansari et al., 2020, 2022a). Therefore, it is important to understand the long-term impact of Post-Covid-19 on driver behaviour to prevent catastrophic consequences for smooth transportation.

The key contributions of the work presented in this paper can be described as.

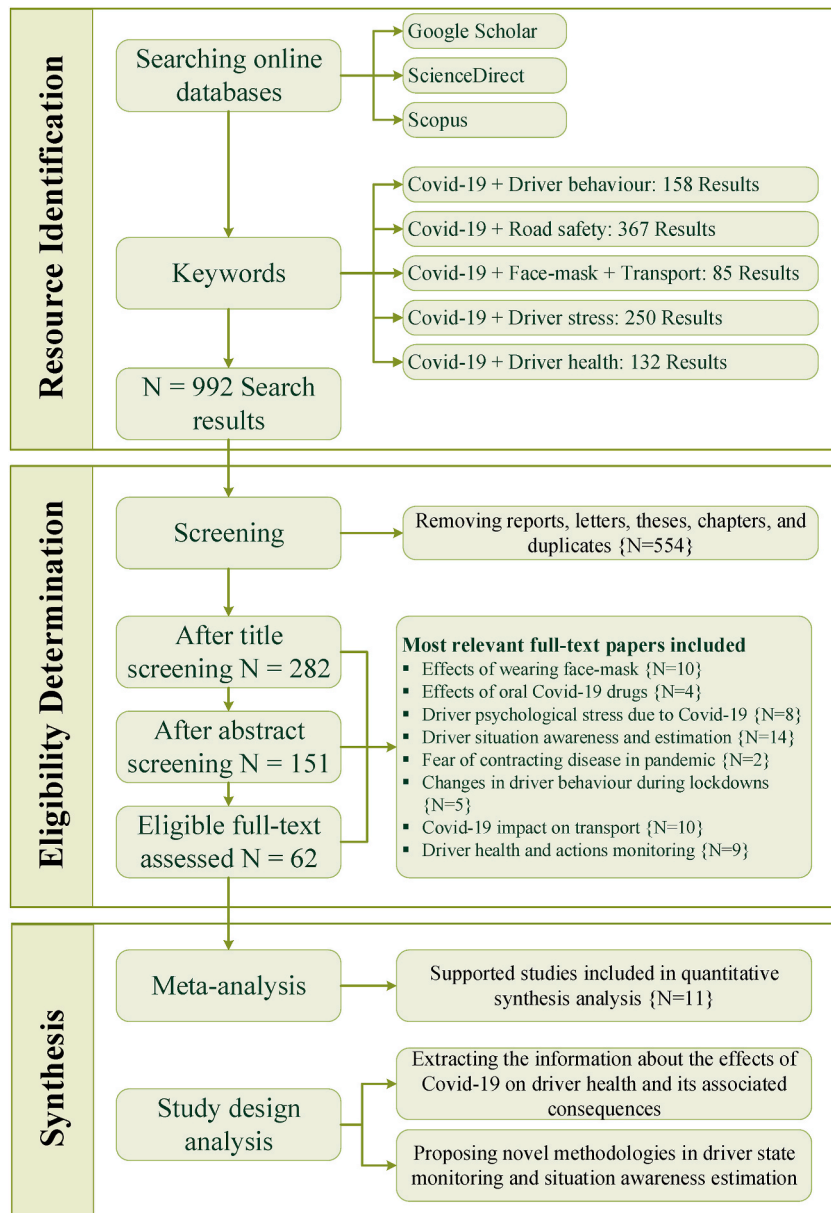


Fig. 1. Prisma systematic review strategy.

1. The paper identifies the core impact of Post-Covid-19 factors on driving behaviour related to health and psychology.
2. A comprehensive perspective analysis of several Post-Covid-19 factors is presented, which are assumed to last for several years.
3. Proposing new research ways and unique opportunities in development of innovative solutions to counteract the challenges involved in detecting the accurate state of driver behaviour impacted by different Post-Covid-19 factors.

The remainder of the paper is organized as follows. Section 2 provides an overview of review methodology deployed in this work. Section 3 discusses the various Post-Covid-19 factors affecting driver behaviour and psychology. Section 4 provides the discussion on the perspective of Post-Covid-19 impact on the transport and health. Section 5 presents the challenges and future directions involved in estimating the Covid-19 impacted driver behaviour. Finally, some conclusions are drawn in Section 6.

## 2. Review methodology

A review of the relevant literature is conducted in this section to demonstrate the research gaps in driver behaviour affected by Covid-19. To gauge the publications, major scientific databases (Scopus, Science Direct and Google Scholar) with the keywords

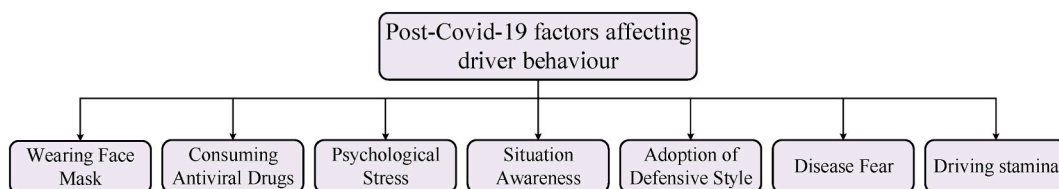


Fig. 2. Hierarchical representation of possible Post-Covid-19 factors.

["Covid19" or "Covid-19" and "driver behaviour" or "driving behaviour", "Covid-19 + road safety" or "Covid-19 + transport", "Covid-19 + Driver stress", and "Covid-19 + Driver health"] from January 2020 to July 2022 were searched. A systematic Prisma search strategy was followed as described in (Ansari et al., 2022b) and presented in Fig. 1. The search resulted in around 992 research publications including theses, reports, chapters, tutorials, conferences, and journal articles. The search results were filtered by removing theses, reports, letters, and duplicate entries which resulted in 554 publications.

Furthermore, to identify the most relevant publications corresponding to the research questions and associated hypothesis shown in Table 1, the publications were screened in following three stages.

- Stage 1 *Title screening*: The publications with titles not related to driver behaviour impacted by Covid-19 were excluded. This resulted in 282 research publications.
- Stage 2 *Abstract screening*: The abstracts of publications remained from stage 1 were evaluated, and the papers that did not contribute to providing the scientific evidence towards the driver health, psychology, and driving performance, were removed, which resulted in 151 research publications.
- Stage 3 *Full-text assessment*: The remaining publications from stage 2 were further evaluated and 62 papers were included that provided original contribution towards the inclusion criteria provided in Fig. 1.

Based on the authors' knowledge search, there was only systematic review article found in the database, focusing on the impact of Post-Covid-19 pandemic on driver behaviour focused on driver's personality and personal barriers (Ahmad et al., 2022). In general, the paper discussed the changes in driver's personality trait towards travel experience and attitude, contagion impact of Covid-19, socio-psychological and financial impact during lockdown. In addition, the paper discussed the importance of adopting the preventive health measures such as hygiene and safety, familiarity with the contagion behaviour of Covid-19 disease, and precautionary measures. However, the study did not aim on the changes occurred in the driver's health and psychology and alternatively on driving performance during Covid-19 or Post-Covid-19 periods. Our study covers the shortcomings and provides an enhanced understanding of several Post-Covid-19 factors that can affect and leverage the driver's health, psychology, and driving performance.

The selected articles were examined and the information associated with the effects of Covid-19 on the driver health, psychology and transport was extracted. The review showed that 16% articles explored the effects of wearing face-mask, 7% discussed the importance of oral Covid-19 drugs, 13% demonstrated the driver psychological stress caused by Covid-19, 22% discussed the driver situation awareness skill and its automated estimation, 3% represented the consequences of disease fear, 8% signified the changes occurred in driving behaviour during Covid-19 lockdown, 16% expressed the impact of pandemic on transportation, and 15% proposed novel methodologies for monitoring the driver health and actions. Furthermore, 11 publications including journal articles, arxiv preprints and Covid-19 related news were included in quantitative synthesis analysis.

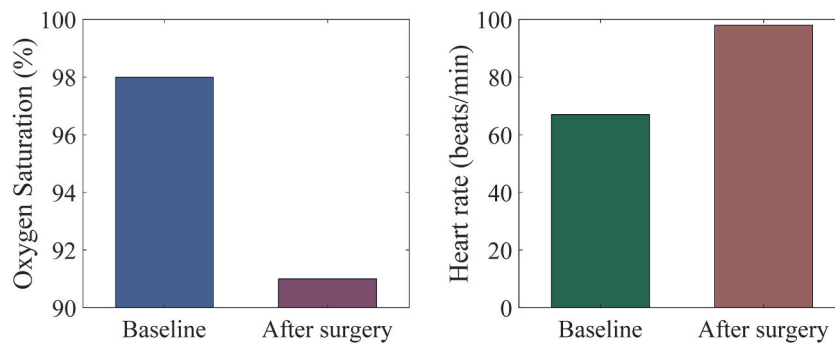
### 3. Post-Covid-19 driving behaviour factors

This section discusses Post-Covid-19 factors that have potential to affect the driver health and mindset. A hierarchy related to different Post-Covid-19 factors is shown in Fig. 2.

#### 3.1. Wearing face mask during driving

Since the declaration of Covid-19 as pandemic by World Health Organization (WHO) in March 2020 (Vanlaar et al., 2021), usage of facemasks particularly for bus, taxi, and home delivery drivers have become mandatory (Dzisi and Dei, 2020). Currently, this restriction is still imposed on bus, taxi, and ride share drivers in various locations of world despite the high vaccinations rates and is assumed to remain in force for the next several years because of new variants of virus. In future, when there will not be any requirement of quarantine or isolation for vaccinated positive Covid-19 drivers with permission to drive freely, drivers will only be confined to wear the approved face mask until they return with a negative test result (Health, 2022).

Wearing facemask is considered a major prevention measure to limit the spread of disease (Agyemang et al., 2021). However, the prolonged usage of facemask has proved to undermine in physiological health parameters such as breath rate, oxygen saturation, and heart rate (Lässing et al., 2020; Scarano et al., 2021; Fukushi et al., 2021). The study reported in (Scarano et al., 2021), observed change in oxygen saturation and heart rate on dental surgeons wearing face mask for more than 2 h. The study reported significant reduction in oxygen saturation (SpO<sub>2</sub>) up to 91% and increased heart rate up to 98 beats per minute (bpm), when wearing mask for 120–240 min as shown in Fig. 3. Psychologically, facemask has resulted in compromised autonomy and competency (Scheid et al.,



**Fig. 3.** Effect of wearing surgical face mask for more than 2 h can significantly affect the human health parameters (Scarano et al., 2021). The oxygen saturation (SpO<sub>2</sub>) is shown at left, and heart rate is shown at right.

2020). Hence, a psychological stress is induced that can result in absent mindedness and unfocused driving.

Based on the above articulation, it can be possibly implied that the prolonged used of facemask can also significantly affect the driver behaviour. Particularly, on long monotonous highways where reduced oxygen saturation can contribute to underload mental fatigue. Though, research in this regard is unclear as extensive exploration and experimentation are required to develop more sophisticated driver identification systems.

### 3.2. Consumption of Covid-19 antiviral drugs

The revolutionary discovery of Covid-19 antiviral medicines will transform the way the Covid-19 virus is treated and will also contribute to reducing the psychological fear of contracting disease. Several antiviral drug groups such as Fusion, Protease, Reverse Transcription, and Neuraminidase inhibitors have been discovered and are under clinical trials (Frediansyah et al., 2021). Ribavirin and Favipiravir are the first tested oral Covid-19 drugs (Frediansyah et al., 2021; Joshi et al., 2021). With drugs still under clinical trials, researchers are working hard to develop an effective Covid-19 drug to be consumed orally.

Every type of medicine and drug has an impact on human activity performance, particularly on driving that can result in fatigued and unfocused driving. There is a perspective that in the future the side effects of oral Covid-19 drugs could also impact the driver behaviour in terms of absenteeism, mental fatigue, and distracted driving (Kumari et al., 2022). Yet, exhaustive research and efforts are required to understand and classify the effects of Covid-19 antiviral drugs on driver health, psychology, and driving stamina. Hence, there is a potential in designing more advanced and intelligent driver monitoring systems, such as tracking health vitals using smart wearable sensors in real-time (Ansari et al., 2021a, 2022a; Choi et al., 2017), or monitoring heart rate variations through radar-based contactless sensors mounted directly on steering wheel (Wang et al., 2019).

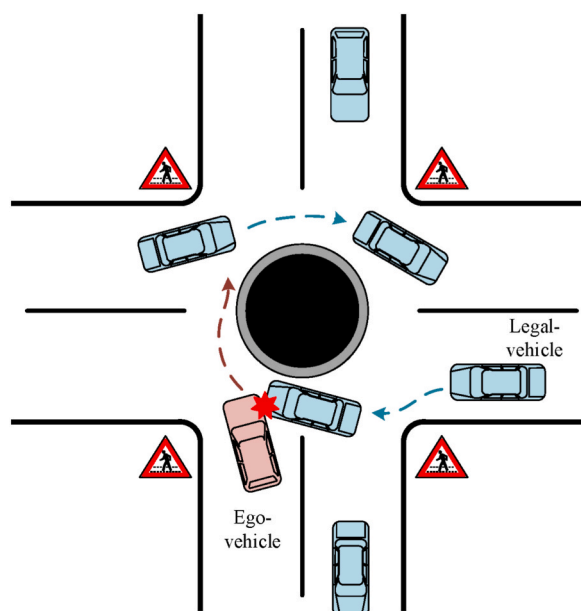
### 3.3. Psychological stress during driving

Covid-19 outbreak has brought an alarming psychological distress and fear among people, resulting in socio-economic crisis, and boosting mental stress (Lopetrone and Biondi, 2022). Yet, psychological effects on the driver or driving behaviour are unclear. However, there is a perception that Post-Covid-19 psychological stress has strong relationship with driving behaviour (Montoro et al., 2022). It is reasonable to assume that stress of contracting the disease during driving from unknown passengers will be high in ride share, buses, and taxis, forcing more hygiene care restriction after every trip (Zavareh et al., 2022). Furthermore, positive Covid-19 passengers can also induce a psychological stress and fear in the drivers that could encourage speedy completion of the trip and risk-taking behaviour, resulting in increased probability of speeding and unpredictable manoeuvres.

The facemask psychological stress as reported in (Goh et al., 2020), can even impact vaccinated positive Covid-19 drivers during driving by providing extra prevention to the passengers. Hence, the consequences would include increased driving vigilance, adoption of more defensive driving style, and alternatively reduction in driving stamina. Hence, there is exhaustive research required to develop advanced driver monitoring systems that can detect the psychological stress through variations occurred in health vitals or through facial expression.

### 3.4. Driver situational awareness

Driver awareness of surrounding scenes, environment, and traffic flow is necessary. Self-prediction of road-agents such as speed of oncoming vehicles, stationary obstacles, trajectory of pedestrians towards the driver's path, and maintaining the vehicle within the required lane, are important driving tasks carried out by the driver (Li et al., 2020; Avetisyan et al., 2022). Knowing the information of surroundings and road-agents is a driver skill that contributes to driver situational awareness level. During the Covid-19 lockdowns, on empty road, young drivers were thrilled in speeding and involved in various motor vehicle collisions (Sekadakis et al., 2022; Al-Hussein et al., 2022). The main causes behind were poor driver situation awareness, careless driving, and over-confidence. These short-term effects were quickly reduced as soon as the lockdowns were lifted (Truelove et al., 2021). However, the situation awareness



**Fig. 4.** Roundabout scenario (right-hand driving): Ego-vehicle crossing illegally possibly due to unawareness or misinterpretation the speed of legal-vehicle coming from right hand, ending in collision.

**Table 2**

Perspective of various Post-Covid-19 factors affecting driving nature: Effects and consequences.

Post-Covid-19 factor	Effects	Perspective Consequences
Facemask (Lassing et al., 2020; Scarano et al., 2021; Fukushi et al., 2021)	Prolonged wearing the facemask can result in low respiratory rate, reduced oxygen saturation, and increased heart rate.	The extended use of facemask can result in drowsy and fatigued driving due to drastic change in physiological driver parameters.
Oral Covid-19 drugs (Kumari et al., 2022)	People with mild Covid-19 symptoms could consume oral Covid-19 medicines, whose mild side-effects can result in absenteeism, dizziness and mental fatigue.	It could be recommended that drivers should not drive when consuming Covid-19 drugs. Otherwise, this could result in sleep and fatigued driving.
Psychological stress (Montoro et al., 2022; Zavareh et al., 2022; Goh et al., 2020)	The virus has brought psychological stress of keeping hygiene conditions and retaining social distance.	A mental distress could be induced when a taxi driver takes a positive Covid-19 patient, resulting in prompt completion of trip and ultimately becomes susceptible to making driving errors.
Situation awareness (Salmon and Plant, 2022; Watson-Brown et al., 2021)	The positive Covid-19 driver sustaining mild symptoms can contribute to poor situational awareness of surrounding and misjudging the speed of oncoming vehicles in complex driving scenarios.	The driving becomes challenging due to poor situation awareness resulting in erroneous turns, and inappropriate application of steering wheel and pedals, and ending in serious crashes.
Disease fear (Siddique et al., 2021)	The fear of contracting disease has brought anxiety, and depression.	The consequences would include distracted driving, where bus, rideshare or taxi drivers would pay more attention to positive Covid-19 passengers instead of focusing on driving.
Driving stamina (Lopetrone and Biondi, 2022)	The anti-viral Covid-19 medicines and psychological stress could increase driver vigilance, where drivers can embrace defensive driving. Hence, resulting in reduced driving stamina.	Because of reduced driving stamina, the bus and taxi drivers can opt to reduce their working shift until they recover from disease.

under the effect of various Post-Covid-19 factors such as, wearing facemask for long hours can contribute in poor understanding of surrounding vehicles and external scenes, resulting in fatal crashes (Goh et al., 2020).

The components required for developing the driver situation awareness include feeling of vehicle speed, route trajectory and road lines, hazards perception, and scanning the actions of other road-agents (Salmon and Plant, 2022). In the perception of Post-Covid-19 scenario, it is assumed that the likelihood of taking erroneous turns, misinterpreting the speed of oncoming vehicles, missing a traffic signal, and unawareness of pedestrians, will be high among positive Covid-19 drivers bearing mild flu like symptoms (sneezing, running nose). This can be caused by continuous wearing of facemask, itchy eyes, and getting confused with the green light of next traffic signal with the forthcoming red-light signal. Hence, resulting in poor situational awareness of the surrounding scenes and risks estimation. For example, in a roundabout scenario as shown in Fig. 4, an ego-vehicle driver (assumed positive Covid-19 patient) may overlook the approaching vehicle holding the right to pass the roundabout and ending in crash. Such driving mistakes caused by poor situation awareness are no different from inactive, fatigued, and drunk driving (Ansari et al., 2021b, 2022b; Watson-Brown et al., 2021). Therefore, innovative solutions need to be devised, and extensive exploration is required to accurately estimate the driver

situational awareness caused by Covid-19 disease.

### 3.5. Disease fear

Covid-19 brought higher prevalence of anxiety, depression, poor sleep quality, and fear of contracting disease (Siddique et al., 2021). A recent study conducted in (Siddique et al., 2021), suggested that women are more susceptible in having the fear of Covid-19 disease compared to men. Hence, it can be implied that the fear of contracting the disease is greater among female drivers compared to male drivers. For example, a female taxi driver can invest more attention towards the passenger's hygiene behaviour by looking frequently in rear-view mirror, resulting in distracted driving. On the upmost, if the positive Covid-19 passenger is not wearing a facemask, then an anxiety and fear start to build up in a driver when he/she begins to know in the middle of the trip, reflecting through erratic application of steering wheel. The situation would then become critical for the driver and could induce mental overload conditions (Ansari et al., 2022a).

### 3.6. Summary

The possible Post-Covid-19 factors affecting driver behaviour and performance were reviewed in this section. A perspective towards the effects and consequences of each factor is summarised in Table 2.

## 4. Discussion

As the world is now learning and adapting to live with the contagious Covid-19 disease, it is announced by numerous governments that the Covid-19 virus will be treated like other daily routine illnesses such as flu and common cold (RACGP, 2021; CityAM, 2021). With the passage of time, most parts of world are out of lockdown and returning to the normal life. The government and policy makers are dedicated to design safe travel policies and rules for Post-Covid-19 (Awad-Núñez et al., 2021a). The road users are directed to adhere to the rules and regulations to limit the infection of disease while driving with family and friends, or using public transport (Awad-Núñez et al., 2021b).

Considering the current trend, there is a high possibility that in future there will not be any quarantine or isolation required for positive Covid-19 patients and will be allowed to move freely. This initiative is recently adopted by New South Wales (NSW) government Australia where mandatory self-isolation for positive Covid-19 is no longer required from October 14, 2022 (Health, 2022). This implies that the ride share, bus and taxi drivers considered as conveyor for spread of disease will be allowed to provide services with some restrictions (Li et al., 2022). Hence, the long lasting Post-Covid-19 restrictions may include wearing the face mask, taking anti-viral Covid-19 drugs, and adopting defensive and more vigilant driving (Yan et al., 2021; Biswas et al., 2021).

Face covering using approved facemask is essential in limiting the spread of pulmonary contagious airborne diseases (Natnael et al., 2021). With the passage of time, mandatory face covering requirement is slowly removed from public transport and rideshare services in various parts of the world because the majority of people are now vaccinated and there is some degree of herd immunity. Particularly in Australia, the condition of wearing facemask is removed since September 20, 2022 in passenger transport services, with recommendations to follow the Covid-safe hygiene practices such as, wearing facemask, wiping high touching surfaces inside the vehicle regularly, and get tested if feeling Covid-19 symptoms (South Australia, 2022). This has indeed returned the taxi demand and recovery of public transport (Li et al., 2022; Hsieh and Hsia, 2022). However, it has also raised concerns and challenges. Particularly, in scenarios, when Covid-19 tested positive taxi or bus driver still performing duties with mild symptoms. In such cases, drivers may be recommended to wear facemask and take antiviral drugs to limit the spread of disease until they return negative results.

Recently, Paxlovid (nirmatrelvir and ritonavir) and Lagevrio (molnupiravir) have been approved as the first Covid-19 oral antiviral drugs in Australia but not fully registered to treat Covid-19 disease (Kumari et al., 2022; Government, 2022). It is declared that the drugs may cause possible side effects of nausea, dizziness, and shortness of breath. However, these are new medicines and currently under surveillance to fully classify the possible side effects in a diverse age and gender groups. Hence, it may be recommended that the drivers with mild symptoms should vigilantly drive the vehicle and stick to defensive driving styles to cope with the unexpected road situation.

The circumstantial effects of wearing facemask or taking antivirals are not limited to health vitals only but can also raise the psychological stress and risk perception while driving or travelling in public transport (Zavareh et al., 2022). There are several possible scenarios discussed in Section 3 relating to stress and disease fear that directly affect the driver's situation awareness skill. Although, vaccines and antiviral medicines significantly reduce the fear of contracting disease or increase immunity towards Covid (Kumari et al., 2022; Mohapatra et al., 2022). However, there can be several challenges associated with them. One possible perception can arise where road situation awareness skill can be greatly reduced, due to the effect of oral antivirals on the mental health of the drivers (Mohapatra et al., 2022). Hence, innovative solutions need to be devised that can intelligently monitor the driver health as well as psychological stress caused specifically by facemask and antiviral drugs. Such developments require extensive research to fully understand the impact on the driver's experience, activities, and health vitals for smooth and Covid-19 sustained transportation. Some possible future directions in developing intelligent methodologies in this regard are discussed in the following.

## 5. Challenges and future directions

To develop flexible intelligent systems that can effectively monitor the driver's states, reactions, and leveraging of vehicle functions



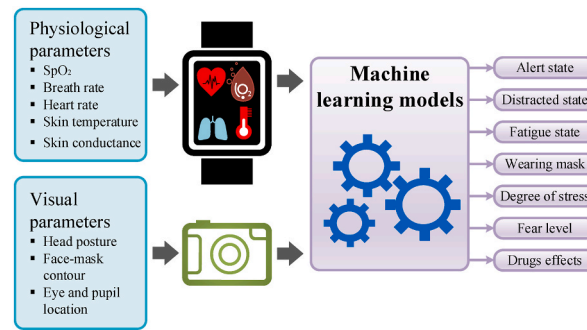


Fig. 5. Schematic diagram of driver states measurement and classification.

under the effect various Post-Covid-19 factors as discussed above, innovative solutions and advanced methodologies need to be devised. An analysis of the challenges involved and future research directions in this field are conducted below.

### 5.1. Driver state monitoring

Monitoring the driver state under the effect of Post-Covid-19 factors can become challenging. This is particularly true when measuring variations in the health vitals, psychological stress, and fear of contracting the disease. Various driver behaviour monitoring methods are discussed in literature (Ansari et al., 2023), including intrusive and non-intrusive techniques. Keeping them as baseline, innovative solutions can be devised to diagnose the effect of the Post-Covid-19 factors. This section proposes a hybrid methodology that can be deployed to measure the effects of different factors discussed in Section 3.

Facemask is considered as one of the important Post-Covid-19 factors, resulting in discomfort, particularly for drivers who wear vision-spectacles causing foggy glasses, and ultimately influence the driver behaviour to make driving errors. Several object detection algorithms based on computer vision techniques, and innovative deep learning models are proposed in detecting the contour of mask or respirator (Nowrin et al., 2021; Nagrath et al., 2021). However, the literature is not strong on methods proposed to determine the health variations as well as psychological effects induced in drivers during long-hours of driving due to prolonged usage of facemasks.

It is of utmost important to investigate the temporal behaviour of driver under the influence of anti-viral Covid-19 drugs, and disease fear. To understand the transition in driver states as well as psychological stress caused by facemask, the systems should not only be confined to vision-based technology, but also monitor the health parameters. For example, monitoring the skin conductance and temperature can help in approximating the anxiety and psychological stress as reported in (Mauriz et al., 2020). Furthermore, monitoring the driver's oxygen saturation ( $SpO_2$ ), respiratory rate, skin temperature, and heart rate, can help in understanding variations in driver's transition from alert state to sleepy condition, and drowsy or fatigued behaviour. Hence, by combining the vision-systems with the driver's physiological monitoring systems can lead to a robust driver detection system. A schematic diagram of possible measurement of driver states under the effect of various Post-Covid-19 factors is proposed and shown Fig. 5.

The intelligent algorithms can learn the hybrid temporal physiological parameters and classify the driver's states based on actions, experience, and sensation generated in driver's health. Although, camera-based systems can effectively monitor the driver's condition while wearing the facemask, however, it becomes failed in providing the physiological behavioural changes occurred during driving. Smart wearable sensors such as, smartwatches, smart wrist-bands, and smart clothes can overcome the shortcomings of vision-techniques, and can precisely monitor the health and psychological aspects of driver performance.

### 5.2. Estimating driver situation awareness

It is important to estimate and predict the driver's awareness under the effect of Covid-19 towards complex driving tasks, such as, crossing through a residential area where children are playing on the kerbside, or a vehicle reversing and merging towards the road from its home driveway, or most importantly, an accelerating vehicle merging on ego-vehicle's respective lane on a highway scenario. In this regard, based on the literature, driver's visual skills are assessed subjectively, where drivers respond to the driving-related questionnaires (Liang et al., 2021; McKerral and Pammer, 2021). In objective evaluation, driver's gaze behaviour, eye blinking and pupil tracking are assessed to approximate the attention driven towards various situational awareness scenarios (Liang et al., 2021; McKerral and Pammer, 2021). However, depending solely on the visual features analysis is not adequate, as it is possible that a driver after scanning the surrounding may miss an approaching vehicle at night whose headlights are turned off in a T-intersection crossing. To overcome these shortcomings, intelligent systems are deployed in commercial cars that provide warnings of hazards through sensory measurement (proximity sensors, radar or LiDAR) (Choi et al., 2021). Researchers are currently involved in forecasting the trajectories of road-agents that could help in providing the information of surrounding scenes and associated risks (Yi et al., 2022).

In the event of Post-Covid-19 scenarios discussed in Section 3.4, driver's vigilance and stamina can be approximated effectively by simultaneous monitoring the driver actions, external scenic understanding, road-agents forecasting, and vehicle dynamics as illustrated in Fig. 6. Intelligent estimators based on multi-layer perceptron are currently deployed to predict the trajectories of external road-agents as reported in (Ansari et al., 2022b). However, for a pandemic-sustained intelligent system, it is important to devise an

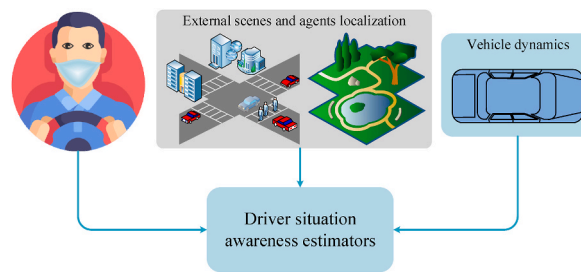


Fig. 6. A perspective framework of estimating driver situation awareness.

algorithmic-policy that should gather the information of positive Covid-19 driver actions, monitor symptoms visually and physiologically, predict the visual motion of hazards surrounding the vehicle, track the vehicle dynamics, and then deploy necessary shared control execution to assist the driver in challenging driving tasks.

## 6. Conclusion

This paper provided a broad spectrum towards the impact of Post-Covid-19 on driver behaviour in the context of road safety and pandemic-sustained transportation. The perspective revolved around the health and psychological effects of various factors such as variations in health parameters due to wearing facemask, effects of Covid-19 anti-viral oral drugs on driving, scenarios involved affecting driver situation awareness, and psychological stress and fear of disease that could result in unpredictable driving behaviour. The paper identified research gaps in detecting the driver state monitoring and estimating the driver situation awareness affected by several Post-Covid-19 factors. In general, possible solutions and approaches in driving to live with the pandemic in the context of road safety and smooth transportation were demonstrated. It was shown that intelligent hybrid and adaptive temporal learning algorithms based on the driver's action monitoring, physiological states, external scenes localization, and vehicle dynamics are potential approaches.

## Financial disclosure

The authors declare that there is no funding received for this work.

## CRediT author statement

Shahzeb Ansari: Conceptualization, Methodology, Formal analysis, Investigation, Writing - Original Draft.  
 Haiping Du: Validation, Writing - Review & Editing, Supervision, Project administration.  
 Fazel Naghdy: Validation, Writing - Review & Editing, Supervision, Project administration.  
 Abdul Sattar, Conceptualization, Investigation, Formal analysis.

## References

- Agyemang, E., Agyei-Mensah, S., Kyere-Gyeabour, E., 2021. Face mask use among commercial drivers during the COVID-19 pandemic in accra, Ghana. *J. Community Health* 1–10.
- Ahmad, N., Harun, A., Khizar, H.M.U., Khalid, J., Khan, S., 2022. Drivers and barriers of travel behaviors during and post COVID-19 pandemic: a systematic literature review and future agenda. *J. Tourism Futures*. ahead-of-print.
- Al-Hussein, W.A., et al., 2022. Investigating the effect of COVID-19 on driver behavior and road safety: a naturalistic driving study in Malaysia. *Int. J. Environ. Res. Publ. Health* 19 (18), 11224.
- Ansari, S., Du, H., Naghdy, F., Stirling, D., 2020. Unsupervised patterns of driver mental fatigue state based on head posture using Gaussian mixture model. In: 2020 IEEE Symposium Series on Computational Intelligence (SSCI). IEEE, pp. 2699–2704.
- Ansari, S., Du, H., Naghdy, F., Stirling, D., 2021a. Application of fully adaptive symbolic representation to driver mental fatigue detection based on body posture. In: 2021 IEEE International Conference on Systems, Man, and Cybernetics (SMC). IEEE, pp. 1313–1318.
- Ansari, S., Naghdy, F., Du, H., Pahnwar, Y.N., 2021b. Driver mental fatigue detection based on head posture using new modified reLU-BiLSTM deep neural network. *IEEE Trans. Intell. Transport. Syst.*
- Ansari, S., Du, H., Naghdy, F., Stirling, D., 2022a. Automatic driver cognitive fatigue detection based on upper body posture variations. *Expert Syst. Appl.*, 117568.
- Ansari, S., Naghdy, F., Du, H., 2022b. Human-machine shared driving: challenges and future directions. *IEEE Trans. Intell. Vehicles*.
- Ansari, S., Du, H., Naghdy, F., Stirling, D., 2023. Factors influencing driver behavior and advances in monitoring methods. In: *AI-Enabled Technologies for Autonomous and Connected Vehicles*. Springer, pp. 387–414.
- Avetisyan, L., Ayoub, J., Zhou, F., 2022. Investigating explanations in conditional and highly automated driving: the effects of situation awareness and modality. *Transport. Res. F Traffic Psychol. Behav.* 89, 456–466.
- Awad-Núñez, S., Julio, R., Moya-Gómez, B., Gomez, J., González, J.S., 2021a. Acceptability of sustainable mobility policies under a post-COVID-19 scenario. Evidence from Spain. *Transport Pol.* 106, 205–214.
- Awad-Núñez, S., Julio, R., Gomez, J., Moya-Gómez, B., González, J.S., 2021b. Post-COVID-19 travel behaviour patterns: impact on the willingness to pay of users of public transport and shared mobility services in Spain. *Eur. Trans. Res. Rev.* 13 (1), 1–18.
- Biswas, P., et al., 2021. Candidate antiviral drugs for COVID-19 and their environmental implications: a comprehensive analysis. *Environ. Sci. Pollut. Control Ser.* 1–24.

- Choi, M., Koo, G., Seo, M., Kim, S.W., 2017. Wearable device-based system to monitor a driver's stress, fatigue, and drowsiness. *IEEE Trans. Instrum. Meas.* 67 (3), 634–645.
- Choi, C., Choi, J.H., Li, J., Malla, S., 2021. Shared cross-modal trajectory prediction for autonomous driving. In: *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, pp. 244–253.
- CityAM. No more lockdowns: UK will treat Covid like seasonal flu. <https://www.cityam.com/no-more-lockdowns-uk-will-treat-covid-like-seasonal-flu-says-chris-whitty/>. (Accessed 5 December 2021).
- Cusack, M., 2021. Individual, social, and environmental factors associated with active transportation commuting during the COVID-19 pandemic. *J. Transport Health* 22, 101089.
- Di Domenico, L., Pullano, G., Sabbatini, C.E., Boëlle, P.-Y., Colizza, V., 2020. Impact of lockdown on COVID-19 epidemic in Île-de-France and possible exit strategies. *BMC Med.* 18 (1), 1–13.
- Dwivedi, Y.K., et al., 2020. Impact of COVID-19 pandemic on information management research and practice: transforming education, work and life. *Int. J. Inf. Manag.* 55, 102211.
- Dzisi, E.K.J., Dei, O.A., 2020. Adherence to social distancing and wearing of masks within public transportation during the COVID 19 pandemic. *Transp. Res. Interdiscip. Perspect.* 7, 100191.
- Frediansyah, A., Tiwari, R., Sharun, K., Dhama, K., Harapan, H., 2021. Antivirals for COVID-19: a critical review. *Clin. Epidemiol. Global Health.* 9, 90–98.
- Fukushi, I., Nakamura, M., Kuwana, S.-I., 2021. Effects of wearing facemasks on the sensation of exertional dyspnea and exercise capacity in healthy subjects. *PLoS One* 16 (9), e0258104.
- Goh, Y., Tan, B.Y., Bhartendu, C., Ong, J.J., Sharma, V.K., 2020. The face mask: how a real protection becomes a psychological symbol during Covid-19? *Brain Behav. Immun.* 88, 1–5.
- Government, N., 2022. Covid-19 antivirals. <https://www.nsw.gov.au/covid-19/management/antivirals>. (Accessed 17 October 2022).
- Gupta, M., Pawar, N.M., Velaga, N.R., 2021. Impact of lockdown and change in mobility patterns on road fatalities during COVID-19 pandemic. *Transp. Lett.* 13 (5–6), 447–460.
- Health, N., 2022. COVID-19 self-isolation rules have changed. <https://www.health.nsw.gov.au/Infectious/covid-19/Pages/default.aspx>. (Accessed 15 October 2022).
- Hsieh, H.-S., Hsia, H.-C., 2022. Can continued anti-epidemic measures help post-COVID-19 public transport recovery? Evidence from Taiwan. *J. Transport Health*, 101392.
- Inada, H., Ashraf, L., Campbell, S., 2021. COVID-19 lockdown and fatal motor vehicle collisions due to speed-related traffic violations in Japan: a time-series study. *Inj. Prev.* 27 (1), 98–100.
- James, K., Thompson, C., Chin-Bailey, C., Davis, K.D., Nevins, D.H., Walters, D., 2021a. COVID-19 related risk perception among taxi operators in Kingston and St. Andrew, Jamaica. *J. Transport Health* 22, 101229.
- James, K., Thompson, C., Chin-Bailey, C., Donaldson Davis, K., Walters, D., Holder Nevins, D., 2021b. Taxi drivers and COVID-19 in Jamaica: occupationally related income decline and health behaviour. *Health Soc. Care Community*.
- Joshi, S., et al., 2021. Role of favipiravir in the treatment of COVID-19. *Int. J. Infect. Dis.* 102, 501–508.
- Katrakazas, C., Michelaraki, E., Sekadakis, M., Yannis, G., 2020. A descriptive analysis of the effect of the COVID-19 pandemic on driving behavior and road safety. *Transp. Res. Interdiscip. Perspect.* 7, 100186.
- Katrakazas, C., Michelaraki, E., Sekadakis, M., Ziakopoulos, A., Kontaxi, A., Yannis, G., 2021. Identifying the impact of the COVID-19 pandemic on driving behavior using naturalistic driving data and time series forecasting. *J. Saf. Res.*
- Kim, K., 2021. Impacts of COVID-19 on transportation: summary and synthesis of interdisciplinary research. *Transp. Res. Interdiscip. Perspect.* 9, 100305.
- Kumari, M., et al., 2022. A critical overview of current progress for COVID-19: development of vaccines, antiviral drugs, and therapeutic antibodies. *J. Biomed. Sci.* 29 (1), 1–36.
- Lässing, J., et al., 2020. Effects of surgical face masks on cardiopulmonary parameters during steady state exercise. *Sci. Rep.* 10 (1), 1–9.
- Lemke, M.K., Apostolopoulos, Y., Sönmez, S., 2020. Syndemic frameworks to understand the effects of COVID-19 on commercial driver stress, health, and safety. *J. Transport Health* 18, 100877.
- Li, J., Giabbanelli, P., 2021. Returning to a normal life via COVID-19 vaccines in the United States: a large-scale agent-based simulation study. *JMIR Med. Informat.* 9 (4), e27419.
- Li, C., Chan, S.H., Chen, Y.-T., 2020. Who make drivers stop? towards driver-centric risk assessment: risk object identification via causal inference. In: *2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, pp. 10711–10718.
- Li, Z., Zhang, C., Kong, X., Zhang, Y., Ma, C., 2022. Revealing Spatial-Temporal Taxi Demand Patterns after Vaccination in COVID-19 Pandemic. *arXiv preprint arXiv: 2210.02624*.
- Liang, N., et al., 2021. Using eye-tracking to investigate the effects of pre-takeover visual engagement on situation awareness during automated driving. *Accid. Anal. Prev.* 157, 106143.
- Liu, J., Cao, Q., Pei, M., 2022. Impact of COVID-19 on adolescent travel behavior. *J. Transport Health* 24, 101326.
- Lopetrone, E., Biondi, F.N., 2022. On the Effect of COVID-19 on Drivers' Behavior: A Survey Study. *Transportation Research Record*, 03611981221103866.
- Mauriz, E., Caloca-Amber, S., Vázquez-Casares, A.M., 2020. Effect of facial skin temperature on the perception of anxiety: a pilot study. In: *Healthcare. Multidisciplinary Digital Publishing Institute*, p. 206 vol. 8, no. 3.
- McKerral, A., Pammer, K., 2021. Identifying objective behavioural measures of expert driver situation awareness. *Accid. Anal. Prev.* 163, 106465.
- Mohapatra, S., et al., 2022. COVID 19 pandemic challenges and their management: a review of medicines, vaccines, patents and clinical trials with emphasis on psychological health issues. *Saudi Pharmaceut. J.*
- Montoro, L., et al., 2022. Essential... but also vulnerable? Work intensification, effort/reward imbalance, fatigue and psychological health of Spanish cargo drivers during the COVID-19 pandemic. *PeerJ* 10, e13050.
- Nagrath, P., Jain, R., Madan, A., Arora, R., Kataria, P., Hemanth, J., 2021. SSDMNV2: a real time DNN-based face mask detection system using single shot multibox detector and MobileNetV2. *Sustain. Cities Soc.* 66, 102692.
- Natnael, T., et al., 2021. Facemask wearing to prevent COVID-19 transmission and associated factors among taxi drivers in Dessie City and Kombolcha Town, Ethiopia. *PLoS One* 16 (3), e0247954.
- Nowrin, A., Afroz, S., Rahman, M.S., Mahmud, I., Cho, Y.-Z., 2021. Comprehensive Review on Facemask Detection Techniques in the Context of Covid-19. *IEEE access*.
- Qureshi, A.I., et al., 2020. Mandated societal lockdown and road traffic accidents. *Accid. Anal. Prev.* 146, 105747.
- RACGP. National Cabinet reveals plan to eventually treat COVID 'just like the flu'. <https://www1.racgp.org.au/newsgp/professional/national-cabinet-reveals-plan-to-eventually-treat>. (Accessed 5 December 2021).
- RACGP, A., 2022. How long should patients wait for a booster after COVID infection? <https://www1.racgp.org.au/newsgp/clinical/how-long-should-patients-wait-for-a-booster-after>. (Accessed 25 January 2022).
- Saba, T., Abunadi, I., Shahzad, M.N., Khan, A.R., 2021. Machine learning techniques to detect and forecast the daily total COVID-19 infected and deaths cases under different lockdown types. *Microsc. Res. Tech.*
- Salmon, P.M., Plant, K.L., 2022. Distributed situation awareness: from awareness in individuals and teams to the awareness of technologies, sociotechnical systems, and societies. *Appl. Ergon.* 98, 103599.
- Scarano, A., Inchingolo, F., Rapone, B., Festa, F., Tari, S.R., Lorusso, F., 2021. Protective face masks: effect on the oxygenation and heart rate status of oral surgeons during surgery. *Int. J. Environ. Res. Publ. Health* 18 (5), 2363.
- Scheid, J.L., Lupien, S.P., Ford, G.S., West, S.L., 2020. Commentary: physiological and psychological impact of face mask usage during the COVID-19 pandemic. *Int. J. Environ. Res. Publ. Health* 17 (18), 6655.
- Sekadakis, M., Katrakazas, C., Michelaraki, E., Kehagia, F., Yannis, G., 2021. Analysis of the impact of COVID-19 on collisions, fatalities and injuries using time series forecasting: the case of Greece. *Accid. Anal. Prev.* 162, 106391.

- Sekadakis, M., Katrakazas, C., Michelaraki, E., Yannis, G., 2022. Driving behavior and its correlation with COVID-19 response measures: a neural network forecasting analysis. *J. Transport. Eng., Part A: Systems* 148 (10), 04022083.
- Shaer, A., Haghshenas, H., 2021. The impacts of COVID-19 on older adults' active transportation mode usage in Isfahan, Iran. *J. Transport Health* 23, 101244.
- Siddique, R.F., Ahmed, O., Hossain, K.N., 2021. Relationship between the fear of COVID-19 disease and sleep quality: the mediating role of stress. *Heliyon* 7 (5), e07033.
- South Australia, G., Keeping the point-to-point community COVID Safe. [https://dit.sa.gov.au/point\\_to\\_point\\_transport/keeping\\_the\\_point-to-point\\_community\\_covid\\_safe](https://dit.sa.gov.au/point_to_point_transport/keeping_the_point-to-point_community_covid_safe). (Accessed 16 October 2022).
- Stavrinos, D., et al., 2020. Adolescent driving behavior before and during restrictions related to COVID-19. *Accid. Anal. Prev.* 144, 105686.
- Truelove, V., Watson-Brown, N., Parker, E., Freeman, J., Davey, J., 2021. Driving through a pandemic: a study of speeding and phone use while driving during COVID-19 restrictions. *Traffic Inj. Prev.* 1–6.
- Tucker, A., Marsh, K., 2021. Speeding through the pandemic: perceptual and psychological factors associated with speeding during the COVID-19 stay-at-home period. *Accid. Anal. Prev.* 159, 106225.
- Vanlaar, W., et al., 2021. The impact of COVID-19 on road safety in Canada and the United States. *Accid. Anal. Prev.* 160, 106324.
- Wang, P., et al., 2019. Noncontact heart rate measurement based on an improved convolutional sparse coding method using IR-UWB radar. *IEEE Access* 7, 158492–158502.
- Wang, W., Miao, W., Liu, Y., Deng, Y., Cao, Y., 2021. The impact of COVID-19 on the ride-sharing industry and its recovery: causal evidence from China. *Transport. Res. Pol. Pract.*
- Watson-Brown, N., Truelove, V., Parker, E., Davey, J., 2021. Drink driving during the COVID-19 pandemic. *Transport. Res. F Traffic Psychol. Behav.* 78, 369–380.
- Yan, Y., Bayham, J., Richter, A., Fenichel, E.P., 2021. Risk compensation and face mask mandates during the COVID-19 pandemic. *Sci. Rep.* 11 (1), 1–11.
- Yasin, Y.J., Grivna, M., Abu-Zidan, F.M., 2021. Global impact of COVID-19 pandemic on road traffic collisions. *World J. Emerg. Surg.* 16 (1), 1–14.
- Yi, B., Cao, H., Song, X., Zhao, S., Guoa, W., Lia, M., 2022. How to identify the take-over criticality in conditionally automated driving? An examination using drivers' physiological parameters and situational factors. *Transport. Res. F Traffic Psychol. Behav.* 85, 161–178. <https://doi.org/10.1016/j.trf.2021.12.007>.
- Zavareh, M.F., Mehdizadeh, M., Nordfjærn, T., 2022. Demand for mitigating the risk of COVID-19 infection in public transport: the role of social trust and fatalistic beliefs. *Transport. Res. F Traffic Psychol. Behav.* 84, 348–362.