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The impact of the COVID-19 pandemic on prehospital emergency care for stroke/transient ischaemic attacks (TIAs) and implications for future policy and service delivery

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Institutional requirements for Publication-Based PhD Thesis

This PhD thesis follows the University College Cork guidance for a Publication-Based Doctoratus Philosophiae (PhD) Thesis. This can be found in section 3 (page 5) of the document below.

Link to guidelines:

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Declaration

This is to certify that the work I am submitting is my own and has not been submitted for another degree, either at University College Cork or elsewhere. All external references and sources are clearly acknowledged and identified within the contents. I have read and understood the regulations of University College Cork concerning plagiarism and intellectual property.

Signed:

Date: 17th September 2024

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List of Abbreviations

Abbreviation	Explanation
ACF	Autocorrelation Function
AMPDS	Advanced Medical Priority Dispatch System
ARIMA	Autoregressive Integrated Moving Average
AS1	Emergency ambulance call
AVL	Automatic Vehicle Location
AuSCR	Australian Stroke Clinical Registry
BC	British Columbia
CAD	Computer Aided Dispatch
CDP-CDP	Collaborative Doctoral Programme in Chronic Disease Prevention
CFR	Community First Responder
COREQ	Consolidated Criteria for Reporting Qualitative Research
CT scan	Computed Tomography Scan
DALY	Disability-adjusted Life Years
DRM	Disaster Risk Management
ECT	Emergency Call Taker
ECAS	Emergency Call Answering Services
ED	Emergency Department

EMDC	Emergency Medical Dispatch Centre
EMS	Emergency Medical Services
EU	European Union
EVT	Endovascular Thrombectomy
GBD	Global Burden of Disease
GP	General Practitioner
GRADE	Grading of Recommendations Assessment, Development and Evaluation guidelines
GRIPP2	Guidance for Reporting Involvement of Patients and the Public
HCP	Healthcare Professional
HIQA	Health Information and Quality Authority
HPSC	Health Protection Surveillance Centre
IAED	International Academies of Emergency Dispatch
ICU	Intensive Care Unit
INAS	Irish National Audit of Stroke
IQR	Interquartile Range
IRR	Incidence Rate Ratio
ISO	International Standards Organisation

JBI	Joanna Briggs Institute
KPI	Key Performance Indicator
MeSH	Medical Subject Headings
MRI	Magnetic Resonance Imaging
NAS	National Ambulance Service
NEOC	National Emergency Operations Centre
NPI	Non-pharmacological intervention
NSS	National Stroke Strategy
PACF	Partial Autocorrelation Function
PHoCoS Consortium	Prehospital Care of Stroke Consortium
PPE	Personal Protective Equipment
PPI	Patient and Public Involvement
PRESS	Peer Review of Electronic Search Strategies
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta Analyses
SD	Standard Deviation
TIA	Transient Ischaemic Attack
TII	Transport Infrastructure Ireland
TREND	Transparent Reporting of Evaluations with Nonrandomized designs
UCC	University College Cork
UK	United Kingdom

USA	United States of America
WHO	World Health Organisation
WSO	World Stroke Organisation

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“The journey, not the destination matters….” T.S. Elliot

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With one down and many more to go, I wish to extend my sincere thanks to Prof. Cathal O'Donnell, Dr Siobhán Masterson, Rory Quinn, Dave Hennelly, Dr Kieran Crosbie-Staunton, Frank Hughes, and Amielia Ahern. Thank you for your trust, your patience, and your collegiality over the last number of years. I really appreciate all your guidance, support, and wisdom on my journey. Without each one of you this

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Patient and Public Involvement

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Where to start on this one…….

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I am not the first and I won’t be the last to say the School of Public Health truly is a wonderful work environment. The welcome I received when I started and the collegiality, I experience each day is testament to the fibre of the school, its people. This is one of those scenarios where this is so many people to mention, and each one added to my experience in their own unique way.

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Family

So, this is the soppy, non-professional me, showing myself up to be the human form of a marshmallow, part of this section.

My PhD would not have been possible without many people, but although each one plays their role in my academic orchestra, there was only ever one conductor, my Mum. Possibly the most caring, selfless, and conscientious person on this planet, and I was lucky enough to have her by my side for my entire PhD journey. When I say journey, I don't just mean the last four years. She was my guiding light from the very beginning. From the point where the prospect of my PhD was barely even a seedling in my imagination. She believed in me, supported me, encouraged me the entire way, and still does to this day. She is the ultimate cheerleader. Mum, I cannot put into words what your unwavering love and support means to me. I can tell you this though, without you there would be no PhD. I wouldn't even have believed I could start on the path, without your advice, direction, and wise old owl wisdom.

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Thesis Abstract

Background and aims

Time plays a fundamental role in managing acute stroke and transient ischemic attack (TIA), with the minimisation of prehospital delays critical to the stroke chain of survival. The COVID-19 pandemic led to worldwide restrictions, resulting in significant societal changes, including alterations to healthcare access and delivery, which particularly impacted time-sensitive conditions. Thus, the aim of this thesis was to investigate the impact of a "shock", such as the COVID-19 pandemic on prehospital emergency care for exemplar time-sensitive conditions; stroke and TIA, with the goal of exploring potential implications for future policy and service delivery.

Methods

This PhD thesis employed a mixed-methods approach, using the multilevel model of triangulation design. This approach was informed by the "Resilient Health System as a Conceptual Framework for Strengthening Public Health Disaster Risk Management". Five studies were conducted. Firstly, a systematic review and meta-analysis synthesised existing evidence on the impact of the COVID-19 pandemic on prehospital care for suspected stroke/TIA and calculated pooled estimates for ambulance time intervals and call volume during the pandemic. Secondly a quasi-experimental study using Republic of Ireland National Ambulance Service data investigated the impact of COVID-19 on ambulance time intervals and emergency call volume for suspected stroke/TIA using linear regression and autoregressive

integrated moving averages. Thirdly, a qualitative study using semi-structured interviews explored the experiences of stroke/TIA survivors, caregivers, prehospital and hospital-based practitioners of acute stroke/TIA care during the COVID-19 pandemic in Ireland. Fourthly, a benchmarking study facilitated the comparison of international terminology and definitions for ambulance times and intervals. This enabled the final study; an international comparative analysis using a quasi-experimental before and after design to compare ambulance time intervals and call volume for suspected stroke/TIA before and during COVID-19, using linear regression and times series analysis. Stakeholder involvement was included throughout all studies.

Results

The meta-analysis demonstrated that pre-COVID-19, the mean response interval was shorter by -1.29 minutes (95% CI: -2.19 to -0.38), and the mean total prehospital interval was shorter by -6.42 minutes (95% CI: -10.60 to -2.25), compared to during the pandemic. Additionally, there was a higher incidence rate ratio (IRR) of emergency calls for suspected stroke/TIA per day pre-COVID-19 compared to during COVID-19 (log IRR = 0.17, 95% CI: 0.02 to 0.33). In Ireland, during the pandemic period, the five included ambulance time intervals increased compared to pre-COVID-19 (all $p<0.001$). Overall, call volume increased during the COVID-19 period compared to the pre-COVID-19 period ($p<0.001$). However, dips in call volume were observed during the initial wave and wave 4. Qualitative interviews with stroke/TIA survivors, caregivers and healthcare professionals revealed that the integrity of the acute stroke/TIA pathway remained intact during the COVID-19 pandemic. However,

overall patient experience and willingness to seek care for suspected stroke/TIA were negatively impacted. Significant heterogeneity in terminology and definitions for ambulance times and intervals were observed in the international benchmarking study. In the international comparative study, on-scene time increased across all seven services between 1.05-3.78 minutes (all <0.001) during the COVID-19 period. Whereas response time interval increased in six of the seven services, ranging from 0.5-9.13 minutes (all p<0.001), and decreased in New Zealand by 1.57 minutes (<0.001). Mean monthly call volume rose across all services during COVID-19, ranging from 1.9-9 minutes, apart from the Netherlands, which saw no change (p=0.4).

Conclusion

This thesis used a multistakeholder mixed methods approach to investigate the resilience of the acute stroke/TIA pathway during a public health crisis, highlighting prehospital delays and potential care avoidance by stroke/TIA survivors. It calls for stakeholder collaboration to optimise the stroke chain of survival and further studies on the pandemic's long-term impacts on stroke/TIA care.

Chapter 1: Background

1.1 Overview

This chapter critically analyses how the management of time-sensitive conditions like acute stroke and transient ischaemic attack (TIA) serve as a key gauge for assessing the COVID-19 pandemic's impact on healthcare access and delivery.

Firstly, stroke and TIA are time-sensitive conditions that require rapid response and treatment within a defined timeframe to prevent mortality and morbidity[1-3]. Secondly, prehospital emergency care is typically the entry point to this time-dependent acute stroke/TIA pathway[3,4]. Activation of this pathway, involving multiple stakeholders, facilitates rapid access to therapies for stroke/TIA[5,6]. Thirdly, the COVID-19 pandemic was an unprecedented public health crisis, posing a significant challenge to the healthcare system[7]. Early reports indicate that the pandemic disrupted the acute stroke/TIA pathway, resulting in treatment delays and reconfiguration of acute stroke/TIA services[1,8-10]. A key change in healthcare seeking behaviour, termed healthcare avoidance was observed during the pandemic[1].

However, the few existing quantitative prehospital studies report that the extent and magnitude of these delays seem to vary internationally[10-12]. Additionally, currently available studies differ in the specific COVID-19 periods they investigate, with most focusing on the early waves of the pandemic[13]. Studies conducted over multiple pandemic waves would allow for the tracking of patterns in prehospital stroke access and delivery.

Thus, to investigate the resilience of the healthcare system to the “shock” a COVID-19 detailed mixed-methods analysis is required, focusing on the healthcare system response and stroke/TIA survivor interaction with the system.

1.2 Stroke and Transient Ischaemic Attacks (TIAs): Exemplar Time-sensitive conditions

1.2.1 Stroke and TIA - description and definitions

The concept and clinical significance of strokes and TIAs are internationally recognised. However, there is some discourse in the literature around their definitions, with evolving definitions being proposed by international bodies and working groups on cerebrovascular disease[14]. A stroke can be defined as *"an acute neurological deficit lasting more than 24 hours and caused by cerebrovascular aetiology"*[15-17]. Stroke is categorised as ischaemic and haemorrhagic (intracerebral haemorrhage and subarachnoid haemorrhage)[15-17]. Typically, ischaemic stroke represents 87% of all strokes, with intracerebral haemorrhages accounting for 10% and subarachnoid haemorrhage for 3%[15-17]. The definition of a TIA has undergone a similar evolution [15,18], from originally being purely time-based to now also being tissue-based[14,15]. Thus, a TIA can be defined as *"a brief episode of neurologic dysfunction caused by focal brain or retinal ischemia, with clinical symptoms typically lasting less than one hour, and without evidence of acute infarction*[19]. TIA is a well-documented indicator of future ischemic stroke, with risk estimates in the range of 7.5-17.3%[20-21]. Studies have indicated that a significant portion of individuals who experienced an initial stroke had previous TIA symptoms[22].

1.2.2 Global epidemiology of stroke and TIA

Stroke continues to be the second leading cause of death globally[23]. It is also the third leading cause of death and disability combined worldwide (represented by DALYs)[23,24]. The most recently published Global Burden of Disease (GBD) study (2019) revealed that the global incidence of stroke was 12·2 million (95% uncertainty interval 11·0-13·6), with a prevalence of 101 million (93·2-111) cases[23]. Furthermore, at that time there were 143 million (133-153) DALYs attributed to stroke and 6·55 million (6·00-7·02) stroke-related deaths[23] globally. In the Republic of Ireland stroke is the leading cause of acquired adult neurological disability and third leading cause of death[25]. From 2013 to 2022, stroke admissions in the Republic of Ireland increased from 4,727 to 5,961 annually[25,26], as per the Irish National Audit of Stroke (INAS). A 7.1% increase in stroke cases was observed from 2020 to 2021, with a 3% increase in case numbers from 2021 to 2022 [25,26].

Unlike stroke, TIA is not included in the GBD study[23] or the INAS. Estimating the incidence of TIAs in a population is challenging due to the presence of disorders that mimic its symptoms[15]. Furthermore, its transient nature and the absence of standardised population level surveillance systems challenge the reporting of TIA incidence and prevalence[15]. However, Degan et al. (2017) estimates that annual TIA crude incidence rates in Western countries range between 29.0 and 61.0 cases per 100,000[27]. Among adults in the United States of America (USA) the estimated overall prevalence of TIA is 2%[15]. The North Dublin population stroke study provides one available Irish estimate of a crude incidence rate of TIA to be 0.45/1000 person-

years[28]. However, this study is more than 10 years old[28], thus emphasising the limited availability of TIA epidemiological data.

1.2.3 Importance of time in stroke/TIA care

Stroke constitutes a medical emergency necessitating prompt evaluation, confirmation of diagnosis, and treatment to prevent brain damage[29]. Thus, time plays a pivotal role in acute stroke/TIA care[30]. Acute stroke care is undeniably time-sensitive; every minute counts throughout the stroke chain of survival[5,31]. Recognition of stroke symptoms and prompt administration of evidence-based acute interventions have demonstrated notable enhancements in stroke/TIA outcomes[32-34]. These interventions include thrombolysis and endovascular thrombectomy (EVT) for ischaemic strokes[32-34]. The goal in this context is acute reperfusion[31-34]. Whilst prompt blood pressure regulation is the key treatment for haemorrhagic strokes[32-34]. For this stroke subtype therapies aim to mitigate hematoma expansion[31-34]. Finally, management in specialised stroke units is considered gold standard for stroke types[31-34]. These interventions are time dependent[6]. Thus, rapid access to specialised care within hospital settings is required[6]. Therefore, minimising the time from symptom onset to treatment reduces the risk of rapid and irreversible neurological damage [30,35].

1.3 The Acute Stroke Care Pathway

Recognising the importance of “the time from symptom onset” to “treatment” in determining overall outcomes, efforts have naturally expanded beyond hospital treatment times[5,6,31]. Internationally, health care systems increasingly focus on

developing comprehensive systems of care that involve the public, collaboration with Emergency Medical Services (EMS), and partnership with referral hospitals[6]. These pathways have the shared goal of minimising prehospital time intervals and enhancing the efficiency of the entire healthcare system[5,6,31]. The stroke chain of survival is an internationally adopted method of conceptualising this pathway[5].

1.3.1 The Stroke Chain of Survival

The stroke chain of survival outlines the essential stages in emergency stroke care, from recognising symptoms to arriving at the hospital[5]. It can be described using the 8Ds; detection, dispatch, delivery, door, data, decision, drug and disposition[5] **(Figure 1.1)**. The stroke chain of survival involves the participation of bystanders, dispatchers, prehospital care practitioners, and hospital-based stroke teams to enhance acute stroke care[5]. Prehospital care practitioners are involved in steps one to four of this pathway[5]. Whereas hospital-based practitioners are involved from stages five to eight [6].

The 8Ds of the stroke chain of survival[5,6] can be described as:

1. Detection - Identifying stroke symptoms marks a crucial initial stage in the stroke survival process.

2. Dispatch - The initial encounter between laypersons and medical personnel during an emergency call.

3. Deliver - Review by prehospital practitioner, selection of appropriate receiving facility and transport to the hospital.

4. **Door -** Handover from prehospital to hospital-based care.

5. **Data -** Utilisation of prehospital and hospital data to inform next steps.

6. **Decision -** Multidisciplinary stroke team make a clinical assessment on treatment plan.

7. **Drug -** Based on the above links of the chain of survival a decision will be made on whether thrombolysis is a viable and appropriate option.

8. **Disposition -** Discharge from hospital-based care to the out-patient rehabilitation phase.

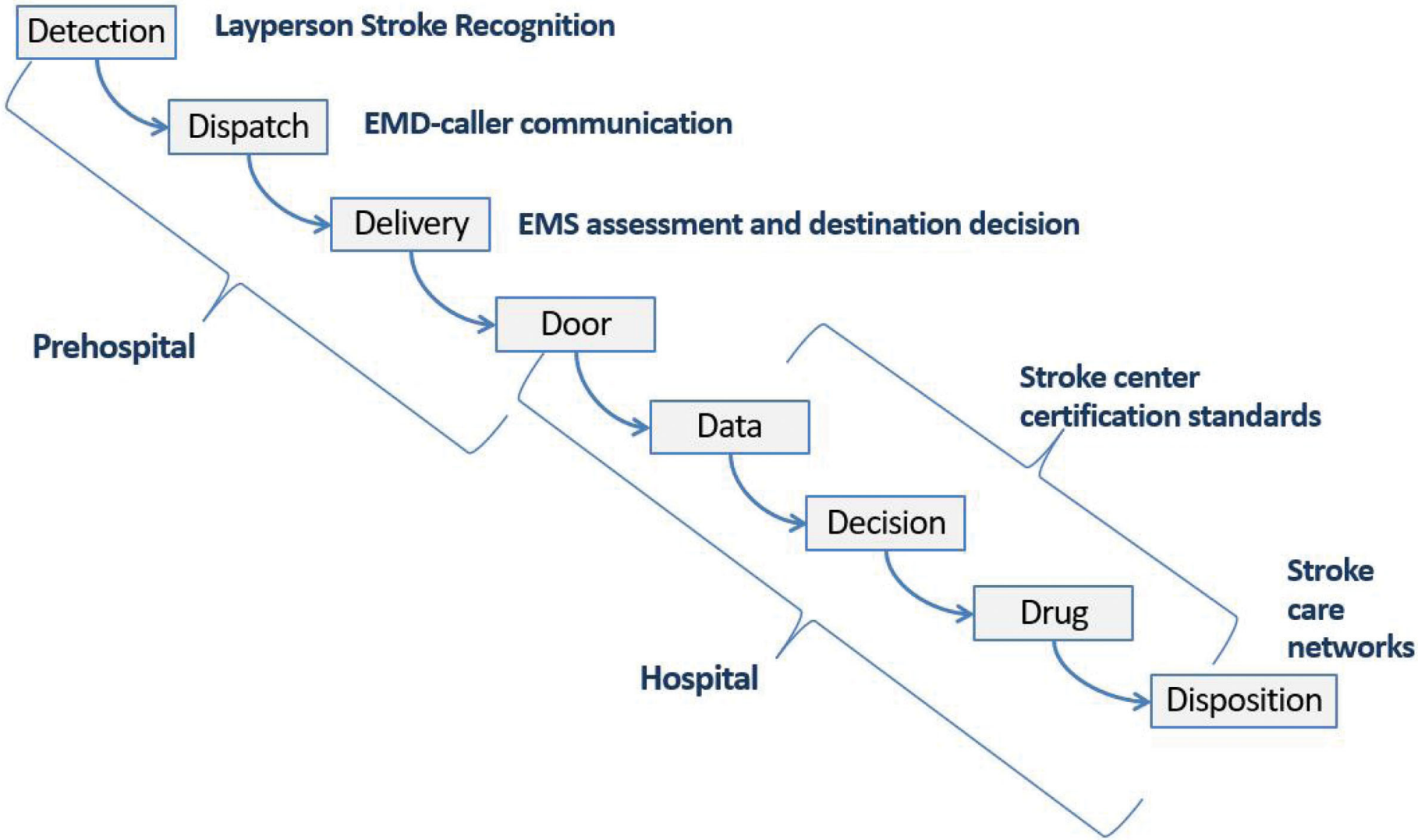

Figure 1.1 - Illustration of the 8Ds of the stroke chain of survival[5]

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1.3.2 Prehospital care - definition and global landscape

Nuance and variation exist in the exact terminology and definition of prehospital care globally[36,37]. However prehospital care can be broadly defined as *"emergency medical care given to patients before arrival at hospital after activation of the EMS"* [37]. Prehospital care typically involves the delivery of medical assistance by emergency medical service providers, including emergency medical dispatchers, emergency medical responders, emergency medical technicians, and paramedics[38]. Most ambulance services globally are equipped with highly specialised and trained emergency medical paramedics or nurses[38,39]. Nevertheless, physician-based EMS systems are prevalent in many European countries[38,39].

1.3.3 Prehospital care in Ireland

The National Ambulance Service (NAS) is the statutory provider of prehospital emergency care in the Republic of Ireland[40,41]. With a network encompassing over 102 ambulance stations throughout the country, NAS handles more than 300,000 calls each year[40,41]. The National Emergency Operations Centre (NEOC) is responsible for managing the call-taking and dispatch operations of the NAS[42]. Within the Dublin metropolitan area (Ireland's capital city) prehospital services are provided by both the NAS and the Dublin Fire Brigade[40,41]. At a community level, NAS is supported by a network of 140 community first responder (CFR) programmes[40,41]. CFRs are trained members of the community who respond to medical emergencies such as stroke and cardiac arrest[40,41]. In contexts such as these, CFRs can provide immediate life-saving care to the patient while awaiting the arrival of an emergency response vehicle[40,41].

1.3.4 Ambulance times/intervals as global prehospital key performance indicators (KPIs)

Ambulance times and time intervals are globally acknowledged Key Performance Indicators (KPIs) for prehospital care[43,44]. Although widely and commonly used these time-based metrics have been criticised for not offering insight into the quality of prehospital care or patient outcomes[44]. However, Ulstein recommendations, among others continue to advocate for adherence to these KPIs in the context of acute stroke care[6,43,44]. Furthermore these indicators are considered particularly important for time-critical conditions, such as stroke/TIA[43,44]. An ambulance "time" is "a specific event within the EMS response", such as at scene time[45]. Whereas an ambulance time "interval" is "the temporal distance between two times", such as response time interval[45]. These indicators measure the time between different stages of the patient journey[45,46].

1.3.5 Ambulance times/intervals in the Republic of Ireland

In an Irish setting, prehospital care KPIs are established by the Health Information and Quality Authority (HIQA)[43]. In the NAS all ambulance time intervals are measured from T5 time ("time which the dispatch code is established")[43], apart from on-scene and conveyance intervals. The dispatch code is generated during the initial triage of the call, relying on responses provided to specific questions by the call-taker[47]. This process is facilitated by triaging software known as the Advanced Medical Priority Dispatch System (AMPDS)[47]. AMPDS offers a scripted caller interrogation protocol to prioritize calls and allocate EMS resources to incidents through the linked ProQA

(Priority Dispatch Corp., ProQAv) software system[47,48]. Seven ambulance times/intervals are measured in Ireland[40,43]. Five of these are included in this project. **Table 1.1** displays the ambulance times/intervals measured by the Irish NAS[43].

Table 1.1 - Ambulance times and intervals reported by the Republic of Ireland's National Ambulance Service[43]

Allocation Performance (Allocation Time minus T5 Time)	**Activation Time (Mobile Time minus T5 Time)**	**Response Time (Resource at Scene Time minus T5 Time)**	**Despatch Code Established**	The time the Despatch Code is established from PROQA (T5)
			Resource Allocation Time	The time a resource* has been allocated to an incident on the CAD.
Mobilisation Performance (Mobile Time minus T5 Time)			**Resource Mobile Time**	The time the resource goes mobile on the incident, either through radio selective call (selcall)** by the crew, voice or Automatic Vehicle Location (AVL) update.
	On Scene Time (Resource Left Scene Time minus Resource at Scene Time)		**Resource At Scene Time**	The time the resource arrives at the scene of the incident. This is captured by a selcall 'At Scene' from the crew, by voice or by AVL update.
		Conveyance Time (At Hospital Time minus Left Scene Time)	**Resource Left Scene Time**	The time the responding crew have completed treatment, have the patient on board and are about to leave the scene for hospital. Given through Selcall 'Left Scene', by voice or AVL update.
			Resource At Hospital Time	The time the resource arrives at the hospital. Given via Selcall 'At Hospital', by voice or AVL update.
		Duration at Hospital (Clear time minus At Hospital Time)	**Patient Handover Time**	The time the paramedic hands the patient over to the receiving ED staff member and the PCR signed off. Time from Ambulance Arrival Screen in ED.
			Resource Clear	The time the crew have completed cleanup and replenishment of supplies and are ready for the next call or where they were stood down without completing the call and are in a position to respond to the next call. Give via Selcall 'Clear' or by voice.

*Resource: prehospital practitioner who attends the patient **Selcall: a radio signaling protocol in use in Europe, Asia, Australia and New Zealand

1.3.6 Emergency call volume as a global prehospital KPI

Emergency call volume is an indicator of the demand for prehospital care services[37,49,50]. A medical emergency call serves as a citizen's entry point to accessing prehospital emergency care services, and ambulance services more generally[49]. Emergency medical dispatchers stationed at the emergency medical dispatch centres (EMDC) manage and prioritise these calls[49]. These can also be known as the "control centre"[49]. These dispatchers rely on information provided by the callers to allocate the available prehospital resources efficiently[49]. They also offer guidance in first aid and/or resuscitation over the phone, assisting callers until the ambulance services arrive[49].

The increasing volume of calls received by ambulance services, is becoming a growing concern within healthcare systems worldwide[50]. The operational strain on healthcare systems, especially on emergency services, has escalated to unprecedented levels[50]. Like other healthcare services, capacity and demand are two challenging and competing components within prehospital care[37,49,50]. It can be challenging to align needs with the appropriate resources[37]. Subsequently, integrating care across the patient pathway is essential. This includes pre-alerting and expediting early meaningful interventions in the emergency department, operating theatres, and other relevant areas, which is crucial for optimising patient survival[37].

1.3.7 Emergency call volume as a prehospital KPI in the Republic of Ireland

In the Republic of Ireland, citizens access emergency medical services by calling 112 or 999[51]. The Emergency Call Answering Services (ECAS) acts as an essential connection between the caller and the emergency services[52]. The ECAS determines the specific emergency service required by the call e.g. an ambulance[52]. They also ascertain the caller's location to route the call to the most suitable centre of that Emergency Service[52]. Subsequently, the call or text is transferred to the respective Emergency Service, which assumes responsibility for the call and initiates the appropriate response [52]. ECAS operators remain engaged, monitoring the call until it is acknowledged by the Emergency Service[52].

1.3.8 Prehospital stroke/TIA care

Prehospital care practitioners play a key role in acute stroke/TIA care[5,6,31]. The prehospital phase of care constitutes the first half of the stroke chain of survival[6] (**figure 1.1**). Whilst on scene prehospital care practitioners are involved in five treatment and assessment processes; 1) EMS stroke identification; 2) stroke severity assessment; 3) destination hospital determination; 4) treatment in transit and 5) co-ordination of pre-arrival hospital care[6].

Ambulance time intervals are pertinent in prehospital stroke/transient ischemic attack care[6]. This is due to the essential role of EMS in promptly transferring patients to specialised secondary care providers[53,54]. As treatment approaches for stroke/TIA rely on timely intervention, minimising delays during the prehospital phase of care is

critical[5,53,54]. The internationally recognised Ulstein recommendations for emergency stroke care outline four key time interval targets on the patient journey[6]. Firstly, that call handling from the ambulance control centre should take <1minute[6]. Secondly that the time the ambulance crew spend on scene should be eight minutes, with transportation time to hospital of fifteen minutes[6]. Finally, once the ambulance arrives at hospital, door to treatment time should be no more than 45 minutes[6].

1.3.9 Acute stroke and TIA policy and guidelines in the Republic of Ireland

In Ireland, ongoing efforts to improve stroke care along the stroke chain of survival have been evident in recent years. According to the Irish National Stroke Strategy 2022-2027 *"outcomes and recovery from stroke are greatly improved by organised pathways of acute stroke care which includes prehospital, hospital and inter-hospital pathways"*[55]. To steer the development of the revised National Stroke Strategy (NSS), four core pillars of stroke care in Ireland were established[55]. These are: 1) stroke prevention; 2) acute care and cure; 3) rehabilitation and restoration to living; 4) education and research[55].

In 2023 the National Clinical Guideline for Stroke for the United Kingdom (UK) and Ireland were the first stroke clinical guidelines published in Ireland [34]. This guidance offers authoritative, evidence-based practice recommendations aimed at enhancing the quality of care provided to all adults who experience a stroke in the UK and Ireland[34]. This guidance is designed to be applicable irrespective of factors such as age, gender, type of stroke, location, or any other characteristic[34].

The National Stroke Strategy and National Clinical Stroke guidelines highlight a TIA as a critical potential warning sign for an impending ischemic stroke [15,33,56]. The highest risk occurs within the first 48 hours following the TIA[15]. In Ireland, like the majority of other European countries, national stroke guidelines address the management of TIAs[33,55,57]. However, some countries rely on local guidelines for TIA management, such as Croatia, Greece, and Slovakia[57]. Accurately distinguishing TIA from other conditions that mimic its symptoms is crucial[15,56,57]. Urgent evaluation of TIA is essential, involving imaging and laboratory studies to mitigate the risk of subsequent strokes[15,56]. Risk stratification for future TIAs or ischemic strokes can be achieved through a structured clinical assessment[15,56]. Immediate initiation of evidence-based therapeutic interventions is imperative to optimise patient outcomes[15,56].

1.3.10 Hospital-based stroke care in the Republic of Ireland

In 2022 the Republic of Ireland had a total of 86 hospitals, 67 of which were publicly funded hospitals[58]. Of these 86 hospitals, 44 were general hospitals[58]. Irish hospitals are generally classified into model one to four, according to the range and complexity of services offered[59]. For stroke, whether a hospital is model one to four is dependent on whether certain services are available. e.g. thrombolysis or rehabilitation units[59] **(table 1.2)**. Therefore, not all Irish hospitals are acute stroke receiving hospitals[55].

Table 1.2 - Definition of hospital models in the Republic of Ireland, in the context of stroke/TIA and ambulance service provision[59]

Hospital Model	Ambulance services	Stroke services
Model 1	General practitioners, hospital staff, and ambulance services will establish protocols for the transfer of patients by ambulance to and between hospitals.	The hospital might feature an onsite stroke rehabilitation unit.
Model 2 Model 2R: Remote rural hospital	General practitioners, hospital staff, and ambulance services will collaborate to establish protocols for the transfer of patients by ambulance to and between hospitals.	Stroke rehabilitation services will be offered.
Model 3	General practitioners, hospital staff, and ambulance services will collaborate to establish protocols for ambulance transfers to and between hospitals.	• An acute stroke unit may be available onsite, offering thrombolysis, rehabilitation, and maintaining a stroke register. • Additionally, a rapid access service for TIAs and stroke prevention clinics will be offered.
Model 4	General practitioners, hospital staff, and ambulance services will collaborate to establish protocols for ambulance transfers to and between hospitals.	• Onsite, there will be both acute and rehabilitation stroke units. These will provide: ○ Thrombolysis services ○ A rapid access service for TIAs ○ Stroke prevention clinics ○ An early supported discharge service ○ A stroke register ○ Vascular surgery facilities ○ Triage protocols for neurosurgical services ○ Advanced stroke imaging, including magnetic resonance imaging (MRI)

The INAS is a clinically led audit, which evaluates the standard of stroke care and the organisation of stroke services in hospitals that admit acute stroke patients in the Republic of Ireland[25,26]. The 2022 INAS report includes 21 acute strokes receiving hospitals[26]. However, this is an underrepresentation, as the audit only includes hospitals meeting defined criteria[26]. Firstly, the audit only covers patients diagnosed with stroke admitted to public hospitals offering acute stroke services to over 25 patients annually. Secondly, hospitals must achieve at least 80% data coverage to be included in hospital-level reporting. If they don't meet this threshold, they are excluded from such reporting but still included in national statistics presented in the INAS reports. Of the 21 acute stroke receiving hospitals in the most recent INAS report, two are EVT stroke centres providing 24/7 treatment[26,55].

INAS collects data on seven key quality indicators relating to hospital-based stroke care in the Republic of Ireland [25,26]. With the implementation of the national stroke policies mentioned above, there have been improvements in the proportion of stroke survivors reaching the hospital within 3 hours of symptom onset from 2013-2022[25,26]. Additionally, there have been notable increases in timely brain imaging over the same period[25,26]. Despite this, thrombolysis rates have significantly declined from 2013 to 2022[25,26].

1.4 The COVID-19 Pandemic - A “Shock” to the Healthcare System

The COVID-19 pandemic increased pressures on the healthcare system, placing a strain on this acute stroke/TIA pathway[10,11,60]. However it is acknowledged that achieving the balance between public health safety and patient-centred care was challenging during the first pandemic in the last one hundred years.

1.4.1 The COVID-19 pandemic – global timeline

On March 11th, 2020, the World Health Organisation (WHO) declared COVID-19 a pandemic[61]. Globally, countries began to adapt various strategies for responding to COVID-19[62,63]. Broadly speaking pandemic strategies can be categorised into five potential strategies[62,63]. These include: exclusion; elimination; suppression; mitigation; and no substantive strategy[62] **(table 1.3).**

Table 1.3 - Types of COVID-19 pandemic response strategies adopted internationally[62]

Strategy	Description	Examples of countries which adopted this strategy
Exclusion	Maximum actions to exclude disease	Some Pacific Island countries and territories
Elimination	Maximum action to exclude disease and eliminate community transmission	Mainland China, Taiwan and New Zealand
Suppression	Action increased in stepwise and targeted manner to substantially lower-case numbers and outbreaks	Most European countries and North America
Mitigation	Action takes to “flatten the peak/curve” to avoid overwhelming health services and protect the most vulnerable	Sweden (initially)
No substantive strategy	Largely uncontrolled pandemic wave	Some lower income countries

As part of these approaches, a suite of non-pharmacological interventions (NPIs) was introduced, which varied greatly internationally[63]. NPIs encompass a broad spectrum of measures, including both top-down (governmental) and bottom-up (self-initiated) actions, designed to disrupt infection transmission by modifying critical aspects of human behaviour[63]. Examples of NPIs include travel bans, curfews, social distancing, restrictions on social gatherings, mask mandates, improved hygiene practices, remote work arrangements, school closures, and lockdowns[63].

In terms of pharmacological measures, the first COVID-19 vaccine was administered globally outside of a clinical trial setting on 8th December 2020[64]. By 8th December 2021, it was estimated that 55.9% of the global population had received at least one dose of a COVID-19 vaccine, 45.5% had received two doses, and 4.3% had received a booster dose[64,65]. Despite the remarkable speed at which COVID-19 vaccines were developed and distributed during 2020 and 2021, more than 3.5 million deaths attributable to COVID-19 have been reported globally since the first vaccine was administered[64,65]. The COVID-19 pandemic officially ended on May 5th 2023 when the WHO declared that the crisis no longer met the criteria to be classified as a public health emergency of international concern[66].

1.4.2 The COVID-19 pandemic - The Republic of Ireland's timeline

The Republic of Ireland recorded its first confirmed case of COVID-19 on 29th February 2020[67]. Subsequently, the country faced five waves of the virus, with the initial wave commencing on 1st March 2020, and the fifth on 19th December 2021[68]. Ireland was one of the few countries internationally that experienced five waves of

COVID-19[69]. In response to the escalating situation, the Irish government implemented a series of non-pharmacological interventions throughout March 2020 to curb the spread of the virus[70,71]. This led to the enforcement of the first lockdown on March 27th, 2020[70,71]. A phased reopening plan, consisting of five stages, was announced by the Taoiseach (Prime Minister) on 1st May 2020[71].

The COVID-19 vaccination programme commenced in Ireland on 29th December 2020[72]. The Republic of Ireland's vaccination rollout has received acclaim as one of the most successful globally[73]. It ranks number one in the European Union (EU) for the percentage of its adult population fully vaccinated [73]. Additionally, it was also ranked at the top within the EU for the number of booster vaccines administered[74]. Nearly two years later, on 28th February 2022, the government lifted most COVID-19 restrictions[75]. The mandate requiring masks in healthcare settings, one of the last remaining COVID-19 public health measures, was removed on April 19th, 2023[76]. **Figure 1.2** summarises key events in the Republic of Ireland's COVID-19 timeline.

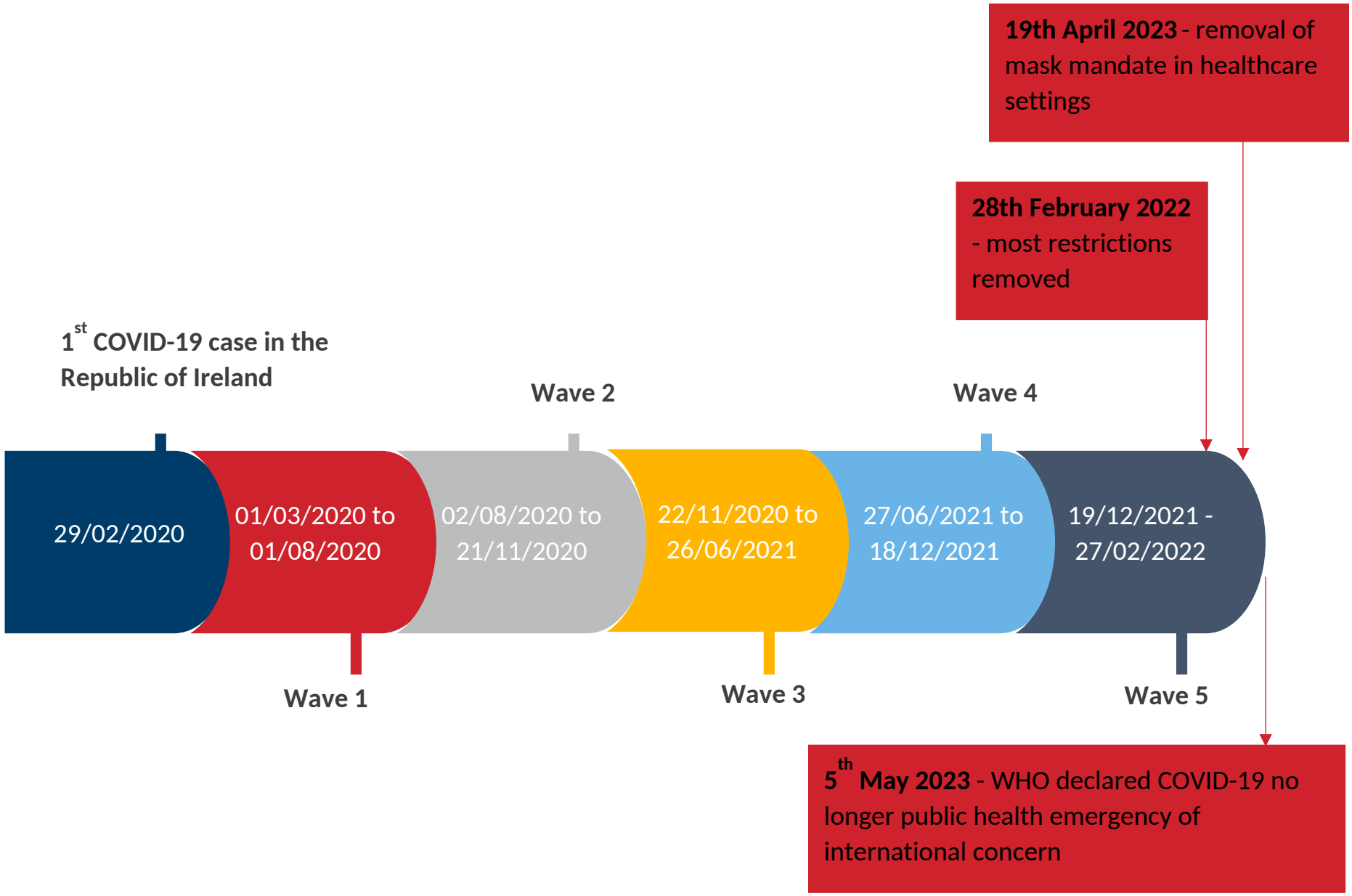

Fig. 1.2 - Key events in the Republic of Ireland's COVID-19 timeline

1.4.3 - Resilient healthcare systems during COVID-19

The COVID-19 pandemic is widely recognised as a significant shock to the healthcare system[7,77-81]. It placed heightened strain on health system operations, public health efforts, and society overall[7,77-81]. Furthermore, the pandemic led to delays in essential and urgent non COVID-19 care[7,77-81], including that for stroke/TIA[10,12]. Thus COVID-19 has been considered as a test of the resilience of healthcare systems[7,77-81].

Resilience implies more than just the ability to bounce back swiftly following a shock[7,77-82]. This is particularly true in the case of a health system capable of learning from experiences[7,77-82]. Ideally, it should not only recover but also evolve beyond its original state, especially if that state could be enhanced[7,77-82]. Consequently, a health system should not merely react but also engage in reflection and action, both during and after a shock, like COVID-19[7,77-82]. This facilitates preparedness for future shocks and ideally enhances the pre-shock condition of the healthcare system [7,77-82]. Thus COVID-19 allows for reflection on three phases of a health system's response: absorption of a shock, adaptation to it, and transformation to fortify the health system[7,77-82]. Viewed in this light, resilience emerges as a dynamic characteristic of a health system that evolves over time, sometimes rapidly, rather than remaining in a static state[7,77-83].

Despite being the most extensively studied global shock to date, it is challenging, if not impossible, to determine with certainty which health systems exhibited the highest resilience to COVID-19[7,77-82]. Currently, the exact mechanisms which confer system resilience during the COVID-19 pandemic are unclear. The answer may evolve

over time[7,77-82]. The resilience of a health system is also shaped by decisions made external to it[7,77-82] However, a focus on service delivery for time-sensitive conditions offers a valuable starting point by examining how health systems managed to absorb, adapt, transform, and learn during the COVID-19 pandemic[7,77-82].

1.4.4 Impact of COVID-19 on acute stroke and TIA care - globally

This heightened focus on the resilience of healthcare came as the healthcare system faced significant disruptions due to the COVID-19 pandemic[60]. A system shock of this nature required a rapid health system response, which at times included service reconfiguration[60]. Internationally, early evidence suggested reduced and delayed presentations of stroke/TIA, along with increases in stroke-related morbidity and mortality[81-85]. The implications on acute stroke care have been described in both the context of changes in healthcare seeking behaviour of stroke/TIA survivors and healthcare delivery[86-88]. The WSO reported wide-ranging effects on stroke services, along with an initial sharp decline in stroke case presentations [89,90].

Many countries needed to substantially restructure their stroke services and noted a marked decrease in less severe strokes [89,90]. An international study investigating the impact of the pandemic on rapid TIA pathways across seven countries found that six of the eighteen clinics continued to deliver in-person assessments during early COVID-19[91]. In contrast, the remaining clinics operated exclusively using telehealth[91]. The majority of studies in this context are hospital-focused[1,10,11,86,92-94]. However international studies have reported prolonged ambulance time intervals for suspected stroke/TIA during COVID-19[3,95]. However, one Spanish study found that

"time spent on-scene" was the only interval that increased during COVID-19[96]. Whereas a Polish study reported an increase in all time intervals from "call to hospital arrival" during the pandemic[95]. A further study, conducted in Thailand, had similar results, however reported no change for the time from "scene to hospital arrival"[3].

In the Republic of Ireland emergency admissions for stroke and TIA reduced in quarter two to four of 2020 (411 fewer episodes of admission, -12.1%) compared to expected rates based on quarter one of 2020[97,98]. However a COVID-19 report by the INAS found no statistically significant difference in the number of cases admitted with haemorrhagic stroke (p=0.577, CI: 18.9-22.2) or ischemic stroke (p=0.315, CI: 86.5-94.4) between the pre-COVID-19 period (March-May 2018 and 2019) and the COVID-19 period (March-May 2020)[99].

Thus, current literature mainly focuses on hospital-based stroke care during the COVID-19 pandemic, rather than prehospital care, which is the typical entry point in the chain of survival. Furthermore, the few prehospital studies available were conducted during the earliest COVID-19 wave, only evaluating initial impacts on stroke/TIA. Comparing different COVID-19 waves allows for identifying the impact of varying restrictions and provides a longer-term evaluation of the pandemic's impact. Also, as the majority of existing evidence is quantitative in nature, little is known about the mechanisms or reasons behind observed changes in healthcare system response and healthcare seeking behaviour for stroke/TIA during the COVID-19 pandemic.

1.5 Summary

The stroke chain of survival is centred on the principle that "time is brain," emphasising the critical importance of timely intervention for stroke and TIA[5,6,31]. The COVID-19 pandemic, a global public health crisis, demanded a rapid and immediate response from healthcare systems[7,77-82]. Maintaining the stroke chain of survival amidst these challenging circumstances served as a true test of healthcare system resilience[9,77-81].

Despite prehospital care being the common entry point to the chain of survival, most research prior to this thesis has focused on single-centre, hospital-based studies[91-94]. As a result, the global impact of the COVID-19 pandemic on prehospital emergency care for stroke and TIA remains largely unknown. Additionally, existing research primarily addresses the early periods of COVID-19, lacking the ability to determine the pandemic's continued impact. No studies have been conducted in Ireland on this topic. The Republic of Ireland, having been one of few countries to experience five waves of COVID-19[69], is an ideal case study to examine the longer-term impacts of this "shock" on time-sensitive conditions. Finally, current literature is predominantly quantitative and lacks detailed insights into potential changes in healthcare system response and stroke/TIA survivor interaction with the healthcare system in this context.

This PhD aims to address this gap by focusing on the prehospital phase of acute stroke/TIA care over two years of the pandemic, employing a mixed-methods approach. It considers both the healthcare system response and potential changes

in healthcare-seeking behaviour. By investigating the pandemic's effects across the entire stroke chain of survival, this thesis seeks to identify delays, improvements, and opportunities at each stage of the chain of survival. The multi-level mixed-methods approach enables the triangulation of findings, allowing for a deeper exploration of the meaning and potential reasons behind any changes observed in healthcare provision and utilisation for these time-sensitive emergencies.

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Chapter 2: Introduction and Thesis Overview

2.1 Introduction

The COVID-19 pandemic was a “shock” to the healthcare system[1-3]. It placed increased pressure on health system operations, delaying necessary and urgent non-COVID-19 care[1-3]. The management of time-sensitive conditions like acute stroke and transient ischaemic attack (TIA) provides a key gauge for assessing the COVID-19 pandemic's impact on healthcare system response and service user interaction with the system. Stroke is the second leading cause of death globally and the third leading cause of death and disability combined worldwide, represented by disability-adjusted life years (DALYs)[4,5]. In the Republic of Ireland, stroke is the primary cause of acquired adult neurological disability[6].

Given the time-sensitive nature of stroke/TIA intervention, it is crucial for stroke/TIA survivors to promptly seek medical attention after symptoms develop[7,8]. Prehospital stroke management aims to reduce the time to diagnosis and treatment by adhering to the stroke chain of survival[9-11]. Prehospital care can be broadly defined as emergency medical care given to patients before arrival at hospital after activation of the Emergency Medical Services (EMS)[12]. Prehospital care is frequently a stroke survivor’s first point of contact with the stroke chain of survival[13-15]. The stroke chain of survival defines the key steps in emergency stroke care from symptom recognition to hospital arrival[11]. This involves the "8Ds": detection, dispatch, delivery, door, data, decision, drug/device, and disposition[11,13,16]. Prehospital practitioners are involved in the initial four steps of this chain of survival[11,13,16]. Treatments for ischemic stroke, including thrombolysis, and blood pressure management for

haemorrhagic stroke require timely administration[17]. Therefore, minimising the interval between symptom onset and treatment helps to prevent rapid and irreversible neurological damage[8,17].

The World Health Organisation (WHO) declared COVID-19 as a pandemic on 11th March 2020[18]. Due to their time-critical nature stroke and TIA could be viewed as especially susceptible to pressures on healthcare system delivery or shifts in patients' healthcare-seeking behaviours. The implications of this "shock" on acute stroke/TIA care have been described in both the context of changes in healthcare seeking behaviour of stroke/TIA survivors and healthcare delivery[19,20]. The World Stroke Organization (WSO) reported an initial sharp decline in the presentation of stroke/TIA cases, accompanied by a widespread impact on stroke services[19,20]. In the Republic of Ireland the behavioural response of non or late attendance with stroke/TIA in the first wave of the COVID-19 was unexpected by healthcare professionals in the area of stroke[21]. Globally, prehospital delays have been reported for stroke/TIA patients during the COVID-19 pandemic which can impact on later stages of the acute stroke/TIA pathway[22-24].

From the above it is clear that the COVID-19 pandemic affected healthcare utilisation worldwide, especially for acute time-sensitive conditions like stroke and TIAs[25,26]. However, there was early emergence of varying, dynamic, and conflicting evidence across countries with different healthcare systems, COVID-19 experiences and acute stroke/TIA pathways[1,2].

2.2 Aim

The overall aim of this thesis was to investigate the impact of a "shock", such as the COVID-19 pandemic on prehospital emergency care for exemplar time-sensitive conditions; stroke and TIA, with the goal of exploring potential implications for future policy and service delivery.

2.3 Objectives

This aim was addressed by five specific objectives outlined below:

1. to review and synthesise published evidence on the impact of the COVID-19 pandemic on prehospital emergency care for suspected stroke/TIA.

2. to compare ambulance time intervals and emergency call volume for suspected stroke/TIA in the Republic of Ireland, before and during the COVID-19 pandemic.

3. to explore experiences of stroke/TIA survivors, caregivers, and healthcare professionals of acute stroke/TIA care in the Republic of Ireland during the COVID-19 pandemic.

4. to compare terminology and definitions of ambulance times and time intervals from the ambulance services of a range of countries to facilitate international benchmarking.

5. to compare ambulance time intervals and emergency call volume for suspected stroke/TIA across seven international services before and during the COVID-19 pandemic.

2.4 Stakeholder Involvement

Stakeholder involvement inspired and informed the body of work presented in this thesis from its early to final stages.

Active involvement in research by stakeholders enables those affected by decisions to influence the pursuit and conduct of research projects[27]. Stakeholders can be defined as *"any potential knowledge user whose primary role is not directly involved in research"*[28]. This can include individuals with healthcare conditions, their families, friends, and caregivers, healthcare professionals, decision-makers, and others[27,28].

In this thesis, stakeholder involvement was included in two forms:

1. Patient and Public Involvement (PPI)

2.Stakeholder involvement from those in prehospital, emergency medicine, neurology or stroke medicine clinical practice, research, or policy roles

2.4.1 PPI

PPI is defined as *"research being carried out 'with' or 'by' members of the public rather than 'to', 'about' or 'for' them"*[29]. Two panels of stroke/TIA survivors and family caregivers of stroke/TIA survivors were involved in this PhD project. A group of five stroke survivors; 3 male and 2 female, from the Cork Stroke Support Centre[30] were involved in the systematic review **(chapter 3)**. Secondly, the University College Cork (UCC) stroke/TIA PPI group was established to ensure this PhD project was shaped by the lived experience of stroke/TIA throughout all phases of the research. The UCC group includes 13 members; seven stroke survivors (5 male, 2 female); 2

TIA survivors (1 male, 1 female) and four family caregivers (3 female, 1 male). This group were involved from research question development to dissemination across the remaining four studies **(chapters 4-6)**.

Both panels were involved in all stages of the research cycle, from the point of refining the PhD research question to dissemination for their respective studies. The PPI contributors advised that raising the alarm and transport to hospital were key milestones in their stroke/TIA journeys. Thus, the PPI panels believed the focus of the PhD should be on ambulance care for stroke/TIA survivors during the COVID-19 pandemic.

Figure 2.1 below illustrates the key turning points influenced by PPI in this doctoral research[31,32]. These turning points describe three key areas within the thesis where PPI had the greatest impact. This infographic was co-designed with the UCC stroke/TIA PPI panel.

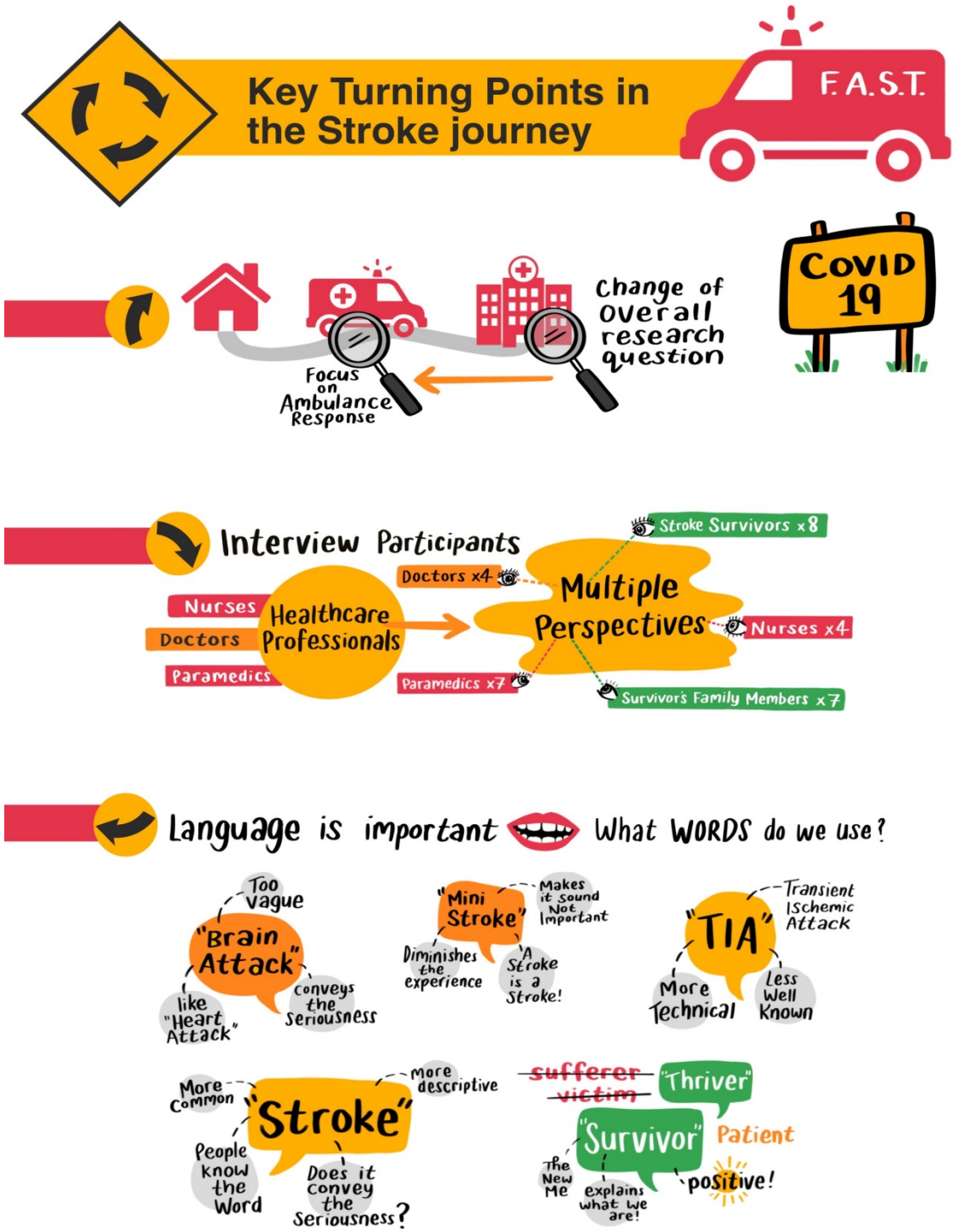

Figure 2.1 - Co-designed graphic with PPI contributors of the key turning points in the stroke/TIA journey depicting the influence of PPI on this PhD research

The inclusion of PPI in each study is described in **Chapter 3-6** using the Guidance for Reporting Involvement of Patients and the Public (GRIPP 2) checklist (short version)[33].

2.4.2 Stakeholder involvement from those in clinical practice, research, and policymaking

Numerous national and international stakeholders from prehospital care, emergency medicine, neurology, and stroke medicine were engaged in this project from its inception. These partners were involved in research question development, identification of outcomes, recruitment of participants, interpretation of findings and dissemination of results.

During this PhD project, the PhD candidate, Edel Burton founded two international consortia of relevant stakeholders. One was specifically related to the terminology benchmarking and international comparative study **(chapter 6)**; Prehospital Care of Stroke (Phocas) Consortium. The second consortium was established to continue work on harmonising international emergency care time interval terminology after this PhD; International Standardisation of Emergency Care Time/Interval Terminology (InterSECTT) Consortium.

A full list of stakeholders is included in the acknowledgment section of this thesis.

Outputs related to stakeholder involvement in this PhD project are included in ***Appendix 2.1***.

2.5 Multi-level Mixed Methods Research Design

The multi-level mixed methods design is commonly adapted in studies investigating dynamic multilevel systems such as public health crises[34]. However constant discourse and conflicting interpretations remain in the literature regarding the definition, conceptualisation and implementation of this approach[34]. Thus in 2020, Headley and Plano Clark proposed a refined definition taking previous definitions and approaches into account[34].

This updated definition defines a multilevel mixed methods research design as

"Driven by a multilevel theory about a system for the purpose of better understanding three characteristics of that system; the holistic ***structure*** *of the system, the individual components* ***(levels)*** *that emerge from, give rise to or evolve in tandem with the structure; and the process* ***(mechanisms)*** *at work between the components and the structure……." A multilevel mixed methods research design incorporates both quantitative and qualitative data and analytical tools to generate meta-inferences about one or more aspect of a multi-level phenomenon – system-levels – mechanisms – that transcend what could be inferred from a traditionally qualitative or traditionally quantitative approach alone"* [34].

Headley and Plano Clark propose six defining features of a multilevel mixed methods research design[34] **(table 2.1)**.

Table 2.1 - Features of a multilevel mixed methods research design[34]

Design Feature	Specification
1. Theoretical grounding	• Incorporates a theory about a multilevel system with assumptions about the system as a whole (*structure*), the components of the system (*levels*), and processes that contribute to the maintenance or evolution of the system (*mechanisms*)
2. Mixed methods research design	• Includes at least two strands of inquiry (qualitative and quantitative), each of which investigates structure, level(s), and/or mechanism(s) • Integrates the strands to generate meta-inferences that expand upon the inferences drawn from the strand analyses alone
3. Sampling strategy	• Involves more than one level of the system
4. Data collection	• Generates evidence about more than one level and/or between-level mechanisms
5. Data analysis	• Generates within- or between-level inferences for each strand • Generates findings sufficient to support across-level meta-inferences during integration
6. Integration	• Supports across-level meta-inferences about more than one aspect of the system: 1. Characteristics of structure 2. Characteristics of levels 3. Nature of between-level mechanisms

This PhD thesis tested the resilience of the healthcare system to a "shock"[1] like a pandemic, using time-sensitive conditions stroke and TIA as exemplars. In this context, it evaluated the health system response and also the interaction of service users (stroke/TIA survivors, and caregivers) with the healthcare system. Thus, the structure here was the healthcare system. The levels were (1) regional healthcare systems – one region within Ireland **(chapter 5)**; (2) national healthcare system – nationwide coverage from the Republic of Ireland **(chapter 4)**; and (3) international healthcare systems – ambulance services from seven countries **(chapter 6)**. The mechanisms were factors which influenced ambulance time intervals and call volume for suspected stroke/TIA during the COVID-19 pandemic.

The six components of the multilevel mixed methods research design **table 2.1)**, as they apply to this PhD project, are described using subheadings and **table 2.2** below.

Table 2.2 - Application of the six features of a multilevel mixed methods design[34] applied to this PhD project

Design feature	Application in this PhD thesis
1. Theoretical grounding	**Theory:** Resilient Health System as a Conceptual Framework for Strengthening Public Health Disaster Risk Management[35] **Structure:** Healthcare system resilience during a public health crisis **Levels:** • Regional: one region in the Republic of Ireland • National: ambulance service covering Republic of Ireland • International: seven ambulance services from seven countries
2. Mixed methods research design	**Mechanisms:** Factors affecting ambulance time intervals and call volume for suspected stroke/TIA **Design:** Triangulation design: multilevel model[36] **Quantitative:** • National level **(chapter 4):** quantifying ambulance time intervals and call volume before and during the COVID-19 pandemic in the Republic of Ireland • International level **(chapter 6)**: quantifying ambulance time intervals and call volume

	before and during the COVID-19 pandemic across seven international services **Qualitative:** • Regional level **(chapter 5)**: qualitative exploration of multistakeholder experiences of early stages of acute stroke/TIA care during the COVID-19 pandemic in one region in the Republic of Ireland **Integrative:** • Across the levels which factors influenced ambulance time intervals and call volume in the context of healthcare system response and service user interaction with the healthcare system
3. Sampling strategy	**Quantitative:** • National level **(chapter 4):** control centre data from the National Ambulance Service (Republic of Ireland) of all adult suspected stroke/TIA cases from 2018-2021 • International level **(chapter 6)**: control centre data from seven international ambulance services of all adult suspected stroke/TIA cases from 2018-2021 **Qualitative:**

	• Maximum variation sample[37,38] of stroke/TIA survivors, caregivers, nurses, doctors and paramedics from one region within the Republic of Ireland
4. Data collection	• Level 1 – regional **(chapter 5)**: Semi-structured interviews • Level 2 – national **(chapter 4)**: Secondary data analysis of ambulance control centre data from the Republic of Ireland • Level 3 – international **(chapter 6)**: Secondary data analysis of ambulance control centre data from seven international ambulance services
5. Data analysis	Within-level: • Level 1 – regional **(chapter 5)**: qualitative reflexive thematic analysis and patient journey mapping[39,40] • Level 2 - national **(chapter 4)**: quantitative descriptive statistics, linear regression and interrupted-time series analysis • Level 3 - international **(chapter 6):** quantitative descriptive statistics, linear

	regression and time - series analysis Across – level: • Systematic review and meta-analysis **(chapter 3)**: meta-analysis of published evidence on ambulance time intervals and call volume. Comparison across the three levels. • International benchmarking of ambulance time terminologies and definitions **(chapter 6a)**: facilitating accurate comparison across the three levels.
6. Integration	**Structure:** Resilience of the system during COVID-19 in the context of healthcare system response and service user interaction with the healthcare system **Levels:** This allows for deeper insights into healthcare system response and service user interaction with the healthcare system during the pandemic. The quantitative

	results **(chapter 4 and 6)** provided the numerical evidence on ambulance times (healthcare system response) and call volume (service user interaction). Whereas the qualitative results provided rich insights into potential reasons and mechanisms for these observations **(chapter 5)**. **Mechanisms**: Critical discussion of results across levels in the discussion chapter of this thesis **(chapter 7**) to understand how and why healthcare system response and service user interaction was impacted by the COVID-19 pandemic.

2.5.1 Theoretical grounding

This PhD investigated the impact of a "shock"[1]; the COVID-19 pandemic, on healthcare system delivery for time-sensitive conditions; stroke and TIA. Thus, the health system focused "Resilient Health System as A Conceptual Framework for Strengthening Public Health Disaster Risk Management"[35] was chosen as the underpinning conceptual framework **(figure 2.2)**.

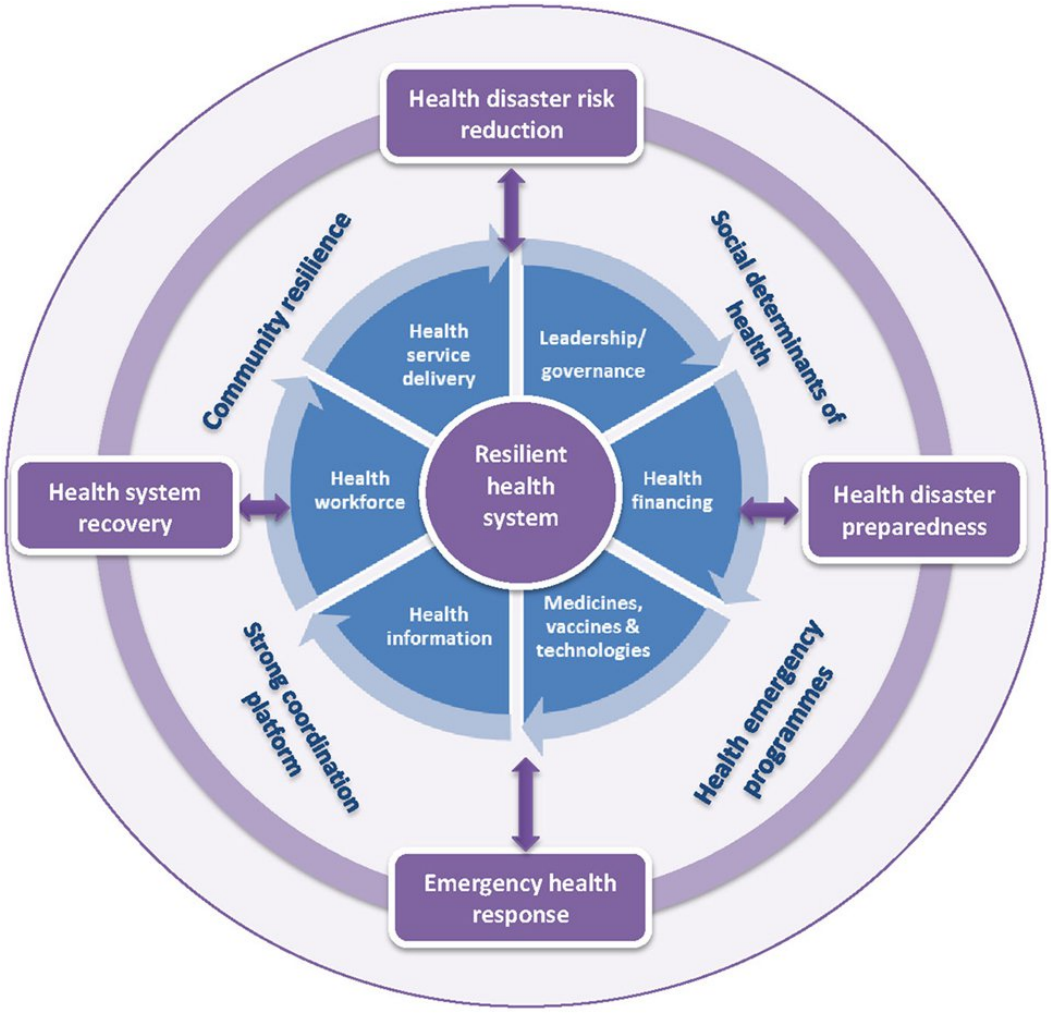

Figure 2.2 - Resilient Health System as A Conceptual Framework for Strengthening Public Health Disaster Risk Management[35]

*(permission granted to reuse the image in this thesis)

This framework is a combination of the World Health Organisation "building blocks" of the healthcare system framework[35,41] and the principles of disaster risk management[35,41,42]. This approach was proposed by a WHO member in response to public health crises including the Ebola virus disease outbreak in 2014-2015[35]. The six building blocks of the healthcare system include: service delivery, health workforce, health information systems, access to essential medicines, financing, and leadership/governance[41]. Whilst disaster risk management describes the process of administrative and operational protocols to execute interventions targeted at mitigating the adverse effects of disaster hazards[42].

This framework theorises a multi-level system, making assumptions about the structure, levels and mechanisms of the system.

Structure:

This framework proposes that the system consists of the WHO six building blocks, [35,41]. A resilient health system is one *"which is able to effectively prepare for, withstand the stress of, and respond to the public health consequences of disasters"*[43]. The framework includes discussion on five key elements of a resilient healthcare system[43]:

1. Recognition of the strengths and weakness of the building blocks of the system

2. Awareness of the exposure of the system to a range of risks and threats

3. Ability to respond to a wide-ranging spectrum of public health concerns before and during the disaster

4. Capacity to promptly and successfully adapt to volatile and changeable situations, using coordinated methods for addressing public health emergencies like disasters

5. A resilient healthcare system should possess the ability to self-regulate

This PhD focuses on the public health issue of a pandemic to investigate system responsiveness and consequences of the presence or absence of resilience. With the overall aim of learning for prehospital stroke and TIA care, in routine or crises circumstances.

Levels:

The framework proposes that the six building blocks exist at each level of the healthcare system.

In the context of this PhD project the six building blocks will be investigated at a regional **(chapter 5)**, national **(chapter 4**) and international **(chapter 6)** level.

Of the six building blocks, the meaning of service delivery, health workforce, health information systems, and access to essential medicines are self-explanatory. However, the remaining building blocks: leadership/governance and financing may be operationalised differently in different circumstances. In this PhD project leadership/governance includes the COVID-19 public health measures introduced during the pandemic, and the different approaches taken[44]. Health financing refers to the different healthcare system structures of the countries in **chapter 6** and COVID-19-related health financing for items such as personal protective equipment (PPE) and vaccines[44].

Mechanisms:

The framework conceptualises the interaction of levels with the system. In this PhD these are factors relating to the building blocks which impact on ambulance time intervals and call volume.

This framework was applied from the conceptualisation stage of this PhD. The resilience of the healthcare system during the COVID-19 pandemic **(structure)** was investigated. This was done on a regional, national, and international basis, to understand which building blocks of the healthcare system affected system response (ambulance time intervals) and service user interaction with the system (call volume) (**levels)**. The goal was to understand the factors influencing ambulance time intervals and call volumes **(mechanisms)**.

2.5.2 Mixed methods research design

The multilevel model of triangulation design is the mixed methods design applied in this PhD project[36]. The triangulation design involves implementing the qualitative and quantitative phases during the same time period, with both phases having equal importance in answering the overall research question[36]. The multilevel variant of the triangulation design is described and illustrated below.

Within this PhD project qualitative data was collected and analysed at a regional level **(chapter 5)**. Quantitative data from the pre-COVID-19 and COVID-19 time periods were collected and analysed on a national **(chapter 4)** and international level **(chapter 6)**. The findings from each level of the system were then merged to form one overall interpretation of the PhD findings. This interpretation was facilitated and

informed by the results of the quantitative systematic review and meta-analysis **(chapter 3)** and qualitative international benchmarking study of ambulance times terminology and definition **(chapter 6a)**. **Figure 2.3** illustrates the triangulation: multilevel model design used in this PhD project.

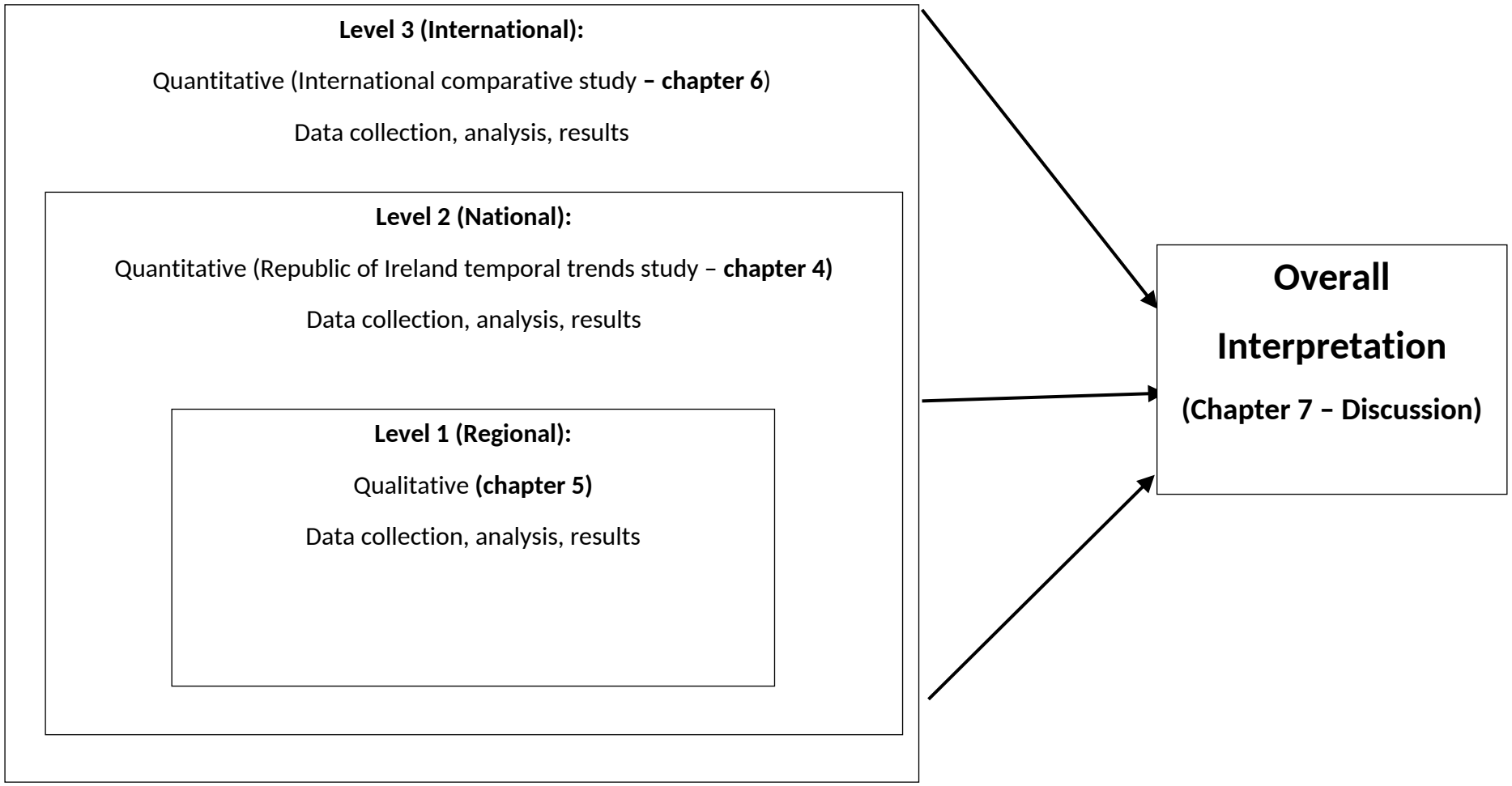

Figure 2.3 - Illustration of the triangulation: multilevel model of mixed methods design used in this PhD project. Adapted from Creswell et. al 2007[36]

2.5.3 Sampling strategy

Sampling strategies were conducted at a regional **(chapter 5)**, national **(chapter 4)** and international level **(chapter 6)** in this PhD project. Detailed descriptions of these strategies for each study can be found in its respective chapter.

For the qualitative study **(chapter 5)**, sampling was conducted in one region in the South of Ireland. This included stroke/TIA receiving hospitals and ambulance stations in this region. Maximum variation sampling was conducted. Stroke/TIA survivors who were admitted to any of these hospitals during the COVID-19 pandemic and their caregivers were eligible for inclusion. Nurses, doctors or paramedics who worked in this region during the same period were also eligible.

In terms of the quantitative studies **(chapter 4 and 6)**, all adult cases of suspected stroke/TIA included in the control centre data of the Republic of Ireland National Ambulance Service **(chapter 4)** and seven international ambulance services **(chapter 6)** from 2018-2021 were eligible for inclusion.

2.5.4 Data collection

Different data collection methods were conducted across the different studies. Details of data collection for each study is included in the respective chapters **(chapter 3-6)**.

The qualitative study **(chapter 5)** involved one-on-one and dyadic semi-structured interviews.

Whereas the quantitative studies **(chapter 4 and 6)** were secondary data analyses where data collection involved submitting data request forms to the relevant ambulance services.

2.5.5 Data Analysis

Within level data analysis was conducted separately for each study **(chapter 3-6)**. The results of the systematic review and meta-analysis **(chapter 3)** and the international benchmarking study **(chapter 6b)** facilitated across-level analysis.

2.5.6 Integration

The findings from all five PhD studies (**chapter 3-6**) were integrated in **chapter 7** to present a critical analysis of the resilience of the healthcare system, on a regional, national, and international level in the context of stroke and TIA. Consistent outcomes of (i) ambulance time intervals (healthcare system response) and (ii) call volume (service user interaction with the healthcare system) was investigated in different manners across all levels **(chapters 3-6)**. Thus, the factors influencing the impact of the pandemic on these outcomes were holistically synthesised.

2.6 Thesis Outline

This thesis includes seven chapters, four of which directly answer the aim and objectives above. **Figure 2.4** provides an overview of how the thesis aim and objectives align with each chapter, and related papers.

Chapter 1 presents information on the global burden of disease of stroke/TIA. Furthermore, an overview of prehospital stroke care is provided. Finally, the context of the COVID-19 pandemic is given along with a summary of its reported global impact on prehospital stroke/TIA care.

International evidence on the impact of the COVID-19 pandemic on ambulance time intervals and emergency call volume for suspected stroke/TIA is included **in chapter 3**. A meta-analysis combining findings from various studies to provide an overall estimate is described. This was required as international evidence on the impact of COVID-19 and its magnitude in this context was conflicting. Like **chapter 3**, time intervals and emergency call volume were examined in **chapter 4**, using Republic of Ireland National Ambulance Service control centre data.

Chapter 5 explores the perspectives of stroke/TIA survivors, caregivers, and healthcare professionals on the emergency/pre-treatment phase of acute stroke/TIA care in Ireland during the COVID-19 pandemic. Findings from in-depth interviews and a patient journey mapping approach are described in this chapter.

The final study chapter, **chapter 6** details two parts of an international study. Firstly, an ambulance time/interval international benchmarking study is detailed. During the

systematic review **(chapter 3)** heterogeneity in ambulance time/interval terminologies and definitions was identified. Thus, to conduct an accurate and meaningful international comparative study, benchmarking needed to be conducted. As a result of this benchmarking, the Republic of Ireland time interval definitions were used in the international comparative study **(chapter 6b).** This final study compares time intervals and emergency call volume for suspected stroke/TIA pre-COVID-19 and during COVID-19 across seven international ambulance services.

Chapter 7 of this thesis summarises the main findings, strengths, and limitations of this body of work, along with potential policy implications and suggestions for future research. As per the multi-level mixed methods approach[34] adopted in this thesis, the discussion chapter triangulates both the quantitative **(chapter 3,4,6b)** and qualitative **(chapter 5 and 6a)** strands of inquiry of this thesis at the interpretation level.

The impact of the COVID-19 pandemic on prehospital emergency care for stroke/transient ischaemic attacks (TIAs) and implications for future policy and service delivery

Aim

To investigate the impact of a "shock", such as the COVID-19 pandemic on prehospital emergency care for exemplar time-sensitive conditions; stroke and TIA, with the goal of exploring potential implications for future policy and service delivery.

Objective 1:	**Objective 2:**	**Objective 3:**	**Objective 4:**	**Objective 5:**
To review and synthesise published evidence on the impact of the COVID-19 pandemic on prehospital emergency care for suspected stroke/TIA.	To compare ambulance time intervals and emergency call volume for suspected stroke/TIA in the Republic of Ireland, before and during the COVID-19 pandemic.	To explore experiences of stroke/TIA survivors, caregivers, and healthcare professionals of acute stroke/TIA care in the Republic of Ireland during the COVID-19 pandemic.	To compare terminology and definitions of ambulance times and time intervals from the ambulance services of a range of countries to facilitate international benchmarking.	To compare ambulance time intervals and emergency call volume for suspected stroke/TIA across seven international ambulance services before and during the COVID-19 pandemic.
Chapter 3	Chapter 4	Chapter 5	Chapter 6a	Chapter 6b
Protocol published in HRB Open, 2022 Paper published in Prehospital Emergency Care, 2023	Published in BMJ Open, 2024	***The Journal of Multidisciplinary Healthcare Accepted for Publication*** *Journal of Multidisciplinary Healthcare | Taylor & Francis*	Published in Annals of Emergency Dispatch & Response, 2023	***Minor Revisions after peer review with the Journal of the American Heart Association*** *American Heart Association Journals*

Figure 2.4 - Overview of thesis including aims and objectives

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Chapter 3a: Effects of the COVID-19 pandemic on prehospital emergency care for adults with stroke and transient ischaemic attack: A protocol for a systematic review and meta-analysis

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Burton E, Aladkhen J, O'Donnell C, Masterson S, Merwick Á, McCarthy VJC *et al*. Effects of the COVID-19 pandemic on prehospital emergency care for adults with stroke and transient ischaemic attack: A protocol for a systematic review and meta-analysis [version 2; peer review: 3 approved]. *HRBOpenRes* 2022, 5:24 (https://doi.org/10.12688/hrbopenres.13534.2)

3.1 Abstract

Background

The COVID-19 pandemic impacted on health service provision worldwide, including care for acute time sensitive conditions. Stroke and TIAs are particularly vulnerable to pressures on healthcare delivery as they require immediate diagnosis and treatment. The global impact of the COVID-19 pandemic on prehospital emergency care for stroke/TIA is still largely unknown. Thus, the aim of this study is to conduct a systematic review and meta-analysis to investigate the impact of the COVID-19 pandemic on prehospital emergency care for stroke and TIA.

Methods

Following the Preferred Reporting Items for Systematic Reviews and Meta Analyses (PRISMA) guidelines, the review is registered on PROSPERO (registration number CRD42022315260). Peer-reviewed quantitative studies comparing prehospital emergency care for adults with stroke/TIA before and during the COVID-19 pandemic will be considered for inclusion. The outcomes of interest are ambulance time intervals and emergency call volumes for stroke/TIA. A systematic search of databases including PubMed, Embase and Scopus will be conducted. Two authors will independently screen studies for inclusion based on predetermined inclusion and exclusion criteria. Data extraction and quality assessment will be conducted by two authors. Meta-analysis will be performed to calculate overall pooled estimates of ambulance time intervals (primary outcome) and stroke/TIA call volumes (secondary outcome), where appropriate. Where heterogeneity is low a fixed-effects

model will be used and where heterogeneity is high a random-effects model will be used. Subgroup and sensitivity analyses will include location, stroke/TIA diagnosis and COVID-19 case numbers.

Results

Data on primary and secondary outcomes will be provided. Results of subgroup/sensitivity analyses and quality assessment will also be presented.

Conclusions

This review will identify existing evidence reporting the impact of the COVID-19 pandemic on prehospital emergency care for adult patients with stroke/TIA. It will also provide summary estimates of effects on ambulance time intervals and emergency call volume.

3.2 Introduction

The COVID-19 pandemic was a "shock" to the healthcare system, globally[1]. COVID-19 was declared a pandemic by the Director-General of the WHO at the media briefing on 11 March 2020[2]. Consequently, it is reported that the pandemic affected non-COVID-19 healthcare in many countries[3,4]. Public health guidelines were introduced in an effort to manage the pandemic, including travel restrictions and stay at home orders[3,4]. These interventions may have impacted on healthcare seeking behaviour[3,4]. Furthermore, the healthcare workforce was directly impacted through sickness and periods of isolation/restriction of movements for cases and contacts[5].

Globally, delayed, and reduced admissions for non-COVID-19 related care have been linked to increased mortality and morbidity[6,7]. Reports from multiple countries indicated that calls to EMS services vastly increased over the course of the pandemic[8]. As a result, further pressure was put on prehospital emergency services[8].

The prehospital phase of healthcare is defined in a WHO report as the period before arrival at a hospital, clinic, and other fixed healthcare setting[9]. Prehospital care generally includes the provision of care by EMS providers such as emergency medical dispatchers, emergency medical responders, emergency medical technicians, and paramedics[10]. As ambulance time intervals are internationally recognised key performance indicators for prehospital emergency care they will be used as the primary outcome of interest in this review[11]. Ambulance time intervals are relevant

to prehospital stroke/transient ischaemic attack (TIA) care as the role of the EMS in this context involves prompt transport to secondary care specialists[12]. As treatment strategies for stroke/TIA are time-dependent, it is important to minimise time delays in the prehospital phase of care[12].

In 2019, stroke was the second leading cause of DALYs globally, in the 50–74 years and 75+ years age groups[13]. Up to one in three strokes are preceded by a TIA, with approximately 50% of these occurring within a year after the TIA[14]. Stroke and TIA can have similar presentations and are being included in this review as it is focusing on information provided to the call taker by the caller before clinical assessment has been performed. Also, within the timeframe in which prehospital care practitioners care for the patient it may not be possible to differentiate between symptoms of a stroke/TIA. Furthermore, some dispatch systems, such as the Advanced Medical Priority Dispatch System (AMPDS)[15], have the same code for suspected stroke and TIA.

Stroke is a medical emergency and requires immediate evaluation, confirmation of diagnosis and treatment in order to prevent brain damage[16]. The acute ischaemic stroke chain of recovery involves recognition (of symptoms), reaction (emergency services alerted), response (medical assessment), reveal (brain imaging), and Rx (prescription i.e. treatment initiation)[17]. Early diagnosis and treatment are also imperative for TIA, to reduce mortality and the risk of stroke[18]. Stroke and TIA could be considered as particularly vulnerable to pressures on healthcare delivery or

changes in care seeking behaviours by patients. Due to the time-sensitive nature of stroke/TIA intervention it is imperative that stroke/TIA survivors present to hospital as soon as possible after symptoms develop[16]. An increased volume of emergency calls may mean that not as many call takers or ambulances are available. Furthermore, patients may have been hesitant to call an ambulance during COVID-19 due to fear of contracting the virus[8]. Recent preliminary evidence suggests that stroke and cardiac arrest were the emergency cases most affected by the COVID-19 pandemic[8].

There has been a global decrease in the number of patients seeking medical care for stroke and TIA during the pandemic[19–21]. Thus, COVID-19 has potentially had a disruptive effect on the stroke chain of survival[7,22]. It has been reported that stroke admissions in Southern Europe have fallen by 25% over the pandemic period[21]. Furthermore, the number of EMS calls dispatched to stroke dropped, and a 30-minute delay in response times has been reported, in this region[21]. One narrative review stated that the suggested disruption in the emergency stroke care pathway due to the COVID-19 pandemic has resulted in a global surge of prehospital mortality[8].

Research in this area has previously focused on the nature and volume of EMS calls, prehospital stroke triage and acute stroke hospital-based care, during the COVID-19 pandemic[8,23–25]. However, it is still largely unknown what impacts on prehospital emergency care for stroke and TIA were seen and how they varied in

different countries, with different approaches to the management of the pandemic and different underlying healthcare systems. Thus, this systematic review and meta-analysis aims to summarise the existing international evidence on the impact of the COVID-19 pandemic on prehospital emergency care for adult patients with stroke/TIA and estimate the ambulance time intervals and emergency call volumes for stroke/TIA.

3.3 Protocol

3.3.1 Methods and design

This protocol was developed using the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocols Checklist (PRISMA-P)[26]. The proposed systematic review and meta-analysis will follow the Preferred Reporting Items for Systematic Reviews and Meta Analyses (PRISMA) guidelines[27]. This review is registered on PROSPERO (registration number CRD42022315260) ***(appendix 3.1)***.

3.3.2 Aim

To summarise the existing international evidence on the impact of the COVID-19 pandemic on prehospital emergency care for adult patients with stroke/TIA and estimate the ambulance time intervals and emergency call volumes for stroke/TIA.

3.3.3 Objectives

- To investigate if ambulance time intervals (activation time interval, response

time interval, patient care time interval) for adults with stroke/TIA differed before and during the COVID-19 pandemic.

- To investigate if the volume of EMS calls for stroke/TIA differed before and during the COVID-19 pandemic.

Participants

Adult patients (≥18 years of age) with stroke/TIA.

Exposure

Prehospital emergency care for stroke/TIA during the COVID-19 pandemic.

Comparison

Prehospital emergency care for stroke/TIA prior to the COVID-19 pandemic.

Outcome

Primary outcomes: activation time, response time, patient care time.

Secondary outcome: EMS call volume for stroke/TIA.

3.3.4 Ambulance time intervals

Ambulance time intervals include three main time periods in the time from receipt of the emergency call by the call center operator to the patient arriving at the hospital[28]. Activation time interval covers *"the period from receipt of the call to mobilisation of a fully crewed emergency ambulance"*[28]. Response time interval covers *"the period from receipt of the call to the arrival of the ambulance at the scene of the emergency"*[28]. Patient care time refers to *"the time from arrival of an ambulance crew at the scene to arrival at hospital"*[28]. In this review "patient care time" will include time spent on scene and the transport to hospital time[28]. The terminology used to describe these three key time periods can vary between

countries and publications[8,28]. Regardless of the term used, these three distinct periods of time are a key focus of this review. Thus, the search terms of the review relating to prehospital care have remained broad to encompass as many variations as possible. The time periods chosen are due to clinical significance and previous inclusion in ambulance time-related studies. Due to international variation in terminology and definitions, a standardised definition needed to be used. Members of the ambulance service are advising on this task.

3.3.5 Criteria for considering studies for the review

Inclusion criteria

Table 3.1 details full inclusion and exclusion criteria and justifications for each. This systematic review will include:

- Quantitative studies where prehospital care for adult stroke/TIA patients was compared before and during the COVID-19 pandemic.
- Stroke/TIA diagnosis does not have to be confirmed at hospital level. Due to the context of this study stroke/TIA can be suspected (based on symptoms given to call taker) or a working diagnosis after review by an EMS team. A study will not be excluded based on the definition of stroke/TIA diagnosis. However, if available in the study, whether the stroke/TIA was suspected or confirmed will be outlined in the review.
- Studies need to include data on ambulance time intervals or stroke/TIA emergency call volumes in order to be considered for inclusion. A study needs to include data on at least one of: activation time interval, ambulance response time interval or patient care time interval to be eligible for inclusion. Regardless

of the terminology used in a particular study, if data are available on any of these three time periods of interest the study is eligible for inclusion.

- Cases identified by the call taker as suspected stroke/ TIA will be included and if the data are available these calls will be put in context of calls made to the wider EMS system.
- Primary, peer – reviewed studies in any language.

Exclusion criteria

- Studies where all participants are children, or where data for adults cannot be extrapolated.
- Case reports, case series, letters, commentaries, notes, editorials, and conference abstracts, dissertations, reviews, opinion pieces.

Table 3.1 - Inclusion and exclusion criteria for study selection

Criterion	Inclusion	Exclusion	Justification
Language	All languages	N/A	Translation of articles will ensure the largest pool of potentially eligible articles
Focus	Quantitative studies on the impact of the COVID-19 pandemic on prehospital emergency care for adult patients with stroke/TIA	Qualitative articles Opinion pieces	Pooled estimates can be calculated
Types of articles	Peer reviewed journal articles	Editorials or other opinion pieces Reviews Unpublished (grey) literature including theses, dissertations, editorials, and book chapters Newspapers and websites Conference abstracts/proceedings	Primary peer reviewed literature will provide numeric information related to primary and secondary outcomes for possible inclusion in a meta-analysis
Geographic location	Any	N/A	COVID-19 is a global concern

3.3.6 Search strategy for identifying relevant studies

Bibliographic database searches

Initial search[29,30]: ProQuest and PubMed will be used to search for relevant articles. The librarian recommended these databases due to the context of the study, and the range of articles available on these databases. Words and phrases found in the title, abstract, and index of these papers will inform the final search strategy.

Second search: Using the identified search terms a formal search of Embase (Elsevier), ProQuest, PubMed, Scopus (Elsevier), Web of Science (Clarivate) and Wiley will be conducted. These searchers will be included in the final PRISMA flow chart[27].

Reference list search: Backward and forward citation searching will be conducted on all included studies. The Peer Review of Electronic Search Strategies (PRESS) will be used to evaluate the search strategy[31,32]. The number of studies identified in the reference list screening will be included in the PRISMA flow chart[27].

An expert university librarian was involved in the selection of initial search terms and databases for this protocol. The librarian also advised on refining and designing the final search strategy. They advised on the most appropriate Medical Subject Headings (MeSH) terms for the search strategy and offered input into adapting these terms for the selected databases. **Table 3.2** details a sample initial search strategy for the PubMed database. **Table 3.3** details the final search strategy for the PubMed

database.

Table 3.2 - Sample search terms for the PubMed database

Initial Keywords
stroke OR cerebrovascular accident OR transient ischaemic attack OR TIA
emergency medical service OR EMS OR ambulance OR emergency care OR paramedic OR 999 OR 911 OR 112 OR prehospital
COVID-19 OR SARS-CoV-2 OR covid 19 OR coronavirus

Table 3.3 - Final search strategy for the PubMed database

Stroke/TIA	(“cerebrovascular accident*” [Title/Abstract] OR “cerebrovascular disease*” [Title/Abstract] OR “transient ischaemic attack*” [Title/Abstract] OR “transient ischemic attack*” [Title/Abstract] OR “TIA” [Title/Abstract] OR “cerebrovascular event*” [Title/Abstract]) OR (stroke*[MeSH Terms])
Prehospital	(“pre hospital”[Title/Abstract] OR prehospital[Title/Abstract] OR “pre-hospital”[Title/Abstract] OR EMS[Title/Abstract] OR ambulance*[Title/Abstract] OR “emergency care”[Title/Abstract] OR paramedic*[Title/Abstract] OR 999[Title/Abstract] OR 112[Title/Abstract] OR 911[Title/Abstract] OR “emergency department*”[Title/Abstract] OR “out-of-hospital”[Title/ Abstract] OR emergenc*[Title/Abstract] OR “hospital referral*”[Title/Abstract] OR “emergency admission*”[Title/Abstract] OR “time-to-treatment”[Title/Abstract] OR “acute stroke care”[Title/Abstract] OR “acute stroke therapy”[Title/Abstract]) OR (emergency medical services[MeSH Terms])
COVID-19	(“COVID-19” [Title/Abstract] OR covid [Title/Abstract] OR coronavirus*[Title/Abstract] OR “novel coronavirus*” [Title/ Abstract] OR lockdown*[Title/Abstract] OR pandemic*[Title/Abstract]) OR (SARS-CoV-2[MeSH Terms])
Combined search	(((“COVID-19” [Title/Abstract] OR covid [Title/Abstract] OR coronavirus*[Title/Abstract] OR “novel coronavirus*” [Title/ Abstract] OR lockdown*[Title/Abstract] OR pandemic*[Title/Abstract]) OR (SARS-CoV-2[MeSH Terms])) **AND** ((“cerebrovascular accident*” [Title/Abstract] OR “cerebrovascular disease*” [Title/Abstract] OR “transient ischaemic attack*” [Title/Abstract] OR “transient ischemic attack*” [Title/Abstract] OR “TIA” [Title/Abstract] OR “cerebrovascular event*” [Title/Abstract]) OR (stroke*[MeSH Terms]))) **AND** ((“pre hospital”[Title/Abstract] OR prehospital[Title/Abstract] OR “pre-hospital”[Title/Abstract] OR EMS[Title/Abstract] OR ambulance*[Title/Abstract] OR “emergency care”[Title/Abstract] OR paramedic*[Title/Abstract] OR 999[Title/Abstract] OR 112[Title/Abstract] OR 911[Title/Abstract] OR “emergency department*”[Title/Abstract] OR “out-of-hospital”[Title/ Abstract] OR emergenc*[Title/Abstract] OR “hospital referral*”[Title/Abstract] OR “emergency admission*”[Title/Abstract] OR “time-to-treatment”[Title/Abstract] OR “acute stroke care”[Title/Abstract] OR “acute stroke therapy”[Title/Abstract]) OR (emergency medical services[MeSH Terms]))

3.3.7 Selection of studies for inclusion in the review

Identified citations will be collated and uploaded into Endnote™ 20 (Clarivate Analytics, PA, USA) and duplicates removed. Titles and abstracts of published literature will be imported into Covidence (https://www.covidence.org/), and screened using the software, by two independent reviewers (EB and JA) for assessment against the inclusion/exclusion criteria for this review. Potentially relevant sources will be retrieved in full, and their citation details imported into Covidence. The full text of selected citations will be assessed in detail against the inclusion criteria by EB and JA.

Reasons for exclusion of sources of evidence at full text that do not meet the inclusion criteria will be recorded and reported in the systematic review. Any disagreements that arise between the reviewers at each stage of the selection process will be resolved through discussion between EB and JA. If necessary, any disagreement will then be referred to a third reviewer; VMc and resolved by consensus.

The results of the search and the study inclusion process will be reported in full in the final systematic review and presented in a PRISMA flow diagram[27].

3.3.8 Data extraction and management

A standardised data extraction form has been composed using Microsoft Word (version 2102), which fulfils the eligibility criteria **(Table 3.1)**. This template has been

compiled based on the aim and objectives of the review and what data will be required to effectively report the results of this review.

EB will extract the data from the included papers. JA will check a random sample of 20% of these studies for accuracy of data extraction. Finalising the data extraction form may be an iterative process, and modification or revision may occur after piloting. Any disagreements will be resolved upon discussion with VMc. This process ensures transparency and clarity in the process of data extraction. The categories below will be included in the first version of the form, which can be found in **table 3.4**. Any modifications to the existing data extraction form will be reported in the systematic review.

Table 3.4 - Categories included in the data extraction form for this systematic review and meta-analysis

Author(s), month, year of publication, country
Aims/purpose
Study design
Country/region
Income level of country
Emergency dispatch system
Sample size in studies, sex, age
Activation time interval before and during the pandemic
Response time interval before and during the pandemic
Patient care time intervals before and during pandemic
Call volumes before and during the pandemic
Time period (pre and during COVID-19 pandemic)
Method of stroke/TIA diagnosis
COVID-19 cases numbers/ICU numbers/hospitalisations

3.3.9 Appraisal of the quality of included studies

The appropriate Joanna Briggs Institute (JBI) Critical Appraisal tool[33] will be used to appraise the quality of each included study. The JBI tools will be used as it is anticipated that eligible studies will be cohort studies, cross-sectional or quasi-experimental studies. JBI offers a critical appraisal tool for each of these designs. The JBI checklist offers a series of questions to which “Yes”, “No”, “Unclear” and “Not

applicable" are the provided answers. These checklists will be used to assess the risk of bias in individual studies. The overall quality of cumulative evidence will be assessed using the Grading of Recommendations Assessment, Development and Evaluation guidelines (GRADE)[34].Two reviewers (EB and JA) will independently assess study quality. If necessary, discrepancies will be resolved by VMc.

3.3.10 Presenting and reporting the results

A PRISMA flow diagram[27] will be included in the review to illustrate the study selection process and will also provide a rationale for excluding studies. Tables displaying study characteristics and quality assessment will be included. Forest plots will be used to present pooled estimates. If a study is eligible for inclusion in the review but does not include sufficient data for inclusion in a meta-analysis the corresponding study authors will be contacted for access to raw data, in the first instance. If raw data cannot be obtained, the findings of the relevant studies will be included in a separate table or narratively presented.

Meta-analyses will be conducted, where the data allows, to calculate pooled estimates of the difference between ambulance time intervals. These intervals include the time of call to ambulance being dispatched (activation time interval), time from ambulance being dispatched to arrival at the incident location (response time interval), and time spent on scene and from the incident location to the hospital (patient care time interval). Additionally, call volumes for stroke/TIA before and during the COVID-19 pandemic will be analysed.

Where heterogeneity is low (I2 value of less than 50%) a fixed-effects model will be used and where heterogeneity is high (I2 value of 50% or more) a random-effects model will be used, according to the Cochrane Handbook criteria[35].

The following subgroup/sensitivity analyses will be performed using RevMan 5.4, where the data allows:

1. According to location. (Classification will be determined once articles are selected).
2. According to income level of country. (Determined by World Bank Classification[36]).
3. According to study quality. (Determined by appropriate JBI critical appraisal tool[33]).
4. According to COVID-19 case numbers/hospitalisations in the country/area at the time of the study. (John Hopkins Coronavirus Resource Centre and Oxford Martin School data will be used[37,38]).
5. According to the number of weeks since the WHO categorised COVID-19 as a pandemic. (This was stated by the Director-General of the WHO at the media briefing on 11 March 2020[2]).
6. According to stroke/TIA diagnosis (suspected stroke/ TIA, working diagnosis after review by EMS, or hospital confirmed diagnosis).

A funnel plot will be used to assess publication bias if ten or more studies are included in the meta-analysis. Any asymmetry of the funnel plot arising from publication bias will be addressed using the trim and fill method[39].

If any further subgroup/sensitivity analyses need to be carried out during the meta-analysis process, these will be identified as post hoc analyses.

3.3.11 Consultation with stakeholders

Clinical stakeholders

A Consultant Neurologist (AM) aided in the development of the research question for this review. AM will be asked about resources on the review topic that might not be identified through the searching of databases, and references. The Consultant Neurologist will help with dissemination of review results and offer suggestions on how best to disseminate the results of the review to the medical community. Members of the Republic of Ireland National Ambulance Service Clinical Directorate advised on terminology and clinical significance of time periods, in this protocol. They will also be involved throughout the systematic review and will offer suggestions on how to best disseminate the results of the review to the prehospital emergency care community.

Patient and Public Involvement (PPI)

PPI is described in this protocol and will be described in the systematic review using the GRIPP 2 checklist (short version)[40].

A PPI panel of 5 stroke survivors (2 female, 3 male) from a stroke support group were involved in the development of this protocol and subsequent review from an early stage. The PPI panel were consulted on this protocol by means of two face- to-face

meetings. PPI contributors were involved in this protocol to advise on development of the research question, which stakeholders to target for involvement in the review, possible search terms, terminology surrounding stroke/TIA survivors and their research priorities.

The PPI contributors emphasised that they believe that the period from onset of symptoms to arrival at hospital was the most important part of the care pathway. They were asked to advise on preferred terminology around the term “stroke survivor” or “stroke patient” and any colloquial terms used for stroke/TIA. Also, they were asked what they felt would be important to know about the impact of the COVID-19 pandemic on prehospital emergency care for those with a stroke/TIA during the COVID-19 pandemic.

As a result, the research question focuses on prehospital emergency care for those with stroke/TIA. PPI had a very positive effect on this protocol[41]. The PPI contributors used their lived experience to highlight key issues of importance and aspects of stroke/TIA care they felt could have been affected by the COVID-19 pandemic. The PPI panel prefer the term “stroke/TIA survivor” to refer to those who had a stroke/TIA. Thus, where possible this terminology will be used in outreach and dissemination of the review results, especially those targeted towards general audiences.

This group of PPI contributors will also be involved in interpreting the results of this review to identify gaps and aid in the dissemination of the results.

3.4 Conclusion

This systematic review and meta-analysis will summarise existing evidence investigating the impact of the COVID-19 pandemic on prehospital emergency care for those with stroke/TIA. This work may also influence policy guidelines and future research on prehospital management of non-communicable diseases during a pandemic, and prehospital care more broadly. The results may also inform our understanding of healthcare system resilience in response to crises on a broader level. The findings of this review will be disseminated through peer and public presentations, conferences, a policy brief for relevant clinical programmes (stroke and emergency medicine) and a peer-reviewed journal article.

Chapter 3b: Effects of the COVID-19 pandemic on prehospital emergency care for adults with stroke and transient ischaemic attack: A systematic review and meta-analysis

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Burton E, Aladkhen J, O'Donnell C, Masterson S, Merwick Á, McCarthy VJC, et al. Effects of the COVID-19 Pandemic on Prehospital Emergency Care for Adults with Stroke and Transient Ischaemic Attack: A Systematic Review and Meta-Analysis. Prehospital Emergency Care. 2024;28(6):803-22.

Full article: Effects of the COVID-19 Pandemic on Prehospital Emergency Care for Adults with Stroke and Transient Ischaemic Attack: A Systematic Review and Meta-Analysis (tandfonline.com)

3.5 Abstract

Introduction

COVID-19 has challenged global healthcare systems and resulted in prehospital delays for time-sensitive emergencies, like stroke and TIAs. However, there are conflicting international reports on the level of effect of the pandemic on ambulance time intervals and emergency call volumes for these conditions.

Objectives

The purpose of this study was to synthesise the international evidence on the effect of COVID-19 on ambulance time intervals and emergency call volume for suspected stroke and TIA.

Methods

Following a published protocol, we conducted a systematic search of six databases through 31st May 2022. We re-ran this search on 26th April 2023, to check for any new papers. We considered for inclusion peer-reviewed quantitative studies comparing prehospital emergency care for adults with suspected stroke/TIA before and during the COVID-19 pandemic. Two authors screened titles/abstracts and full text articles. One author carried out data extraction, with a random selection of articles being checked by another author. We calculated overall pooled estimates of ambulance time intervals (activation, response, patient care, and total prehospital intervals) and stroke/TIA emergency call volume. Subgroup and sensitivity analyses included location and stroke/TIA diagnosis. Two authors assessed study quality using the appropriate Joanna Briggs Institute tool. We worked with Patient and Public Involvement contributors and clinical and policy stakeholders throughout the review.

Results

Of 4,083 studies identified, 52 unique articles met the inclusion criteria. Mean response interval (-1.29 min [-2.19 to -0.38]) and mean total prehospital interval (-6.42 min [-10.60 to -2.25]) were shorter in the pre-COVID-19 period, compared to the COVID-19 period. Furthermore, there was a higher incidence rate of emergency call volume for suspected stroke/TIA per day pre-COVID-19 compared with the COVID-19 period (log IRR = 0.17 (0.02 to 0.33)). Ambulance time interval definitions and terminology varied between regions and countries.

Conclusions

Our review indicates that prehospital delays for suspected stroke/TIA increased during the COVID-19 pandemic. Furthermore, emergency call volume for suspected stroke/TIA decreased during this period. In order to minimise delays in future pandemics or other healthcare emergencies future research may involve understanding the potential reasons for these delays.

3.6 Introduction

The COVID-19 pandemic challenged global healthcare systems and altered healthcare utilisation patterns[42,43]. COVID-19 public health measures such as personal protective equipment (PPE) and cleaning protocols contributed to workflow delays, particularly for time-dependent emergencies such as stroke/TIA[44-46]. Also, in some instances, EMS practitioners were redeployed to non-traditional roles such as COVID-19 testing and vaccination during the pandemic[47].

The WHO defines prehospital emergency care as *"the period before arrival at a hospital, clinic, and other fixed healthcare setting"*[9]. However, terminology surrounding prehospital/emergency care differs in different healthcare systems and regions.

Stroke an TIAs require immediate diagnosis and treatment[48]. Prompt recognition of symptoms and contact with EMS is a crucial component of emergency stroke/TIA care[49]. Minimising time to treatment and prehospital delays reduces stroke-related morbidity and mortality[49]. However, the WHO and many international reports have acknowledged the wide-ranging effects of the pandemic on stroke/TIA services and a marked decline in acute stroke presentations[50,51]. Furthermore, many studies report a decline in the presentation of patients with milder stroke symptoms and TIAs during the COVID-19 pandemic[19,52-56]. Patient reluctance to seek medical attention may be due to fear of contagion and strict public health measures[51].

Conflicting reports on the change in healthcare utilisation patterns for stroke/TIA exist globally[57]. Some studies suggest a decrease in stroke presentations, and delayed health care interaction, whereas others found an increase in stroke cases during the pandemic[44]. Thus, the aim of this review was to summarise the existing international evidence on the effects of the COVID-19 pandemic on prehospital emergency care for adult patients with suspected stroke/TIA and estimate the ambulance time intervals and emergency call volumes for stroke/TIA.

3.7 Methods

We used the PRISMA guidelines[27] and registered the review on PROSPERO (registration number CRD42022315260). We published the review protocol on HRB Open[58].

3.7.1 Objectives

- To investigate if ambulance time intervals from call commenced to arrival at hospital differed before and during the COVID-19 pandemic for adults with suspected stroke/TIA.

- To investigate if the volume of EMS calls for adults with suspected stroke/TIA differed before and during the COVID-19 pandemic.

Participants

Patients ≥18 years of age with suspected stroke/TIA.

Exposure

Prehospital emergency care for stroke/TIA during the COVID-19 pandemic.

Comparison

Prehospital emergency care for stroke/TIA prior to the COVID-19 pandemic.

Outcome

Primary outcomes: activation, response, patient care, total prehospital intervals[59].

Secondary outcome: EMS call volume for suspected stroke/TIA.

3.7.2 Ambulance Time Intervals

Activation interval[28] covers *"the period from receipt of the call to mobilisation of a fully crewed emergency ambulance*". Response interval[28] covers "*the period from receipt of the call to the arrival of the ambulance at the scene of the emergency*". Patient care interval[28] refers to *"the interval from arrival of an ambulance crew at the scene to arrival at hospital"*. In terms of the Spaite et al.[59] definitions, this would be the sum of the "on scene" and "transport interval." We also included studies that included the sum of the three-time periods, total prehospital interval.

The intervals chosen are due to clinical significance and previous inclusion in ambulance time/interval studies[28]. Due to international variation in terminology and definitions, a standardised definition needed to be used. The broader definition of patient care interval improves the inclusivity of the review. Studies that include the interval spent on scene, the interval from scene to hospital, and the entire period from arrival on scene to arrival at hospital can be included, based on this definition.

3.7.3 COVID-19 Pandemic

The WHO declared COVID-19 a pandemic on March 11, 2020[2]. However, different definitions of COVID-19 periods/waves exist internationally. Thus, we included studies that compared any time period before and during COVID-19.

3.7.4 Criteria for considering studies for the review

We developed inclusion/exclusion criteria using existing literature and expert stakeholder involvement. Expert stakeholders included authors AM, COD, and SM and members of the Prehospital Care of Stroke (PHoCoS) Consortium. This is a consortium of international prehospital care practitioners and researchers. EB is the founder of this consortium, and all authors are members of this group. **Table 3.5** contains the full list of inclusion/exclusion criteria for this review.

Table 3.5 - Inclusion and exclusion criteria for study selection

Criterion	Inclusion	Exclusion	Justification
Language	All languages	N/A	Translation of articles will ensure the largest pool of potentially eligible articles
Focus	Quantitative studies on the impact of the COVID-19 pandemic on prehospital emergency care for adult patients with suspected stroke/TIA	Qualitative articles Opinion pieces	Pooled estimates can be calculated
Types of articles	Peer reviewed journal articles	Editorials or other opinion pieces Reviews Unpublished (grey) literature including theses, dissertations, editorials, and book chapters Newspapers and websites Conference abstracts/proceedings	Primary peer reviewed literature will provide numeric information related to primary and secondary outcomes for possible inclusion in meta-analyses
Geographic location	Any	N/A	COVID-19 is a global concern

Expert stakeholders recommended that if studies did not mention patient age, we include these, unless the setting was solely pediatric. Paediatric cases were excluded due to age-related differences in risk factors, etiopathogenesis, and clinical presentations for pediatric stroke[60]. If age was mentioned, we extracted data for those 18 years and above, if possible. Proxies for call volume, such as prehospital stroke code/alert activation, and arrival by ambulance, were included on the recommendation of expert stakeholders.

3.7.5 Search strategy for identifying relevant studies

An expert university librarian advised on the search strategy and database selection. COD, SM, and AM also inputted into potential search terms. We conducted an initial search in ProQuest and PubMed[29,30,61,62]. As per the PRESS process[31,32,63,64], a second subject area librarian reviewed the search strategy ***(Appendix 3.2)***. We performed a systematic search in Embase (Elsevier), ProQuest, PubMed, Scopus (Elsevier), Web of Science (Clarivate), and Wiley on 31st May 2022, and re-ran the search on 26th April 2023. ***Appendix 3.3*** contains the complete search strategy. We translated non-English articles using DeepL Translator https://www.deepl.com/en/translator. Authors EB and JA performed backward and forward citation searching using Web of Science (Clarivate) and Scopus (Elsevier).

3.7.6 Selection of studies for inclusion in the review

We uploaded identified citations into EndnoteTM 20 and removed duplicates. Authors EB and JA carried out title/abstract and full-text screening using Covidence

(https://www.covidence.org/). Authors were contacted for full-text articles where only abstracts were available or if further information was required. The Covidence software displayed any conflicts that arose during the independent title/abstract screening process. EB and JA then met to discuss these conflicts. Minor conflicts arose, primarily on the definition of call volume and studies that included both hospital and prehospital care. These were resolved through discussion and no other author was required to reach consensus.

A similar process was carried out for full-text screening. Conflicts here arose due to uncertainty around whether call volume referred to only suspected stroke/TIA in some articles. This was resolved by consulting prehospital care experts (SM and COD). Once EB and JA agreed on the final number of articles for inclusion, 56 articles were transferred to two further reviewers. SM has expertise in prehospital care and AM has expertise in clinical neurology. SM and AM reviewed all included articles, using a consistent template ***(Appendix 3.4)***. The purpose of this step was to ensure that selected articles met the clinical criteria for inclusion. Due to the heterogeneity of language surrounding call volumes, SM offered guidance on the appropriateness of inclusion of some articles. Due to the above reasons, after the screening by SM and AM two articles were excluded.

3.7.7 Data extraction and management

EB used a standardised data extraction form in Microsoft Word (version 2102) to extract the data ***(Appendix 3.5)***. The version of the form in the protocol was iteratively amended[58]. We added stroke and/or TIA, definition of emergency call and

total prehospital interval to the form. We did not collect data on the dispatch systems of studied ambulance services, as these were not reported in included articles and insufficient service details were included to extrapolate this information. JA checked a sample of the extracted data.

3.7.8 Appraisal of the quality of included studies

EB and JA independently assessed study quality using the appropriate Joanna Briggs Institute (JBI) checklist[33,65]. We chose the JBI checklists[33,65] as there are checklists for cohort, cross-sectional, and quasi-experimental studies. The JBI checklists[33,65] include questions on design, conduct, and analysis, with "Yes," "No," "Unclear," and "N/A" as possible answers. JA and EB followed the JBI critical appraisal guidelines closely to ensure consistency. For cohort studies, question six was answered with "N/A" in all cases, as the outcome is present in both the COVID-19 and pre-COVID-19 periods[66,67]. Furthermore, we used the GRADE tool to appraise the combined quality of the cumulative evidence[34].

3.7.9 Presenting and reporting the results

Studies that separated patient care interval into "on-scene" interval and "scene to hospital" interval and one study reporting confidence intervals only were reported narratively.

Where studies reported median and inter-quartile range (IQR) we approximated to respective mean and standard deviation using the method explained in Wan et al[68]. Thus, we assumed the data had a normal distribution. We summarised the pooled

effect measure using the mean difference and its 95% confidence interval (CI) along with the test for its significance. The meta-analysis of call volumes was based on a log transformed incidence rate ratio (IRR) effect measure. This compared the incidence per day in the pre-COVID-19 period to the COVID-19 period. For both outcomes the pre-COVID-19 period was compared to the COVID-19 period. Thus, if the mean difference has a negative value between the pre-COVID-19 and COVID-19 periods it means that intervals were shorter during the pre-COVID-19 period and longer during the COVID-19 period.

We used the Q statistic to test for study heterogeneity[69,70]. We used the random effects model for the estimation of pooled effect and test for its significance[71]. We used the nonparametric Begg's test[72] to explore publication bias. P-values were two-tailed at a 0.05 level of significance (p-values less than 0.05 are considered statistically significant). We used Stata V17.0 to perform the meta-analyses.

We carried out subgroup analyses based on country, study quality, COVID-19 cases/deaths/intensive care unit (ICU)/hospital numbers[37,38], and income level[36] as per protocol. All COVID-19 related parameters were not represented for each interval meta-analysis. This is due to the differing numbers of studies being included in the meta-analysis for each interval, representing different countries. Thus, if the majority of countries did not have information on one of the aforementioned parameters, or only studies set in the same country were included, this parameter was not included in the subgroup analysis for that interval. Furthermore, for each

interval meta-analysis, included studies were divided into categories based on the levels of COVID-19 cases/deaths/ICU/hospital numbers. These cutoffs differed between interval meta-analyses due to differing numbers in each represented country.

We performed sensitivity analyses based on week numbers since 11th March 2020, when the WHO declared COVID-19 a pandemic[2], definition of stroke/TIA diagnosis, ambulance time intervals and call volume definitions. The latter two factors were recommended during the review process by expert stakeholders. The results of the meta-analyses on the included studies are presented using forest and funnel plots.

3.7.10 Patient and Public Involvement (PPI)

We worked with a PPI panel of five stroke survivors (two female, three male) from a stroke support group to refine the research question, develop the protocol[58], and disseminate review results. EB facilitated three face-to-face meetings with the PPI panel. First, the panel members were consulted on their language preferences surrounding people who have had strokes/TIAs. Then the PPI contributors were asked to suggest synonyms for “stroke” and “TIA.” These were then included in the search strategy. The group members were also asked to identify key outcomes that were important to them in the prehospital phase of their stroke journeys. The group members were also involved in the interpretation of findings as EB presented the group with key findings to discuss and identify potential gaps. Finally, the panel was tasked with identifying key stakeholder groups to target for dissemination. We

describe PPI in this review in detail using the GRIPP 2 checklist (short version - ***appendix 3.6***)[40].

3.8 Results

3.8.1 Study Selection

A total of 4,083 studies were identified from database searches **(Figure 3.1)**. After de-duplication, 2,770 records were screened for title and abstract and 2,467 records were excluded. The full text of 290 records were assessed. Thirteen full-text articles could not be retrieved. Forty-two papers were found to be eligible for inclusion. Backward and forward citation searching resulted in a further 10 eligible papers. A total of 52 articles were included, which equated to 50 studies.

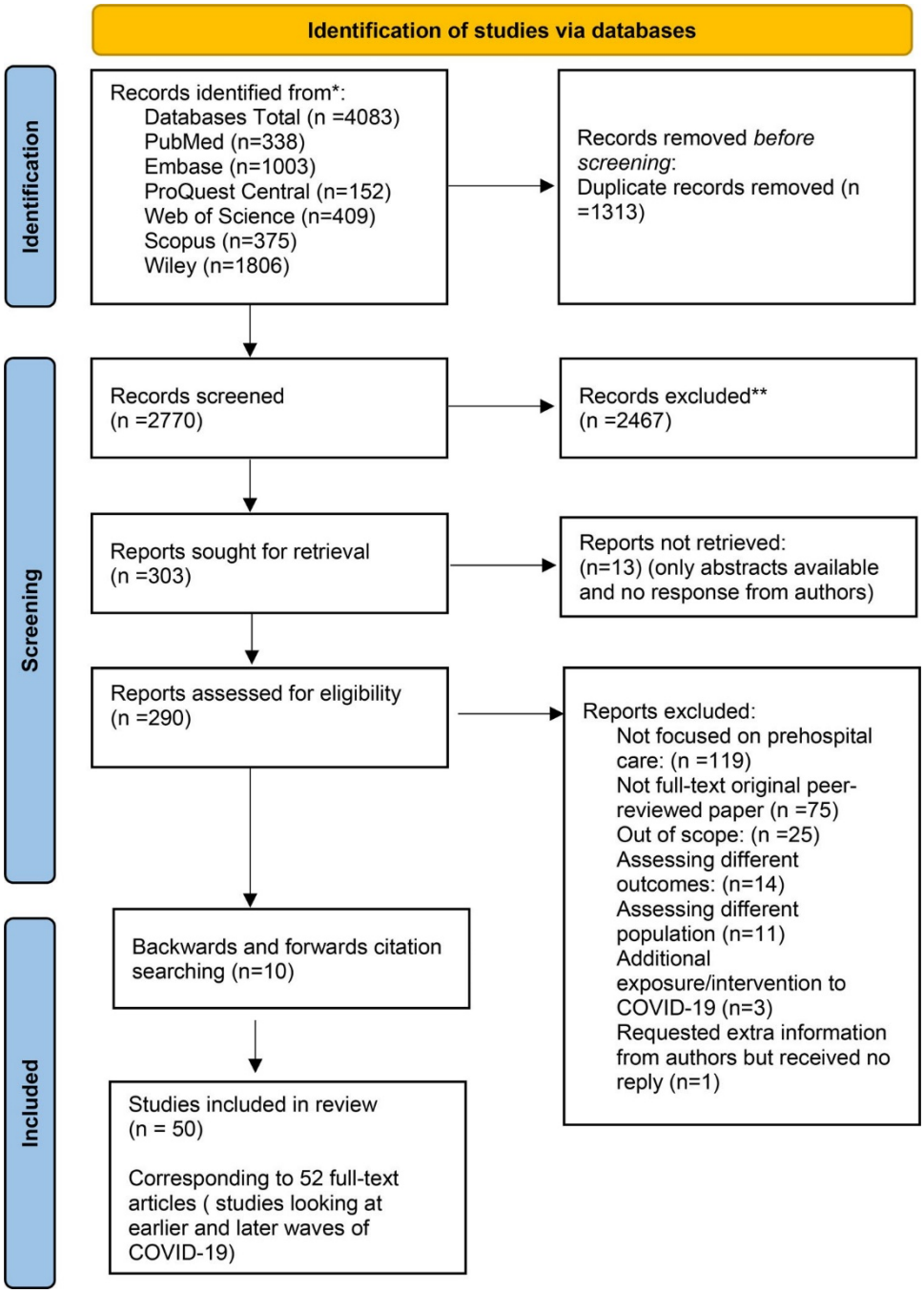

Figure 3.1 - PRISMA flow diagram for this systematic review and meta-analysis

3.8.2 Study Characteristics

Our review includes studies from multiple countries. The USA (n = 12) and Spain (n = 8) were the most common study settings. Of the 52 articles, 14 focused on prehospital care alone, with the remainder including prehospital and hospital settings. Most papers described registry/database studies (n = 25), fifteen were multisite, and twelve were single-site studies. **Table 3.6** summarises characteristics of the included studies.

Table 3.6 - Characteristics of included studies

Study	Publication Date	Aim	Setting	Design	Country
Cadilhac et al.[73]	February 2021	To describe the impact of the COVID-19 pandemic on stroke services from the perspective of hospitals participating in the Australian Stroke Clinical Registry (AuSCR) up until the end of June 2020.	Prehospital and Hospital	Multicenter analysis of stroke registry and survey (mixed-methods study) *	Australia
Gardiner et al.[74]	December 2020	To compare the pre - lockdown and post-lockdown aeromedical retrieval patient characteristics during a period of Coronavirus 2019 (COVID-19) social isolation.	Prehospital	Retrospective observational study*	Australia
Ferron et al.[75]	March 2021	To examine the impact of the ongoing COVID-19 pandemic EMS call volumes, determinants (types of calls) and patient acuity at scene of arrival.	Prehospital	Cross-sectional*	Canada
Grunau et al.[76]	January 2021	To examine all-cause emergency health services utilization in British Columbia (BC), Canada, a jurisdiction with a low COVID-19 incidence, to see if encounter patterns also decreased.	Prehospital	Observational study*	Canada
Yu et al.[54]	October 2021	To assess the changes in emergency department, visit volume, care processes, and outcomes for stroke and myocardial infarction from before compared with after the declaration of the pandemic and through the various phases of restrictions, in the population of Ontario, Canada.	Prehospital and Hospital	Cohort study*	Canada
Tan et al[77]	September 2021	To evaluate our institution's experience as a designated COVID-19 hospital with acute stroke patients during the early months of the COVID-19 pandemic.	Prehospital and Hospital	Single center retrospective observational study	China
Wu et al.[78]	November 2020	To investigate the impact of the COVID-19 outbreak on stroke emergency care in Beijing (capital of China) during the pandemic.	Prehospital and Hospital	Multicenter retrospective database analysis*	China

Study	Publication Date	Aim	Setting	Design	Country
Charlton et al.[79]	April 2021	To explore the incidence of ambulance activation for a range of the most common emergency conditions occurring across Northeast England, as well as the number of out-of-hospital cardiac arrest deaths.	Prehospital	Cross-sectional*	England
Laukkanen et al.[80]	April 2021	To examine if there was a change in the number and characteristics of EMS missions and patients in early phase of the COVID-19 pandemic compared with previous years.	Prehospital	Retrospective observational study*	Finland
Gil-Jardiné et al.[81]	March 2021	To assess whether the automatic classification of the content of calls to the emergency medical communication centers could provide relevant and responsive indicators.	Prehospital	*Retrospective retrieval of call records***	France
Pop et al.[82]	September 2020	To perform a detailed analysis of variations in the acute stroke pathway activity for the Alsace region, during the first month of the outbreak, using the same time period from 2019 as a comparator.	Prehospital and Hospital	Multicenter retrospective review	France
Ikenberg et al.[83]	November 2020	To analyze numbers and patterns of Code Stroke patients dispatched by EMS during the COVID-19 pandemic at a German Comprehensive Stroke Centre, which is located at one of the pandemic hotspots in Germany.	Prehospital and Hospital	Single center retrospective analysis	Germany
Teo et al.[56]	July 2020	To determine whether COVID-19 has resulted in delays in stroke presentations and affected the delivery of acute stroke services in a comprehensive stroke center in Hong Kong.	Prehospital and Hospital	Single center retrospective review of stroke registry*	Hong Kong
Libruder et al.[84]	July 2021	To investigate the effect of the COVID-19 outbreak on admission rates and in-hospital care for acute stroke and TIA in Israel, shortly after the start of the pandemic.	Prehospital and Hospital	Multicentre retrospective observational study	Israel
Naccarato et al.[85]	May 2020	To evaluate the effects of the COVID-19 pandemics on stroke management during the first month of Italy's lockdown.	Prehospital and Hospital	Single center retrospective study	Italy
Padroni et al.[86]	June 2022	To analyse the impact of SARS-CoV-2 on stroke care in the province of Ferrara, north-eastern Italy, over the course of the pandemic, from March 2020 to April 2021.	Prehospital and Hospital	Single center retrospective analysis	Italy
Paolucci et al.[87]	January 2022	To compare stroke network performances on endovascular thrombectomy during the pandemic period with a mothership model with those of the drip-and-ship model.	Prehospital and Hospital	Multi-site retrospective cohort study***	Italy

Study	Publication Date	Aim	Setting	Design	Country
Zini et al.[88]	October 2020	To analyse stroke code admissions, hospitalizations, and stroke belt performance for ischaemic stroke patients in the metropolitan Bologna region, comparing temporal trends between 2019 and 2022 to define the impact of COVID-19 on the stroke network.	Prehospital and Hospital	Single center retrospective observational study	Italy
Tanaka et al.[89]	October 2021	To investigate the changes in the clinical characteristics including onset to door time in patients with TIA/mild stroke before and during the COVID-19 pandemic using data from three hospitals in the Fukuoka Prefecture, Japan.	Prehospital and Hospital	Multicenter retrospective study	Japan
Tani et al.[90]	December 2021	To determine the impact of the coronavirus disease 2019 pandemic on emergency hospitalisations of patients with stroke in Japan.	Prehospital and Hospital	Multicenter observational study*	Japan
Melaika et al.[91]	February 2021	To assess the impact of the COVID-19 lockdown on prehospital stroke care and referral patterns.	Prehospital and Hospital	Single center prospective observational study	Lithuania
Blek et al.[55]	April 2022	To assess the impact of the COVID-19 epidemic across the Masovian Voivodeship on suspected stroke patients' characteristics, prehospital vital parameters, clinical and neurological status, emergency procedures performed in the prehospital phase and EMS processing times.	Prehospital	Retrospective cohort study*	Poland
Kucap et al.[92]	August 2020	To analyse interventions of emergency medical teams during the SARS-CoV-2 pandemic, and to compare obtained data with the same periods in 2018-2019.	Prehospital	Retrospective analysis*	Poland
Nadolny et al.[93]	October 2020	To assess the number of ambulance calls, type of emergency that led to the call, and final International Classification of Disease, Tenth Revision, Clinical Modification (ICD-10) diagnoses established by the leader of an emergency medical team – EMT.	Prehospital	Retrospective analysis*	Poland
Rodrigues et al.[94]	August 2021	To evaluate COVID-19's effect on the number of stroke code activations and timings during the first two months of the pandemic.	Prehospital and Hospital	Single center retrospective observational analytical study	Portugal
Kim et al.[95]	December 2021	To identify the impact of COVID-19 on EMS processing times and transfers to the emergency department among patients with acute stroke symptoms before and during the COVID-19 pandemic in Busan, South Korea.	Prehospital	Retrospective observational study*	South Korea

Study	Publication Date	Aim	Setting	Design	Country
Lee et al.[96]	March 2021	To analyse the prognosis and time spent at the prehospital and hospital stages in management of patients with acute ischaemic stroke during the COVID-19 outbreak.	Prehospital and Hospital	Multicentre retrospective study	South Korea
Park et al.[97]	February 2022	To evaluate whether emergency medical centers for critical care during COVID-19 were effective in reducing ambulance diversions and shortening prehospital times for patients.	Prehospital	*Retrospective observational study***	South Korea
Seo et al.[98]	February 2022	To identify the impact of the sudden outbreak of coronavirus disease 2019) on EMS response for patients with acute stroke.	Prehospital and Hospital	Cross-sectional* (25 safety centers)	South Korea
Montaner et al.[99]	August 2020	To investigate whether the COVID-19 pandemic affects acute stroke care through interruptions in the stroke chain of survival.	Prehospital and Hospital	Multicentre descriptive analysis	Spain
Ramírez-Moreno et al.[100]	January 2021	To compare the healthcare activity of two stroke units in the same periods of 2019 and 2020, with an emphasis on what happened during the state of alarm.	Prehospital and Hospital	Multicentre retrospective comparison	Spain
Ramos-Pachón et al.[101]	May 2021	To investigate the impact of the COVID-19 pandemic on acute stroke care quality and clinical outcomes to detect healthcare system's bottlenecks from a territorial point of view.	Prehospital and Hospital	Multi-Centre crossed- data nation-based cohort analysis*	Spain
Riera- López et al.[53]	October 2021	To examine the impact of the COVID-19 in stroke codes in our EMS among 3 periods of time: the COVID-19 period, the same period the year before, and the 2019-2020 seasonal influenzas period.	Prehospital	Retrospective observational cohort study*	Spain

Study	Publication Date	Aim	Setting	Design	Country
Rudilisso et al.[102]	July 2020	To analyse the impact of the COVID-19 outbreak on the chain of acute stroke care in a Comprehensive Stroke Centre.	Prehospital and Hospital	Single center study comparing March 2019 and March 2020**	Spain
Tejada Meza et al.[103]	September 2020	To analyse the impact of the COVID-19 epidemic outbreak on hospital stroke admissions and their characteristics in our region.	Prehospital and Hospital	Multicentre observational study	Spain
Tejada Meza et al.[104]	December 2020	To analyse the impact of the COVID-19 epidemic outbreak on reperfusion therapies for acute ischaemic stroke in the northwest of Spain.	Prehospital and Hospital	Multicentre Retrospective observational study	Spain
Tejada Meza et al.[105]	June 2021	To analyse the effect of the COVID-19 pandemic on the 3-month functional outcomes of patients hospitalised due to acute ischaemic stroke in Aragon (Spain).	Prehospital and Hospital	Multicentre regional analysis	Spain
De Marchis et al.[106]	March 2022	To investigate changes in weekly admissions, clinical patient characteristics, delivery of acute therapy and functional 3-month outcome amongst patients with acute cerebrovascular events during the lockdown period compared to rates from 2018 and 2019 based on the prospective Swiss Stroke Registry.	Prehospital and Hospital	Multicentre-center retrospective analysis*	Switzerland
San et al.[107]	May 2021	To evaluate the rate of EMS use after the COVID-19 pandemic.	Prehospital	Retrospective study*	Turkey
John et al.[108]	December 2020	To compare ischaemic and haemorrhagic stroke patterns with COVID-19 to non-COVID-19 controls and to describe changes in stroke admission patterns during the pandemic.	Prehospital and Hospital	Single centre retrospective observational study	United Arab Emirates
Aboul Nour et al.[109]	June 2021	To showcase our experience with emergency department stroke alerts and inpatient stroke admissions – comparing a time period before and a time period during the pandemic in a comprehensive stroke and thrombectomy capable centers of a large tertiary health system in southeast Michigan and serving a large African American population.	Prehospital and Hospital	Multicentre retrospective cohort study	USA
Clodfelder et al.[110]	April 2022	To examine potential differences in care for myocardial infarction and ischemic stroke during the pandemic compared to the year prior, specifically whether delay in care was occurring that may be deleterious to patient outcomes.	Prehospital and Hospital	Multicentre retrospective cohort study	USA

Study	Publication Date	Aim	Setting	Design	Country
Goldberg et al.[111]	February 2021	To evaluate the impact of coronavirus disease 2019 (COVID-19) on EM) use for time-sensitive medical conditions.	Prehospital	Retrospective analysis*	USA
Greenwood et al.[112]	June 2021	To determine the impact COVID-19 had on hospital stroke patient volumes, prehospital stroke transport, hospital arrival times and treatment times for patients evaluated as acute stroke alerts at the emergency room of Baptist Hospital of Miami.	Prehospital and Hospital	Retrospective single centre two phase study	USA
Jasne et al.[113]	September 2020	To quantify trends in stroke code calls and treatments at three Connecticut hospitals during the local emergence of COVID-19 and examine patient characteristics and stroke process measures at a Comprehensive stroke Centre before and during the pandemic.	Prehospital and Hospital	Multicenter retrospective pre- and during-event cohort analysis	USA
Nguyen-Huynh et al.[114]	October 2020	To compare temporal trends in volume of acute stroke alerts, patient characteristics, telestroke care and short-term outcomes pre-and post – shelter-in-place orders.	Prehospital and Hospital	Multicentre cohort study	USA
Satty et al.[115]	April 2021	To evaluate EMS responses in an EMS region when it experienced low to moderate burden of COVID-19 disease to assess overall trends, response and management characteristics and non-transport rates.	Prehospital	Retrospective review* (22 EMS agencies)	USA
Sharma et al.[116]	February 2021	To quantify excess stroke-related deaths and characterise its association with social distancing behaviour and COVID-19 related vascular pathology.	Prehospital and Hospital	Retrospective population level-based analysis*	USA
Siegler et al.[117]	August 2020	To evaluate the impact of the current COVID-19 pandemic on the number, etiologies, and severity of new acute ischaemic stroke diagnoses (according to the National Institute of Health Stroke Scale) and the proportion of patients with acute large vessel occlusion in our tertiary centre.	Prehospital and Hospital	Single centre prospective cohort study	USA
Study	**Publication Date**	**Aim**	**Setting**	**Design**	**Country**

Siegler et al.[118]	January 2021	To evaluate the effect of the coronavirus disease 2019 pandemic on systems of care in the management of acute stroke.	Prehospital and Hospital	Multicentre retrospective observational registry study*	USA
Velasco et al.[119]	January 2021	To examine the impact of the COVID-19 pandemic on acute stroke care at a non-urban medical centre located in an area without widespread community transmission.	Prehospital and Hospital	Single centre retrospective review of prehospital quality improvement database	USA
White et al.[120]	July 2021	To assess the impact of COVID-19 on acute ischaemic stroke volume, presentation, treatment, and outcomes at comprehensive stroke centers.	Prehospital and Hospital	Multicentre retrospective review	USA

* Carried out in a region/country using emergency medical services (EMS) or administrative data.

** Intervention with COVID-19.

*** No study design included in article.

3.8.3 Time Periods

COVID-19 and comparison periods varied between studies, with most studies taking place in 2020. Most studies included one COVID-19 wave only, with only two studies[55,86], including more than one wave. The definitions of the COVID-19 period varied between studies, from the date of a lockdown to the first COVID-19 case in the country. This information is displayed in **Table 3.7**.

Study	Definition of COVID-19	COVID-19 period start	Comparison periods start	COVID-19 period end	Comparison period end	COVID-19 period length (days)	Comparison period length (days)	COVID-19 period patients (n), age, sex	COVID-19 stroke patients transported by EMS	Comparison Period patients (n), age, sex	Comparison period patients brought by ambulance	Stroke and/or TIA
Cadhilac et al.[73]	First COVID-19 case – January 25th, 2020	01/01/2020	01/01/2019	30/06/2020	30/06/2019	181	181	8729 Jan-Feb 2020 75 years [64-83] Female: 1313 (43%) March-April 2020 74 years [64-83] Female: 1242 (44%) May-June 2020 76 years [66-84] Female: 2586 (45%)	6127	9116 75 years [64-83] Female: 4011 (44%)	6802	Stroke and TIA
Gardiner et al.[74]	Lockdown	16/03/2020	28/01/2020	04/05/2020	15/03/2020	50	48	52 years [29-69] Females: 6399 (38%)	7	Not included	13	Stroke and TIA
Ferron et al.[75]	Onset and establishment phases of pandemic	01/01/2020 *	01/01/2019	26/05/2020	26/05/2019	147	146	2255	717	3495	690	Stroke and TIA
Grunua et al.[76]	Lockdown – 15th March 2020	15/03/2020	15/03/2019	15/05/2020	15/05/2019	62	62	1010	1010	1097	1097	Stroke and TIA
Yu et al.[54]	WHO declaration of COVID-19 as a pandemic on 11th March 2020[2]	11/03/2020	01/01/2020	19/05/2020	10/03/2020	70	70	4242 72 years [61-82] Female: 1559 (44%)	1896	3544 72 years [62-82] Female: 1835 (43.4%)	1981	Stroke

Study	Definition of COVID-19	COVID-19 period start	Comparison periods start	COVID-19 period end	Comparison period end	COVID-19 period length (days)	Comparison period length (days)	COVID-19 period patients (n), age, sex	COVID-19 stroke patients transported by EMS	Comparison Period patients (n), age, sex	Comparison period patients brought by ambulance	Stroke and/or TIA
Tan et al.[77]	Chongqing initiating a first-level response to major public health emergencies	24/01/2020	24/01/2019	10/03/2020	10/03/2019	47	46	110 68 years (± 13) Female: 47 (42.7%)	53	173 68 (±14) Female: 63 (36.4%)	55	Stroke
Wu et al.[78]	Lockdown	24/01/2020	24/01/2019	20/04/2020	20/04/2019	97	96	1281 65.7 years (± 13.1) Females: 427 (33.3%)	694	2354 66 years (±13.3) Females: 771 (32.8%)	1226	Stroke
Charlton et al.[79]	First United Kingdom COVID-19 fatality 5th March 2020 and lockdown 23rd March 2020	02/03/2020	04/03/2019	31/05/2020	02/06/2019	91	91	16,743 No demographic details available	1291	19,639 No demographic details available	1534	Stroke and TIA
Study	**Definition of COVID-19**	**COVID-19 period start**	**Comparison periods**	**COVID-19 period end**	**Comparison period end**	**COVID-19 period**	**Comparison period**	**COVID-19 period patients (n), age,**	**COVID-19 stroke patients**	**Comparison**	**Comparison period**	**Stroke and/or**

			start			length (days)	length (days)	sex	transported by EMS	Period patients (n), age, sex	patients brought by ambulance	TIA
Laukkanen et al.[80]	First COVID-19 wave	01/03/2020	01/03/2019	30/06/2020	30/06/2019 *	122	122	14320 59.1 years (±24.4) Female: 7227 (49.2%)	588	60,256 58.9 years (±24.7) Female: 31,205 (50.3%)	2020 (March-June 2016-2019)	Stroke and TIA
Gil-Jardiné et al.[81]***** *	Lockdown - 17th March 2020	17/03/2020	01/01/2020	10/05/2020	16/03/2020	56	76	No demographic details available	No demographic details available	No demographic details available	Not included	Stroke and TIA
Pop et al.[82]	First month of the outbreak - 17th March lockdown	01/03/2020	01/03/2019	31/03/2020	31/03/2019	31	31	122**** 65.5 years [49.2-78]	174	167**** 64 years [49-78]	288	Stroke and TIA
Ikenberg et al.[83]	Lockdown – 21st March 2020	21/03/2020	01/01/2020	19/04/2020	20/03/2020	30	80	70 73.8 years (± 16)	70	171 71 years (± 16)	171	Stroke and TIA
Teo et al.[56]	First diagnosed COVID-19 case in Hong Kong	23/01/2020	23/02/2019	24/03/2020	24/03/2019	62	61	73 70 (±16.2) Female: 41(56.2%)	73	89 73.6 (±13.1) Female: 44 (49.4%)	89	Stroke and TIA
Study	**Definition of COVID-19**	**COVID-19 period start**	**Comparison periods start**	**COVID-19 period end**	**Comparison period end**	**COVID-19 period length**	**Comparison period length**	**COVID-19 period patients (n), age, sex**	**COVID-19 stroke patients transported by**	**Comparison Period**	**Comparison period patients**	**Stroke and/or TIA**

						(days)	(days)		EMS	patients (n), age, sex	brought by ambulance	
Libruder et al.[84]	COVID-19 restrictions	08/03/2020	01/01/2020	30/04/2020	07/03/2020	67	54	791 73.4 years [65.1-82.3] Female: 346(43.7%)	519	1469 74.2 years [65.2-83] Female: 662 (45.1%)	887	Stroke and TIA
Nacarrato et al.[85]	COVID-19 national quarantine - 9th March 2020	09/03/2020	09/03/2019	09/04/2020	09/04/2019	32	32	16 77 years [67-81] Female: 10(62.5%)	9	29 78 years [70-85] Female: 17 (58.6%)	17	Stroke and TIA
Padroni et al.[86]	COVID-19 wave 1 and 3	*01/03/2020 01/04/2021	01/03/2018 01/03/2019	30/04/2020 01/04/2021	30/04/2018 30/04/2019	122	122	141 March-April 2020: 73.3 years (± 14.9) March-April 2021: 76.4 years (±12.1)	141	164 75.7 years (±12.6)	164	Stroke
Paolucci et al.[87]	COVID-19 wave	15/03/2020	15/03/2019	15/06/2020	15/06/2019	93	93	26 75.9 years (±11) 14 (54%)	26	24 75.9 years (±11.9) 12 (50%)	24	Stroke
Study	**Definition of COVID-19**	**COVID-19 period start**	**Comparison periods start**	**COVID-19 period end**	**Comparison period end**	**COVID-19 period length (days)**	**Comparison period length (days)**	**COVID-19 period patients (n), age, sex**	**COVID-19 stroke patients transported by EMS**	**Comparison Period patients (n), age,**	**Comparison period patients brought by ambulance**	**Stroke and/or TIA**

										sex		
Zini et al.[88]	COVID-19 logistic restrictions put into place by national and local government	01/03/2020	01/03/2019	30/04/2020	30/04/2019	61	61	118 72.9 years (± 16.6) Female: 56 (47.5%)	99	97 76.6 years (±13.7) Female: 54 (55.1%)	84	Stroke and TIA
Tanaka et al.[89]	Beginning of COVID-19 period -surge in number of COVID cases in the Prefecture and timing of declaration of emergency state	01/04/2020	01/04/2019	30/09/2020	31/03/2020	183	366	216 71 years [60-78] Female: 78(36.1%)	68	464 72 years [62-80] Female: 159(32.3 %)	164	Stroke and TIA
Study	**Definition of COVID-19**	**COVID-19 period start**	**Comparison periods start**	**COVID-19 period end**	**Comparison period end**	**COVID-19 period length (days)**	**Comparison period length (days)**	**COVID-19 period patients (n), age, sex**	**COVID-19 stroke patients transported by EMS**	**Comparison Period patients (n), age, sex**	**Comparison period patients brought by ambulance**	**Stroke and/or TIA**
Tani et	State of	01/04/2020	01/04/2019	31/05/2020	31/05/2019	61	61	16,975	8853	19,709	9950	Stroke

al.[90]	emergency							0-44 years: 242 45-54 years :752 55-64 years :1508 65-74 years :3986 75-84 Years :5846 85+ years: 4641 Female: 7234 (42.6%)		0-44 years: 308 45-54 years: 916 55-64 years: 1790 65-74 years :4693 75-84 years: 6702 85+ years: 5300		
Melaika et al.[91]	National lockdown – 16th March 2020	16/03/2020	15/12/2019	16/06/2020	15/09/2020	93	92	251 72.4 years (±12.9) Female: 151 (60.2%)	204	468 72.2 years (±13.5) Female: 280 (59.8%)	289	Stroke and TIA
Study	**Definition of COVID-19**	**COVID-19 period start**	**Comparison periods start**	**COVID-19 period end**	**Comparison period end**	**COVID-19 period length (days)**	**Comparison period length (days)**	**COVID-19 period patients (n), age, sex**	**COVID-19 stroke patients transported by EMS**	**Comparison Period patients (n), age, sex**	**Comparison period patients brought by ambulance**	**Stroke and/or TIA**
Blek et al.[55]	First COVID-19 restrictions introduced by	01/04/2020	01/04/2019	31/03/2021	31/03/2020	365	365	9544 72.8 years (± 15.7)	9544	9378 73.1 years	9378	Stroke and TIA

	Polish government – 15th March 2020							Female: 4102 (50%)		(±13.3) Female: 4111 (52%)		
Kucap et al.[92]	First case in Poland 4th March 2020 – WHO declaration of COVID-19 as a pandemic on 11th March 2022[2]	*15/03/2020	15/03/2019	15/05/2020	15/05/2019	62	62	No demographic details available	No demographic details available	No demographic details available	No demographic details available	Stroke and TIA
Nadolny et al.[93]	First months of the COVID – 19 pandemic – Polish Anti-Crisis act and restrictions	*15/03/2020	15/03/2019	15/05/2020	15/05/2019	62	62	No demographic details available	No demographic details available	No demographic details available	No demographic details available	Stroke and TIA
Study	**Definition of COVID-19**	**COVID-19 period start**	**Comparison periods start**	**COVID-19 period end**	**Comparison period end**	**COVID-19 period length (days)**	**Comparison period length (days)**	**COVID-19 period patients (n), age, sex**	**COVID-19 stroke patients transported by EMS**	**Comparison Period patients (n), age, sex**	**Comparison period patients brought by ambulance**	**Stroke and/or TIA**
Rodrigues et al.[94]	2nd March 2020 – 1st COVID case	*02/03/2020	01/02/2020	30/04/2020	29/02/2020	60	29	106 72 years [65.6-82] (March 2020) 79 years [61-85]	29	74 68.5 years [59-82] Female:	24	Stroke and TIA

								(April 2020) Female: 25 (38.5%) (March 2020) 23 (56.1%) (April 2020)		40 (54.1%)		
Kim et al.[95]	First case in Busan – 21st February 2020 Social distancing measures introduced – 24th February 2020	01/03/2020	01/03/2019	28/02/2021	28/02/2020	365	365	1441 69.4 years (± 27.7) Female: 753(53.3%)	1441	1570 68 years (±13.6) Female: 749(47.7%)	1570	Stroke and TIA
Study	**Definition of COVID-19**	**COVID-19 period start**	**Comparison periods start**	**COVID-19 period end**	**Comparison period end**	**COVID-19 period length (days)**	**Comparison period length (days)**	**COVID-19 period patients (n), age, sex**	**COVID-19 stroke patients transported by EMS**	**Comparison Period patients (n), age, sex**	**Comparison period patients brought by ambulance**	**Stroke and/or TIA**
Lee et al.[96]	First COVID case in Daegu	*18/02/2020	18/02/2018 and 18/02/2019	17/04/2020	17/04/2018 and 17/04/2019	60	118	134 69.8 years (± 12.1) Female: 45 (33.6%)	106	399 69.4 years (± 12.7) Female: 162 (40.6%)	251	Stroke

Park et al.[97]	Intervention – government in Korea implemented emergency medical center for critical care due to COVID-19	01/01/2020 ******	23/03/2020	22/03/2022	31/12/2020	82	284	169,714 18-64 years: 92,833 (54.7%) 65+ years: 76,881 (45.3%) Female: 83,393 (49.1%)	3296	50,049 18-64 years: 26,519 (53%) 65+ years: 23,530 (47%) Female: 24,807 (49.6%)	948	Stroke and TIA
Seo et al.[98]	First COVID-19 case in Seoul - 25th January 2020	01/02/2020	01/02/2019	31/04/2020	31/04/2019	90	89	231 69.3 years (± 11.5) Female: 79 (34.3%)	231	234 69.8 years (±12.1) Female: 93 (39.7%)	234	Stroke and TIA
Study	**Definition of COVID-19**	**COVID-19 period start**	**Comparison periods start**	**COVID-19 period end**	**Comparison period end**	**COVID-19 period length (days)**	**Comparison period length (days)**	**COVID-19 period patients (n), age, sex**	**COVID-19 stroke patients transported by EMS**	**Comparison Period patients (n), age, sex**	**Comparison period patients brought by ambulance**	**Stroke and/or TIA**
Montaner et al.[99]	COVID-19 national emergency and alarm state - 15th March 2020	16/03/2020	16/01/2020	31/03/2020	15/03/2020	16	60	No demographic details available	2	No demographic details available	110	Stroke and TIA
Ramírez-Moreno	State of alarm – 15th March	15/03/2020	15/03/2019	10/05/202	10/05/2019	57	57	40	40	41	41	Stroke and TIA

et al.[100]	2020							70.4 years (±2.7) No information on sex included		71.2 years (±3.5) No information on sex included		
Ramos-Páchon et al.[101]	Lockdown-15th March 2020	15/03/2020	26/01/2020	02/05/2020	14/03/2020	49	49	805 71.2 years (±15) Female: 334 (41%)	565	1033 71.6 years (±15) Female: 480 (46%)	664	Stroke and TIA
Study	**Definition of COVID-19**	**COVID-19 period start**	**Comparison periods start**	**COVID-19 period end**	**Comparison period end**	**COVID-19 period length (days)**	**Comparison period length (days)**	**COVID-19 period patients (n), age, sex**	**COVID-19 stroke patients transported by EMS**	**Comparison Period patients (n), age, sex**	**Comparison period patients brought by ambulance**	**Stroke and/or TIA**
Riera-López et al.[53]	Incidence of COVID-19 infection above the median of the series chosen	01/03/2020	01/03/2019	08/05/2020	08/05/2019	69	69	303 69.2 years (± 15.1) Female: 133 (43.9%)	303 72.5 years (±13.5) Female: 179 (51.9%)	345	345	Stroke and TIA
Rudilisso et al.[102]	28th February 2020 - contingency plans introduced in	01/03/2020	01/03/2019	31/03/2020	01/03/2019	31	31	68 69 years [64-73] Female: 30(44%)	57 70 years [64-75]	83 75 years [73-80] Female:	73 77 years [74-81]	Stroke and TIA

	the hospital to contain the COVID-19 pandemic									37 (45%)		
Tejada Meza et al. [103]	COVID-19-state of emergency in Spain -14th March 2020	14/03/2020	30/12/2019	03/05/2020	13/03/2020	51	75	304 74.3 years (±12) Female: 152 (50%)	164	492 74.1 years (±13.5) Female: 234(47.4 %)	222	Stroke and TIA
Study	**Definition of COVID-19**	**COVID-19 period start**	**Comparison periods start**	**COVID-19 period end**	**Comparison period end**	**COVID-19 period length (days)**	**Comparison period length (days)**	**COVID-19 period patients (n), age, sex**	**COVID-19 stroke patients transported by EMS**	**Comparison Period patients (n), age, sex**	**Comparison period patients brought by ambulance**	**Stroke and/or TIA**
Tejada Meza et al.[104]	COVID-19-state of emergency in Spain - 14th March 2020	14/03/2020	30/12/2019	19/04/2020	13/03/2020	37	75	79 78 years [67-85] >80 years: 32 (40.5%) Female: 37 (59.5%)	32	275 80 years [68-86] >80 years: 130 (47.3%) Female: 132 (48%)	90	Stroke
Tejada Meza et al.[105]	State of alarm 14th March - 21 June 2020	14/03/2020	30/12/2019	04/05/2020	13/03/2020	52	75	93 70.8 years (± 14.5)	34	225 74.6 years	75	Stroke

	- now in second wave at time of writing							>80 years: 27 (29%) Female: 38(40.9%)		(±13.4) >80 years: 95 (42.2%) Female: 105 (46.7%)		
Study	**Definition of COVID-19**	**COVID-19 period start**	**Comparison periods start**	**COVID-19 period end**	**Comparison period end**	**COVID-19 period length (days)**	**Comparison period length (days)**	**COVID-19 period patients (n), age, sex**	**COVID-19 stroke patients transported by EMS**	**Comparison Period patients (n), age, sex**	**Comparison period patients brought by ambulance**	**Stroke and/or TIA**
De Marchis et al. [106]	Lockdown	13/03/2020	13/03/2019	*26/04/2020	26/04/2019	45	45	1487 75 years [63-83] Female: 611 (41%)	710	3004 75 years 964-83] Female: 1293 (43%) (13 March-26th April 2018/2019)	1223 (13 March-26th April 2018/2019)	Stroke and TIA

San et al.[107]	First COVID-19 case in Turkey - 11th March 2020	11/03/2020	11/03/2019	24/04/2020	24/04/2019	45	45	48,159 (all cases) 52.1 years (±24.2) Female: 23,872 (49.6%)	Cerebrovascular disease - 766	43,851 49.3 years (±25.6) Female: 22,351 (51%)	Cerebrovascular disease – 789	Stroke and TIA
Study	**Definition of COVID-19**	**COVID-19 period start**	**Comparison periods start**	**COVID-19 period end**	**Comparison period end**	**COVID-19 period length (days)**	**Comparison period length (days)**	**COVID-19 period patients (n), age, sex**	**COVID-19 stroke patients transported by EMS**	**Comparison Period patients (n), age, sex**	**Comparison period patients brought by ambulance**	**Stroke and/or TIA**
John et al.[108]	No specific definition First COVID-19 case in United Arab Emirates - 29th January 2020 WHO declared COVID-19 as a pandemic on 11th March 2020[2]	01/03/2020	01/03/2019	10/05/2020	10/05/2019	71	71	Ischaemic 130 57.5 years (± 14.3) Female: 36 (27.69%) Haemorrhagic 42 48.9 years (±14.7) Female: 14 (33.3%)	31 11	Ischaemic 109 58.4 years (± 14.6) Female: 35(32.1%) Haemorrh-agic 26 49.3 years (±14.1) Female: 5 (19.2%)	7 3	Stroke and TIA

Study	Definition of COVID-19	COVID-19 period start	Comparison periods start	COVID-19 period end	Comparison period end	COVID-19 period length (days)	Comparison period length (days)	COVID-19 period patients (n), age, sex	COVID-19 stroke patients transported by EMS	Comparison Period patients (n), age, sex	Comparison period patients brought by ambulance	Stroke and/or TIA
Aboul Nour et al. [109]	Amended tier one policy on Emergency Care and admissions of patients with acute ischaemic stroke and TIA went into effect system wide to address resource use optimisation and exposure risk reduction during the COVID-19	20/03/2020	20/03/2019	20/05/2020	20/05/2019	62	62	108 65.6 (years ±14.2) Female: 47 (44%)	55	219 66.5 years (±14) Female: 94 (43%)	61	Stroke and TIA

	pandemic											
Clodfelder et al.[110]	During the COVID-19 pandemic - after WHO 11th March 2020 declaration[2]	19/03/2020	19/03/2019	11/06/2020	11/06/2019	85	85	90 69 years ± 17.5) Female: 29 (49.2%)	59	90**	52 74 years (± 15.3) Female: 29 (55.8%	Stroke and TIA
Study	**Definition of COVID-19**	**COVID-19 period start**	**Comparison periods start**	**COVID-19 period end**	**Comparison period end**	**COVID-19 period length (days)**	**Comparison period length (days)**	**COVID-19 period patients (n), age, sex**	**COVID-19 stroke patients transported by EMS**	**Comparison Period patients (n), age, sex**	**Comparison period patients brought by ambulance**	**Stroke and/or TIA**
Goldberg et al.[111]	10th March 2020 - statewide public health emergency	10/03/2020	10/03/2019	15/05/2020	15/05/2019	67	67	1970*** 51.8 years [CI 51.7-52.0) Female: 963 (48.9%)	40	2424 50.8 years [CI 50.7-50.9] Female: 1256 (51.8%)	45.6	Stroke and TIA
Greenwood et al.[112]	COVID-19 safety protocols introduced in the hospital - 2nd March 2020	01/03/2020	01/12/2019	30/04/2020	31/01/2020	61	62	93 77 years [66-84] Female: 49 (53%)	77	156 73 years [61-83] Female: 94 (60.3%)	101	Stroke
Jasne et al.[113]	First COVID-19 cases in neighboring states - 1st March 2020	01/03/2020	01/02/2020	28/04/2020	29/02/2020	59	29	211 69 years [57-80] Female: 97 (55.7%)	123	167 71 years [61-81] Female: 93	102	Stroke and TIA

										(55.7%)		
Study	**Definition of COVID-19**	**COVID-19 period start**	**Comparison periods start**	**COVID-19 period end**	**Comparison period end**	**COVID-19 period length (days)**	**Comparison period length (days)**	**COVID-19 period patients (n), age, sex**	**COVID-19 stroke patients transported by EMS**	**Comparison Period patients (n), age, sex**	**Comparison period patients brought by ambulance**	**Stroke and/or TIA**
Nguyen – Huynh et al.[114]	Shelter in place order - 15th March 2020	15/03/2020	01/01/2019	09/05/2020	14/03/2020	56	439	783 69 years (± 15.12) Female: 402 (52.1%)	587	8337 68.8: (± 15.78) Female: 4408 (52.9%)	5519	Stroke/TIA
Satty et al.[115]	First COVID-19 cases in Pennsylvania - 7th March 2020	15/03/2020	15/03/2019 *	15/05/2020	15/05/2019 ********	62	62	16,082***** 0-17 years: 635(4%) 18-64 years: 8125 (50.6%) ≥65 years: 7160 (44.5%) Unknown: 152 (1%) Female: 8422 (52.4%)	257	21,881 0-17 years: 4856(6.6 %) 18-64 years: 45,313 (51.8%) ≥65 years: 7160 (44.5%) Unknown: 152(1%) Female:	1162	Stroke and TIA

										47,207 (53.9%) (Age and gender for 15 March-15 May 2016-2019)		
Study	**Definition of COVID-19**	**COVID-19 period start**	**Comparison periods start**	**COVID-19 period end**	**Comparison period end**	**COVID-19 period length (days)**	**Comparison period length (days)**	**COVID-19 period patients (n), age, sex**	**COVID-19 stroke patients transported by EMS**	**Comparison Period patients (n), age, sex**	**Comparison period patients brought by ambulance**	**Stroke and/or TIA**
Sharma et al.[116]	First height of the pandemic – association with case fatalities after the first US COVID-19 related death on 29th Feb 2020	01/03/2020	01/03/2019	16/05/2020	16/05/2019	78	77	No demographic information available	37,800*******	No demographic information available	37,400 *******	Stroke and TIA
Siegler et al.[117]	First New Jersey resident to develop COVID-19 - 1st March 2020	01/03/2020	01/10/2019	15/04/2020	29/02/2020	46	152	53 68 years (±15) Female: 23 (43%)	26	275 68 years (±14) Female: 113 (41%)	71	Stroke

Study	Definition of COVID-19	COVID-19 period start	Comparison periods start	COVID-19 period end	Comparison period end	COVID-19 period length (days)	Comparison period length (days)	COVID-19 period patients (n), age, sex	COVID-19 stroke patients transported by EMS	Comparison Period patients (n), age, sex	Comparison period patients brought by ambulance	Stroke and/or TIA
Siegler et al.[118]	No context specific COVID-19 definition given	01/03/2020	01/03/2019	31/07/2020	31/07/2019	153	153	1464 <50 years: 178/1451 (12%) 50-69 years: 650/1451 (45%) ≥ 70 years: 623/1451 (43%) Female: 675/1451 (43%)	1108	1491 < 50 years: 179/49 (12%) 50-69 years: 602/1491 (40%) ≥ 70 years: 710/1491 (48%) Female: 723/1491 (48%)	898	Stroke
Velasco et al.[119]	Height of COVID-19 in the region	01/01/2020	01/01/2019	30/04/2020	30/04/2019	121	120	51 75.9 years (± 18.9) Female: 22(43.5%)	51	57 77.91 years (±12.6) Female: 32 (56.5%)	57	Stroke and TIA

Study	**Definition of COVID-19**	**COVID-19 period start**	**Comparison periods start**	**COVID-19 period end**	**Comparison period end**	**COVID-19 period length (days)**	**Comparison period length (days)**	**COVID-19 period patients (n), age, sex**	**COVID-19 stroke patients transported by EMS**	**Comparison Period patients (n), age, sex**	**Comparison period patients brought by ambulance**	**Stroke and/or TIA**
White et al.[120]	COVID-19 peak – first positive case in New York City – 1st March 2020	01/03/2020	01/01/2020	30/04/2020	29/02/2020	61	60	100 18-39 years: 4(2.8%) 40-59 years: 20 (20%) 60-79 years: 46 (46%) 80+ years: 32 (32%) Female: 44 (44%)	34	199 18-39 years: 0 (0%) 40-59 years: 39 (19.6%) 60-79 years: 88 (44.4%) 80+ years: 72 (36.2%) Female: 106 (53.3%)	60	Stroke

*More than one time comparison.

**90 transports for stroke alerts 52/59 were confirmed stroke.

***Calls for cardiac emergencies per day.

****Age only available for those with final diagnosis of stroke/mimic.

*****Some children included in the sample.

******Intervention included.

*******Figures were estimated from graph in supplementary material.

******** 21,881 – per year

Key: CI: Confidence interval, [x, y]: IQR

3.8.4 Interventions During COVID-19

Three studies[81,93,97] included interventions introduced during COVID-19, restriction of the emergency stroke care pathway and a new triage system for emergency calls.

3.8.5 Ambulance intervals terminology and definitions

Ambulance intervals were reported by 11 studies. Definitions and terminology varied internationally **(table 3.8 and 3.9)**. Activation interval was the least commonly reported (n = 2), and patient care interval was the most often reported (n = 10).

Table 3.8 - Comparison of ambulance time intervals used in included studies compared to definitions of activation time interval, response time interval, and patient care intervals used in this review[28,59]

Study	Activation interval	Response interval	Patient care interval	Total prehospital interval
Blek et al. 2022[55]	**Not included**	"Contact" not scene arrival	"Contact" not scene arrival	"Hospital admission" not "hospital arrival"
Clodfelder et al. 2020[110]	**Not included**	**Not included**	"Contact" not scene arrival	**Not included**
Lee et al. 2021[96]	**Not included**	*No start time given	***Definition match***	**Not included**
Laukkanen et al. 2021[80]	Two separate intervals Dispatch interval starts at "alarm message"	"Driving from ambulance station" not "receipt of call"	"Time patient encountered" rather than scene arrival and "beginning of transportation" rather than "hospital arrival"	**Not included**
Ramos-Páchon et al. 2021[101]	**Not included**	***Definition match***	**Not included**	**Not included**
Velasco et al. 2021[119]	**Not included**	***Definition match***	**Not included**	"Dispatch" not "call"
Padroni et al. 2022[86]	**Not included**	***Definition match***	***Definition match***	**Not included**
Seo et al. 2022[98]	"Call centre" not call receipt to "safety centre" not "fully mobilized ambulance"	"Safety centre" not "receipt of call"	***On scene and transport time intervals combined***	**Not included**
Kim et al. 2021[95]	"End of call" not "mobilisation of ambulance"	"End of call" not "receipt of call"	***Definition match***	***Definition match***
Paolucci et al. 2022[87]	**Not included**	**Not included**	**Not included**	***Definition match***
Park et al. 2022[97]	"After call does not call"	"After call does not call"	***Definition match***	***Definition match***

Colour key:

Pink: interval not included in study, blue: very different (start and end point don't match), orange: close but incomplete match (start or end point don't match) , green: s
definition matches definition used in this review (start and end point match)

Table 3.9 - The definitions of ambulance intervals used in included articles

Study	Activation interval	Response interval	Patient care interval	Total prehospital interval
Blek et al. 2022[55]	**Not included**	Time from call to contact	Time from contact to hospital admission	Time from call to hospital admission
Clodfelder et al. 2020[110]	**Not included**	**Not included**	**Transportation time** Time from contact to hospital	**Not included**
Lee et al. 2021[96]	**Not included**	On scene arrival time [no start time for interval given in paper]	Scene arrival to door time	**Not included**
Laukkanen et al. 2021[80]	**Emergency call to dispatch** Time between the beginning of the emergency call and an alarm-message transmitted to the ambulance crew by emergency call center (112/911 etc…). **Dispatch time** Time between the alarm-message received by ambulance crew and the moment when the ambulance crew actually responds and starts driving towards the scene.	**Time en-route** Time spent driving from the ambulance station to the scene	**Time at scene** Time between patient encountered by EMS crew and the beginning of the transportation / or ambulance leaving without transportation	**Not included**
Ramos-Páchon et al. 2021[101]	**Not included**	EMS alert to EMS assistance Moment when EMS arrival	**Not included**	**Not included**

		at the scene		
Velasco et al. 2021[119]	**Not included**	**Not included**	Time on scene	Dispatch to Emergency Department (ED)
Padroni et al. 2022[86]	**Not included**	Call to scene time	Scene to hospital arrival	**Not included**
Kim et al. 2021[95]	**Call time**	**Response time**	**Scene time**	EMS processing time – patient's call to ED arrival
			From EMS arrival at the scene to EMS departure from the scene	
	Start of the call to the end of the call	Time elapsed from the end of the call to EMS arrival at scene	**Transport time**	
			From EMS departure from the scene to EMS arrival at Emergency Department (ED)	
Paolucci et al. 2022[87]	**Not included**	**Not included**	**Not included**	Call to door
Seo et al. 2022[98]	**Dispatch time**	**Response time**	**On scene**	**Not included**
			Arrival to departure from scene	
			Transport time	
			Departure from scene to emergency department	
	EMS call center to safety center	From safety centre to arrival at scene		
Park et al. 2022[97]	Activation time	Response time	**On-scene time**	Total time between emergency call and arrival at the hospital – total prehospital

				time
			Time spent on scene by EMS	
	Time required for EMS to deploy after emergency call	Includes the AT and the time to get to the scene of accident	**Transport time**	
			Time from departing scene to arrival at the hospital	

Colour key:

Pink: interval not included in study

3.8.6 Ambulance intervals and call volume meta-analysis

We included ten studies in the ambulance intervals meta-analyses **(Figure 3.2)** and 52 studies in the call volume meta-analyses **(Figure 3.3**). For the meta-analyses, the pre-COVID-19 period was compared to the COVID-19 period. As a result, a negative value for the mean difference indicates shorter mean intervals in the pre-COVID-19 period, thus longer intervals in the COVID-19 period.

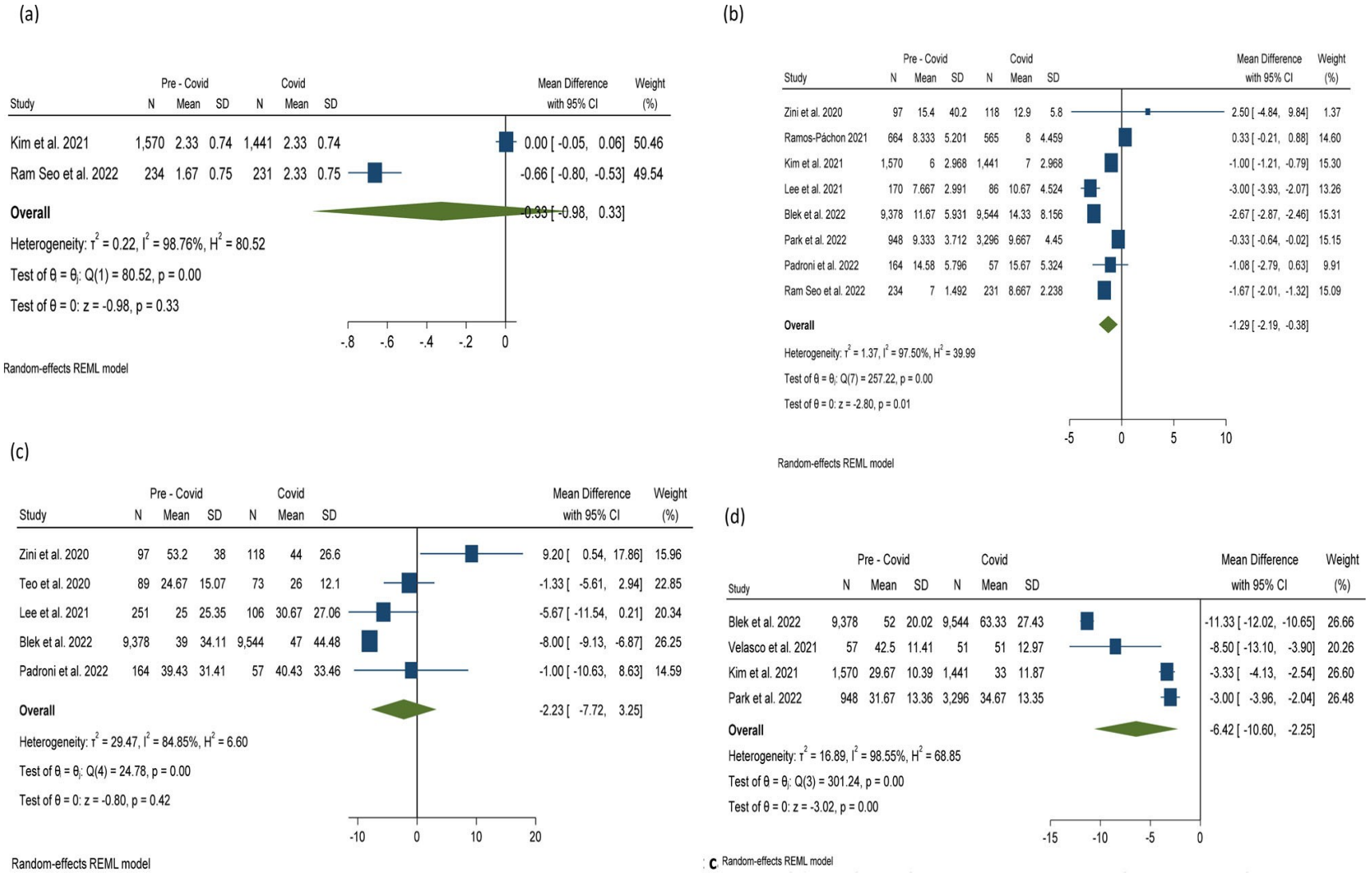

Figure 3.2 - Forest plots of (a) activation time interval, (b) response time interval, (c) patient care time interval, and (d) total prehospital time interval before and during the COVID-19 pandemic

*Intervals compared before and after the COVID-19 pandemic; a negative value indicates a shorter interval in the pre-COVID-19 period, and a longer interval in the COVID-19 period.

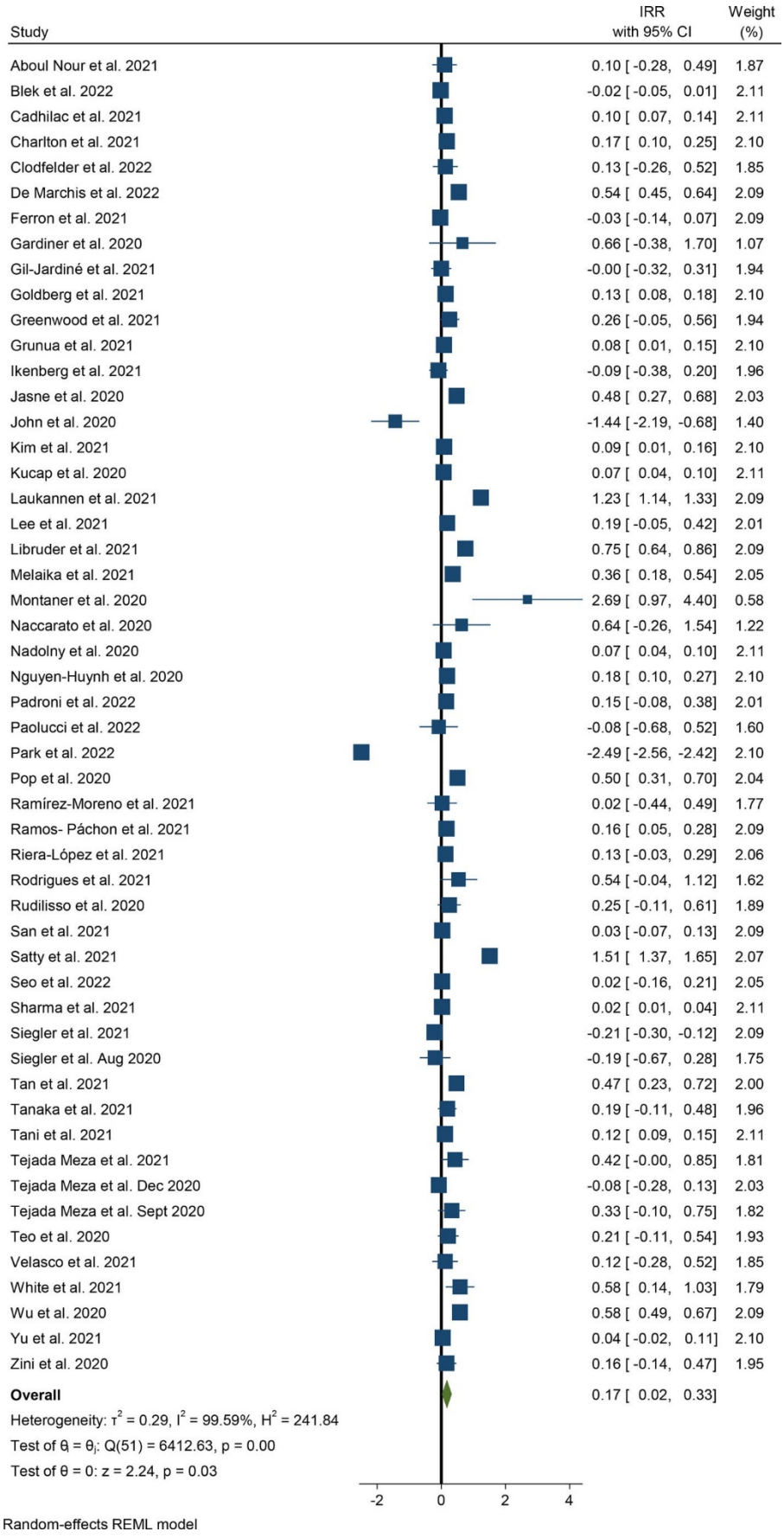

Figure 3.3 - Forest plot of call volume represented as log of incidence rate ratio per day

3.8.6.1 Ambulance time intervals

Activation interval

There was no statistically significant difference in activation interval between pre-COVID-19 and COVID-19 periods (-0.33 min [-0.98 to 0.33]) **(Figure 3.2a)**.

The mean difference between pre-COVID-19 and COVID-19 periods was higher among areas with COVID cases >1,000 per million (-0.66 [-0.80 to -0.53]) compared with <1,000 per million (0.0 [0.05 to 0.06]).

The mean difference between pre-COVID-19 and COVID-19 periods was higher among areas with COVID-19-deaths <200 per million (-0.66 [-0.80 to -0.53]) compared with >200 per million (0.0 [0.05 to 0.06]).

The mean difference between pre-COVID-19 and COVID-19 periods was higher among areas with COVID-19 related ICU admissions <2 per million (-0.66 [-0.80 to-0.53]) compared with >2 per million (0.0 [-0.05 to 0.06]) **(Appendix 3.7 and 3.8)**.

Response Interval

The mean response interval was significantly shorter in the pre-COVID-19 period compared to the COVID-19 period (-1.29 min [-2.19 to -0.38]) **(Figure 3.2b)**.

The mean difference in response interval between pre-COVID-19 and COVID-19 periods was higher among areas with COVID-19 cases >6,000 per million (-2.67 [2.87

to -2.46]) compared with <2,000 per million (-1.44 [-2.49 to -0.38]).

The mean difference in response interval between the pre-COVID-19 and COVID-19 periods was higher among areas with COVID-19 related deaths >6,000 per million (-2.67 [-2.87 to- 2.46]) compared with 0-500 per million (-1.44[-2.49 to -0.38]). The definitions of response interval (-1.08[-2.87 to -2.46]) and emergency call volume also had a significant moderation of difference in response interval between the two periods ***(Appendix 3.9 and 3.10)***.

Patient Care Interval

Overall, there was no statistically significant difference in mean patient care interval between pre-COVID-19 and COVID-19 periods (-2.23 min [-7.72 to 3.25]) **(Figure 3.2c**). However, areas with COVID-19 hospitalisations <300 per million indicated significant moderation of difference in patient care interval between pre-COVID-19 and COVID-19 periods.

The mean difference in patient care interval between pre-COVID-19 and COVID-19 periods was higher among areas with COVID-19-hospitalisations <300 per million -8.00[-9.13 to -6.87]) compared with >300 per million (4.33[-5.66 to 14.31]) ***(Appendix 3.11 and 3.12)***.

Total Prehospital Interval

The mean total prehospital interval was significantly shorter in the pre-COVID-19

period compared to the COVID-19 period (-6.42 min [-10.60 to -2.25]) **(Figure 3.2d**).

Europe had the highest increase in total prehospital interval (-11.33 [-12.02 to -10.65]), followed by North America (-8.50 [-13.10 to -3.90]), and Asia (-3.20 [-3.81 to -2.58]). The increase in total prehospital interval rose with an increase in the volume of COVID-19 cases (-6.42 [-10.6 to -2.2]), COVID-19 deaths (-5.90 [-11.24 to -5.5]), and COVID-19 ICU admissions (-5.90 [-11.24 to -5.5]) ***(Appendix 3.13 and 3.14)***.

3.8.6.2 Narrative Description of Ambulance Intervals

Clodfelder et al.[110] reported mean transport interval of 21.78 min in 2019 (pre-COVID-19) compared to a mean of 20.59 min in 2020 (COVID-19) (CI -0.76 to 3.14). Results of studies that reported patient care interval as two separate variables[95,97,98,119] can be found in ***Appendix 3.15***.

3.8.6.3 Observed Differences in Suspected Stroke/TIA Call Volume Between the Pre-COVID-19 Period and COVId-19 Period

The meta-analysis indicated a significantly higher incidence rate during the pre-COVID-19 period compared with the COVID-19 period (log IRR = 0.17 (0.02 to 0.33)). Specifically, the incidence rate during pre-COVID-19 was 1.19 times (1.02 to 1.39) the incidence rate during the COVID-19 period (16.00% reduction in the incidence rate) **(Figure 3.3)**. Mean call volume per day for suspected stroke/TIA before and during the COVID-19 period are included in **Table 3.10**.

Table 3.10 - Mean number of suspected stroke/TIA calls per day pre-COVID-19 and during COVID-19

Study	Pre-COVID-19	COVID-19
Aboul Nour et al. 2021[109]	0.98	0.89
Blek et al. 2022[55]	25.69	26.15
Cadhilac et al. 2021[73]	37.58	33.85
Charlton et al. 2021[79]	16.86	14.19
Clodfelder et al. 2022[110]	0.69	0.61
De Marchis et al. 2022[106]	27.18	15.78
Ferron et al. 2021[75]	4.73	4.88
Gardiner et al. 2020[74]	0.27	0.14
Gil-Jardiné et al. 2021[81]	1.30	1.30
Goldberg et al. 2021[111]	45.60	40.00
Greenwood et al. 2021[112]	1.63	1.26
Grunua et al. 2021[76]	17.69	16.29
Ikenberg et al. 2021[83]	2.14	2.33
Jasne et al. 2020[113]	5.76	3.58
John et al. 2020[108]	0.14	0.59
Kim et al. 2021[95]	4.30	3.95
Kucap et al. 2020[92]	165.29	153.69
Laukannen et al. 2021[80]	16.56	4.82
Lee et al. 2021[96]	2.13	1.77
Libruder et al. 2021[84]	16.43	7.75

Study	Pre-COVID-19	COVID-19
Melaika et al. 2021[91]	3.14	2.19
Montaner et al. 2020[99]	1.83	0.13
Naccarato et al. 2020[85]	0.53	0.28
Nadolny et al. 2020[93]	165.29	153.69
Nguyen-Huynh et al. 2020[114]	12.57	10.48
Padroni et al. 2022[86]	1.34	1.16
Paolucci et al. 2022[87]	0.26	0.28
Park et al. 2022[97]	3.34	40.23
Pop et al. 2020[82]	9.29	5.61
Ramírez-Moreno et al. 2021[100]	0.72	0.70
Ramos- Páchon et al. 2021[101]	13.55	11.53
Riera-López et al. 2021[53]	5.00	4.39
Rodrigues et al. 2021[94]	0.83	0.48
Rudilisso et al. 2020[102]	2.35	1.84
San et al. 2021[107]	17.53	17.02
Satty et al. 2021[115]	18.74	4.15
Seo et al. 2022[98]	2.63	2.57
Sharma et al. 2021[116]	490.91	479.487
Siegler et al. Aug 2020[117]	0.47	0.565

Study	Pre-COVID-19	COVID-19
Siegler et al. 2021[118]	5.87	7.242
Tan et al. 2021[77]	3.76	2.340
Tanaka et al. 2021[89]	0.45	0.372
Tani et al. 2021[90]	163.11	145.131
Tejada Meza et al. Sept 2020[103]	1.20	0.865
Tejada Meza et al. Dec 2020[104]	2.96	3.216
Tejada Meza et al. 2021[105]	1.00	0.654
Teo et al. 2020[56]	1.46	1.177
Velasco et al. 2021[119]	0.48	0.421
White et al. 2021[120]	1.00	0.557
Wu et al. 2020[78]	12.77	7.155
Yu et al. 2021[54]	28.30	27.086
Zini et al. 2020[88]	1.62	1.377

Definitions of emergency call volume in included studies can be found in appendix ***3.16***.

The volume of COVID-19 hospitalisations, COVID-19 deaths, and COVID-19 related ICU admissions indicated significant moderation of call volume between pre-COVID-19 and COVID-19 periods ***(Appendix 3.17 and 3.18)***.

3.8.7 Publication Bias

Funnel plots for ambulance time intervals and call volume can be found in ***Appendix 3.19 and 3.20.*** Asymmetry of the funnel plots for response, patient care, total prehospital intervals, and call volume suggest possible publication bias.

3.8.8 Appraisal of the Quality of Included Studies

Results of the critical appraisal assessment can be found in ***Appendix 3.21***. Most studies performed well in terms of measuring outcomes and comparability of groups in the exposure and control group, but there were shortcomings in identifying and adjusting for confounders.

3.8.9 GRADE Summary of Findings Table

Overall quality of the cumulative evidence of statistically significant outcomes was considered to be low-very low. The GRADE table can be found in ***Appendix 3.22***.

3.9 Discussion

This study summarised available evidence on the effect of the COVID-19 pandemic on prehospital care for suspected stroke/TIA. COVID-19 cases, deaths, ICU, and hospitalisation numbers seemed to have moderated these findings. These findings are consistent with studies that report that severity of COVID-19 outbreaks can increase the detrimental impact on prehospital care of stroke/TIA[83,101].

Although we observed a statistically significant mean increase in response and total prehospital intervals during COVID-19, evidence on specific parameters for clinical significance in this domain appear to be lacking. However clinical significance could be implied as stroke and TIA are time-sensitive conditions. As 1.9 million neurons are lost per minute in a typical large vessel, supratentorial acute ischemic stroke, expediency is proven to optimise clinical and functional outcomes[121]. As stroke/TIA are usually classified as higher-level responses within the context of emergency care, the standard time window for each interval is relatively short. As a result, even seemingly short periods of time could have clinical significance.

Studies reported that prehospital delays could have resulted from increased EMS workload during the pandemic[55,88,95,96,99,100,119]. The donning and doffing of PPE, ambulance decontamination procedures between patients, and other infection prevention and control processes could have increased ambulance intervals [55,88,95,96,98,99,119]. Also, in some locations searching for receiving hospitals with sufficient capacity increased prehospital delays[55,88,96,119]. One study reported

decreased numbers of general ambulances and the introduction of COVID-19 specific ambulances during the pandemic[98]. Despite the life-threatening nature of cerebrovascular conditions, multiple studies report that patients were still reluctant to contact EMS due to the fear of contracting COVID-19[43,44,48,55,79,86,88,95]. COVID-19 related restrictions, such as social distancing and travel restrictions, may have resulted in the absence of witnesses to stroke[55]. Furthermore, individuals with minor stroke/TIA may not have considered their symptoms as serious or worrisome enough to call an ambulance during a pandemic[19,52-56]. However, one study from Spain reported that patients could not contact the EMS call centre as the system was overwhelmed[101]. Most studies recommend an increased effort to raise awareness of the importance of seeking timely care for stroke/TIA regardless of health care crises[88,120].

We found significant heterogeneity between studies when ambulance intervals and call volume were pooled in a meta-analysis. This can largely be explained by systematic differences between studies. When we carried out subgroup meta-analyses, including studies with common characteristics, we found a reduction in heterogeneity and variance. In term of ambulance time intervals, different locations, severity of the COVID-19 outbreak in an area (investigated using COVID-19 cases/million, COVID-19 deaths/million, COVID-19 ICU cases/million, COVID-19 hospitalisations/million), location of stroke diagnosis, and duration of the COVID-19 period seemed to have increased heterogeneity. In terms of call volume, the location of stroke diagnosis, definition of call volume, income level of the country, and

severity of COVID-19 outbreak seemed to have increased heterogeneity.

Asymmetry of the funnel plots for response, patient care, total prehospital interval, and call volume, may suggest possible publication bias. However, other factors may also have contributed to observed asymmetry. The broad range of results from the critical appraisal of studies and the result of the GRADE process indicate that study quality varies. Quality of included studies, in terms of design and statistical analysis, can influence the symmetry of funnel plots. True heterogeneity can also be a factor. As previously discussed, high levels of heterogeneity are observed between included studies when pooled in meta-analyses. Sample sizes vary between studies, which may also contribute to this observation [122].

The ambulance time intervals chosen[28] for this review captured key intervals within the prehospital phase of care and were chosen on the recommendation of expert stakeholders. Terminology varied between studies. Definitions of ambulance time intervals also differed across articles, with intervals being measured from differing beginning and endpoints. Furthermore, terminology surrounding prehospital care and call volume were heterogenous across the literature. The range of terminology used internationally was challenging to comprehend and synthesise, thus expert stakeholder involvement was critical throughout. Statements of definitions in articles and in the longer-term harmonisation or alignment of international definitions would facilitate optimal international comparison.

A systematic review and meta-analysis were chosen as the most appropriate methodological approach for this review, given its aim to synthesise international evidence on prehospital time intervals and call volume during COVID-19[124,135]. This approach enables the identification and investigation of variations and conflicting findings across studies, supports the generation of evidence-based recommendations, and informs future research and planning for healthcare crises[124]. While a scoping review was initially considered—given its strength in mapping key concepts, summarising available literature, and identifying knowledge gaps—it was deemed less suitable for the specific objectives of this review[124]. As prehospital time intervals and call volume are internationally recognised key performance indicators, a systematic approach with quantitative synthesis was better positioned to evaluate trends, assess heterogeneity, and produce findings that can directly inform decision-making and policy development[124,125].

3.9.1 Strengths and Limitations

Our review had several strengths. We followed a prepared protocol, conducted a robust systematic search including forward and backward citation chaining, and involved PPI contributors and expert clinical stakeholders throughout the process.

However, our review also had limitations. For the fourteen papers focusing on prehospital stroke/TIA care alone, the stroke/TIA cases relied on dispatch or EMS clinician impressions. Thus, no clinical diagnoses were confirmed, so these studies solely focused on suspected stroke/TIA. However, as this review focuses on the

prehospital response to suspected stroke and TIA, these studies are appropriate to include as they offer insight into the system response during the COVID-19 pandemic. Most studies included in this review were observational. Some studies recognised and adjusted for confounders, however residual and unmeasured confounding was of concern in other studies, which did not consider confounders such as traffic volume and urban/rural locations[123]. For these reasons, the power of the cumulative evidence is low. Also, as the COVID-19 pandemic is a rapidly changing phenomenon, further evidence may emerge outside the timeline of this review. However, the inclusion of citation chaining, and the time covered means that the first two years of the pandemic period were captured in this study.

3.9.2 Future Research

The current literature focuses on high-income countries, early pandemic waves, and effects of the pandemic on healthcare systems. Future research may include investigations into targeting cohorts reluctant to present during crises. Qualitative research with stroke and TIA survivors/carers would allow exploration of hesitation to present to hospital during health crises, and potential effects of patient education/public health messaging around cerebrovascular diseases. Also, research comparing multiple waves of the pandemic is required, in a variety of countries with different social, structural, and economic characteristics to track any persistent effects and encourage policymakers and clinicians to formulate appropriate future

action.

3.10 Conclusion

Our findings demonstrate that response interval and total prehospital interval increased for suspected adult stroke/TIA cases during the COVID-19 pandemic. Also, emergency call volume for suspected stroke/TIA deceased during the pandemic. Harmonisation of the terminology and definitions for ambulance intervals would facilitate optimal international comparison. Future research may seek to understand the reasons behind these findings, in order to minimise prehospital delays for suspected stroke/TIA in future pandemics or other health care crises.

3.11 Author contributions

E Burton - Conceptualisation, methodology, formal analysis, investigation, writing - original draft, visualisation, project administration. **J Aladkhen -** Methodology, data curation, writing – review & editing. **C O'Donnell** - Methodology, writing – review & editing. **S Masterson** - Methodology, data curation, writing – review & editing. **Á Merwick** - Conceptualisation, methodology, writing – review & editing, supervision, funding acquisition. **VJC McCarthy -** Conceptualisation, methodology, writing – review & editing, supervision, funding acquisition. **PM Kearney -** Conceptualisation, methodology, writing – review & editing, supervision, funding acquisition. **CM Buckley -** Conceptualisation, methodology, writing – review & editing, supervision, funding acquisition.

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Chapter 4: Temporal trends of ambulance time intervals for suspected stroke/transient ischaemic attack (TIA) before and during the COVID-19 pandemic in Ireland: a quasi-experimental study

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Temporal trends of ambulance time intervals for suspected stroke/transient ischaemic attack (TIA) before and during the COVID-19 pandemic in Ireland: a quasi-experimental study | BMJ Open

4.1 Abstract

Objectives

Time is a fundamental component of acute stroke and transient ischaemic attack (TIA) care. Thus, minimising prehospital delays is a crucial part of the stroke chain of survival. COVID-19 restrictions were introduced in the Republic of Ireland in response to the pandemic, which resulted in major societal changes. However, current research on the effects of the COVID-19 pandemic on prehospital care for stroke/TIA is limited to early COVID-19 waves. Thus, we aimed to investigate the effect of the COVID-19 pandemic on ambulance time intervals and suspected stroke/TIA call volume for adults with suspected stroke and TIA in the Republic of Ireland, from 2018 to 2021.

Design

We conducted a secondary data analysis with a quasi-experimental design.

Setting

We used data from the National Ambulance Service in the Republic of Ireland. We defined the COVID-19 period as "1st March 2020 – 31st December 2021" and the pre-COVID-19 period as "1st January 2018 – 29th February 2020".

Primary and secondary outcome measures

We compared five ambulance time intervals: "allocation performance", "mobilisation performance", "response time", "on scene time" and "conveyance time" between the two periods using descriptive statistics and regression analyses.

We also compared call volume for suspected stroke/TIA between the pre-COVID-19 and COVID-19 periods using descriptive statistics and interrupted time series analysis.

Participants

We included all suspected stroke/TIA cases ≥18 years who called the National Ambulance Service from 2018 to 2021.

Results

40,004 cases were included: 19, 826 in the pre-COVID-19 period and 20,178 in the COVID-19 period. All ambulance time intervals increased during the pandemic period compared with pre-COVID-19 (all $p<0.001$).

Conclusions

A “shock” like a pandemic has a negative impact on the prehospital phase of care for time-sensitive conditions like stroke/TIA. System evaluation and public awareness campaigns are required to ensure maintenance of prehospital stroke pathways amidst future healthcare crises. Thus, this research is relevant to routine and extraordinary prehospital service planning.

4.2 Introduction

Prehospital care is emergency medical care given to patients before arrival at hospital after activation of EMS[1]. Time is a fundamental component of acute stroke care[2]. Prehospital management of stroke aims to shorten time to stroke diagnosis and treatment by following the stroke chain of survival[3,4]. This can be summarised using the "8Ds": detection, dispatch, delivery, door, data, decision, drug/device and disposition[5]. Prehospital practitioners engage in the first four steps of this process[5]. Administration of treatments available for ischaemic stroke, such as thrombolysis, is time-sensitive[6]. Thus, minimising the time window between symptom onset to treatment reduces the occurrence of rapid and irreversible neurological damage[2,6].

However, EMS can face challenges in this context, including extraction, patient access, communication and accurate identification of cerebrovascular disease[7,8]. From the patient perspective, prehospital delays can result from a delay in recognising the relevance of symptoms and in raising the alarm by the patient or bystander witnessing the stroke[3]. Due to the time-dependent nature of interventions for stroke/TIA, it is imperative that stroke/TIA survivors present to hospital as soon as possible after symptoms develop[9].

The WHO classified COVID-19 as a pandemic on 11th March 2020[10]. The first confirmed case of COVID-19 in the Republic of Ireland was notified on 29 February 2020[11]. Thereafter, the Republic of Ireland experienced five waves of COVID-19[12]. The first wave began on 1st March 2020 and the fifth on 19th December 2021[12]. Throughout March 2020, a suite of non-pharmacological interventions was

introduced by the Republic of Ireland's government to contain the virus[13,14]. Subsequently the first lockdown was enforced on 27 March 2020[13,14]. On 1st May 2020, the Taoiseach (Prime Minister) announced a roadmap for the five-phased reopening of society[15]. After almost 2 years of COVID-19 measures, the government removed most restrictions on 28th February 2022[16]. The removal of the mask mandate in healthcare settings occurred on 19th April 2023[17]. Thereafter, on 5th May 2023, the WHO determined that COVID-19 no longer qualified as a public health emergency of international concern[18].

Thus, the COVID-19 pandemic, including the changes mentioned above, has disrupted healthcare systems, placing considerable strain on medical resources, while also inducing notable shifts in social norms and behaviours[19-21]. Furthermore, the WHO and many international reports have acknowledged the wide-ranging impact of the pandemic on stroke services and marked decline in acute stroke presentations[19-21]. Patients may have been hesitant to call an ambulance during the pandemic due to fear of contracting COVID-19[22]. Prehospital delays have occurred for stroke/TIA patients during the COVID-19 pandemic, which can impact on later stages of the acute stroke pathway[9,22,23]. However, there are no national studies to date on whether suspected stroke/TIA ambulance time intervals and call volume in the Republic of Ireland changed before and during the COVID-19 pandemic.

4.2.1 Aims

We aimed to investigate the effect of the COVID-19 pandemic on ambulance time intervals and emergency call volume for adults with suspected stroke/TIA in the Republic of Ireland, from 2018 to 2021.

4.3 Ethics approval

Ethical approval was granted by the Clinical Research Ethics Committee of the Cork Teaching Hospitals ECM 4 (h) 05/04/2022 & ECM 3 (v) 28/03/2023 ***(appendix 4.1)***.

4.4 Methods

4.4.1 Study design

We conducted a secondary data analysis with a quasi-experimental design using data from the NEOC of the NAS in the Republic of Ireland[24,25]. We followed the Transparent Reporting of Evaluations with Nonrandomized Designs (TREND) checklist when reporting this study[26].

4.4.2 Data source

NAS is the statutory prehospital emergency care provider in the Republic of Ireland[27]. NAS provides services to over 102 ambulance stations across Ireland and take upwards of 300,000 calls annually[27]. NEOC operates the call taking and dispatch functions of the NAS[24].

The NEOC data set contains information on emergency call volume and ambulance time intervals (from call received to the resource going clear or being stood down) for all calls made to NAS, captured using Geotagging software[28]. A resource in this context is defined as a NAS paramedic who attends the patient[29]. Geotagging refers to *"the process of adding geospatial identification metadata to various types of media"*[29]. The dataset is vast, with an array of topics and perspectives, including call, resource, and crew. Each topic can be subdivided into a perspective within which there are a list of fields available to return a result such as time, date, patient name, clinical notes, etc. The data are available on request for research purposes by applying to the Business Analyst in NEOC, after approval has been granted by the NAS Research Committee.

From 1st January 2018 to 31st December 2021, 1,028,492 emergency calls (999/112) were made to NAS. A 999/112 call is a call made to the EMS by a member of the public[29].

For this study, we requested a dataset from the resource perspective of AMPDS[30] (further information on the AMPDS stroke code protocol can be found in ***appendix 4.2***) code 28 (term used in the AMPDs system for suspected stroke/TIA call) adult cases between 1st January 2018 and 31st December 2021.

4.4.3 Variables and definitions

Variables on suspected stroke/TIA cases from the NEOC data set included:

4.4.3.1 Outcomes

The primary outcomes for this study were five ambulance time intervals, and the secondary outcome was emergency call volume for suspected stroke/TIA.

Ambulance time intervals

An "ambulance time" is *"a specific event within the EMS response"*,[31] whereas an "ambulance time interval" is *"the temporal distance between two times"*[31]. We analysed five ambulance time intervals in this analysis. We used the Health Information and Quality Authority (HIQA) definitions,[32] which are reported by NEOC **(table 4.1)**.

Table 4.1 - Ambulance times and intervals reported by the National Ambulance Service included in this study[32]

Ambulance Time Interval	Definition	Constituent Ambulance Times	Definition
Allocation performance	Allocation Time **minus** T5 Time	Despatch Code Established (T5 time)	The time the Despatch Code is established from ProQA (priority dispatch system software)
		Resource Allocation Time	The time a resource has been allocated to an incident on the Computer Aided Dispatch (CAD) system
Mobilisation Performance	Mobile Time **minus** T5 Time	Despatch Code Established (T5 time)	The time the Despatch Code is established from ProQA
		Resource Mobile Time	The time the resource goes mobile on the incident, either through radio selective call (selcall*) by the crew, voice or Automatic Vehicle Location (AVL) update
Response Time	Resource at Scene Time **minus** T5 Time	Despatch Code Established (T5 time)	The time the Despatch Code is established from ProQA
		Resource At Scene Time	The time the resource arrives at the scene of the incident. This is captured by a selcall 'At Scene' from the crew, by voice or by AVL update

Ambulance Time Interval	Definition	Constituent Ambulance Times	Definitions
On Scene Time	Resource Left Scene Time **minus** Resource at Scene Time	Resource At Scene Time	The time the resource arrives at the scene of the incident. This is captured by a selcall 'At Scene' from the crew, by voice or by AVL update
		Resource Left Scene Time	The time the responding crew have completed treatment, have the patient on board and are about to leave the scene for hospital. Given through Selcall 'Left Scene', by voice or AVL update
Conveyance Time	At Hospital Time **minus** Left Scene Time	Resource At Hospital Time	The time the resource arrives at the hospital. Given via Selcall 'At Hospital', by voice or AVL update
		Resource Left Scene Time	The time the responding crew have completed treatment, have the patient on board and are about to leave the scene for hospital. Given through Selcall 'Left Scene', by voice or AVL update

*Sellcall - type of protocol used in radio communications systems, in which transmissions include a brief burst of sequential audio tones.

As a result, all ambulance time intervals investigated align with the Ulstein recommendations for emergency stroke care[33].

We used the shortest allocation, mobilisation and response times[32] for the call, regardless of resource. The on-scene and conveyance time[32] for the transporting resource (resource that conveys the patient to hospital) were used. Where there were multiple resources, the transporting resource was assigned to the first resource at scene. If this resource did not have a conveyance time, then the transporting ambulance was assigned to the next ambulance on scene.

Call volume

We classified call volume as the number of unique suspected stroke/TIA cases per day, week, month or wave.

4.4.3.2 Covariates

From the above variables, we identified covariates for inclusion related to prehospital stroke response, based on reviewing the literature and input from expert stakeholders. These included demographic, geographical, service and clinical factors.

Demographic factors included sex (male, female, unknown) and patient age.

Geographical factors included information on the location of the suspected stroke/TIA. Within the NEOC data set, the location of the call is presented in the form of latitude and longitude. We then mapped this to publicly available settlement boundary files from the most recently available Census[34]. An urban settlement is defined as a town with a total population of 1500 or more,[34] whereas a rural

settlement is a town with a population of less than 1500 people[34]. Any calls with latitude and longitude outside of a settlement were classed as rural[34]. We also included geographical location as a potential confounder as evidence suggests urban versus rural incident locations can impact on ambulance time intervals, and thus patient outcomes[35,36].

The NEOC data set in this study included a range of service factors; number of resources, monthly 999/112 calls, call stop reason, hour call starts and time status. We classified hour call starts as early morning (00:00– 5:59), late morning (06:00–11:59), early evening (12:00–17:59) and late evening (18:00–23:59). Method of call included five categories in the initial data set: healthcare professional, emergency services, out of hours doctor, public access and missing. We collapsed these categories into "112 or 999" (public access), "non 112 or 999" (healthcare professional, emergency services, out of hours doctor) and "missing". This variable was included to identify whether the source of the call would have an effect on the time intervals. Call stop reason initially included 28 categories. We recoded this variable into: N/A, patient factor and service factor. Priority dispatch code[37] (Govstd.) included amber, red and green. Red indicates a life-threatening condition other than cardiac or respiratory arrest; amber indicates the condition is serious not life threatening - immediate, and green; non serious or non-life threatening[37]. Time status (time since last known well) was classified, as per the NEOC data set, as <4 hours, >4 hours, unknown. Time since last known well is a key determinant for amber versus red designation. Typically calls with a time status of >4 hours are coded amber.

Clinical variables included AMPDS[30] determinant descriptors and time status (time since patient was last known to be well). Within the code stroke protocol in AMPDS[30], and thus the NEOC data set, there are 13 determinant descriptions. AMPDS provides a scripted caller interrogation protocol to prioritise calls and allocate EMS resources to incidents via the linked ProQA (Priority Dispatch, ProQA software system https://www.prioritydispatch.net/en/proqa). The code is generated during the initial triage of the call, based on responses given to certain questions asked by the call-taker. Further information regarding this process and determinant descriptors including common stroke/TIA symptoms and presentations can be found in ***appendix 4.2***. We recoded these into five categories for clarity of interpretation - not alert, breathing, sudden onset of stroke/TIA symptoms, history of cerebrovascular disease, and other ***(appendix 4.3)***. These five categories were created by grouping common determinants together, for example, those relating to breathing or history of stroke/TIA. Presence of abnormal breathing alone does not trigger a stroke code.

Weeks

The NEOC data set was reported in International Standards Organisation (ISO) weeks[38]. ISO weeks run from Monday to Sunday[38]. Thus, we transformed the data into epidemiological weeks[39] to accurately compare outcomes during the COVID-19 waves. Epidemiological weeks were used by the Health Protection Surveillance Centre (HPSC) in the Republic of Ireland when reporting COVID-19 data[38]. An epidemiological week runs from Sunday to Saturday[38]. Epidemiological weeks were also used to calculate monthly call volume.

4.4.3.3 Additional covariates external to the NEOC data set

COVID-19 pandemic

In this study, we defined the pre-COVID-19 period as "1st January 2018 to 29th February 2020" (790 days) and the COVID-19 period as "1st March 2020 – 31st December 2021" (671 days). This period was chosen to reflect two years before and during the pandemic. The HPSC defined the waves of the COVID-19 pandemic in the Republic of Ireland as follows[12]:

Wave 1: 1st March 2020 to 1st August 2020 = 154 days

Wave 2: 2nd August 2020 to 21st November 2020 = 112 days

Wave 3: 22nd November 2020 to 26th June 2021 = 217 days.

Wave 4: 27th June 2021 to 18th December 2021 = 175 days.

Wave 5 (partial): 19th December 2021 to 31st December 2021 = 13 days.

Only partial data from wave 5 are included in this study, due to data availability at the time of conducting the study. The HPSC's website states that wave 5 was from 19th December 2021 to 27th February 2022. Thus, to ensure all 2021 data were included, reflecting two pandemic and two pre-pandemic years, we analysed partial data from wave 5.

Pandemic waves were included in this analysis as they represent changes in the suite of measures introduced during the COVID-19 pandemic in the Republic of Ireland. Moreover, there is evidence indicating that fluctuations in COVID-19 case numbers, transitioning from baseline to 'surges', can lead to alterations in EMS utilisation[40,41].

Traffic volume

Traffic volume is "*the number of vehicles that pass a given point on the roadway in a specified period of time*" [42]. Publicly available traffic count data from Transport Infrastructure Ireland (TII) was used[42,43]. For 2019 - 2021, weekly national data from the COVID-19 traffic patterns report[42] were summed for each month. As this report did not include 2018, data from the TII monthly traffic volume report were used[44]. This report was presented by areas covered by traffic counters, thus mean monthly traffic volume was calculated. An expert stakeholder from the TII advised on this process to ensure standard methods were used. We included traffic volume in the ambulance time interval analysis, as this could impact on the response and conveyance intervals[45,46]. Furthermore, it is as an indicator of the changes in public health restrictions throughout the waves.

Nitrogen dioxide levels

We followed the method laid out in Spohn et al. 2022[47] to calculate monthly nitrogen dioxide levels for the Republic of Ireland using publicly available Environmental Protection Agency data[48]. Data files are available for regions Cork, Dublin, Waterford, Limerick and Galway. However, county coverage can vary per year. Nitrogen dioxide levels (presented in Âµg/m3) measured per day per area covered by a nitrogen dioxide metre are available. We calculated the mean value per day per area using this data. From this, we calculated a mean monthly value per area. The mean value of these readings was calculated, providing an approximate mean monthly nitrogen dioxide level for the Republic of Ireland. In the suspected stroke/TIA emergency call

volume analysis, we included nitrogen dioxide levels for the period of analysis as this pollutant can increase the risk of cerebrovascular disease[49-52].

4.4.4 Statistical analysis

4.4.4.1 Descriptive statistics

Categorical variables are presented as frequencies and percentages, and numerical variables are presented as mean (± SD) or median (with IQR). We carried out $\chi 2$ tests and t-tests to test for differences in the independent variables between the COVID-19 and pre-COVID-19 periods. We considered p values of <0.05 to be statistically significant.

4.4.1.2 Linear regression analyses

Ambulance time intervals

We carried out multivariable ordinary least squares linear regression on the five ambulance times intervals in **table 4.1**. For the regression analyses, the log of the performance times was used as the dependent variables since the exploratory analysis identified heteroscedasticity in these variables ***(appendix 4.3)***.

We also scaled the two numeric covariates, monthly emergency calls and monthly traffic volumes, removed any cases where the relevant time interval was missing and removed the cases with missing call method.

We included a number of covariates in the five regression models, to reflect relevant service and geographical factors:

- Number of days since 1st January 2018 (numdays). The numdays variable was

included in the ambulance time interval analysis to try and control for the effect of time on the time intervals.

- COVID-19 waves 1 - 5.
- Time of call, call method, number of resources.
- Call location, prioritisation code, AMPDS dispatch determinant, time status (time since last known well).
- Monthly total emergency call volume.
- Monthly mean traffic volume.

4.4.1.3 Interrupted times series analysis

Call volume

We carried out an interrupted time series analysis using an autoregressive integrated moving average (ARIMA) model, following the method described by Righetti and Hyndman et al[53]. This allowed us to test the effect of the COVID-19 pandemic on suspected stroke/TIA call volume.

We defined the variables for inclusion as follows:

- A dummy variable to denote the COVID-19 pandemic (assigned 0 to all values up until March 2020 and 1 to all values from March 2020 to Dec 2021).
- A variable to capture change over time (i.e., the cumulative effect of the intervention). This was done by assigning 0 to all values up until March 2020 and then successive integers from 1 to 22 to each month from March 2020 to December 2021.

- The first of these variables represents the effect of an abrupt intervention maintained over time and the second of an intervention (COVID-19) with cumulative effect over time.
- Predictor variables: total monthly emergency call volume and mean monthly nitrogen dioxide levels.

We used the auto. arima function in the forecast package[54] in R V.4.0.3 to carry out the analysis. This automatically fits multiple models to the call volume time series and chooses the one of best fit. The selected model was an ARIMA (0,0,0). The ARIMA model was then fit to the pre-COVID data-19 (where the variables measuring COVID-19 impact are set to 0) and used to predict the expected call volume for each month of COVID from March 2020 to Dec 2021. We carried out a Box Ljung test of the model residuals.

4.4.5 Patient and Public Involvement

EB worked with a Patient and Public Involvement (PPI) panel of 13 stroke and TIA survivors and their family members from refinement of the research question to dissemination of findings. We describe PPI in this study in detail using the Guidance for Reporting Involvement of Patients and the Public (GRIPP2 checklist (short version)[55] ***(appendix 4.4)***.

4.6 Results

4.6.1 Overall sample

We included 40,004 suspected adult stroke/TIA cases between 1st January 2018 and 31st December 2021. Of these, 19, 826 cases occurred pre-COVID-19 period, and 20,178 cases occurred during the COVID-19 period. The mean age was 70.4 (±16.9) years, and 19,006 (47.51%) stroke/TIA survivors were male. ***Appendix 4.5*** includes the breakdown of suspected stroke/TIA cases per year and by sex. ***Appendix 4.6*** includes the geographical breakdown of calls.

4.6.2 Sample Characteristics during the pre-COVID-19 and COVID-19 periods

Table 4.2 displays the sample characteristics during the pre-COVID-19 and COVID-19 period, including over the five waves.

Table 4.2 - Characteristics of suspected adult stroke/TIA cases during the pre-COVID-19 versus COVID-19 period

Variable	Pre-COVID-19 (N = 19,826)	COVID-19 (N = 20,178)	p-value
Sex*			
Male	9198 (46.4%)	9808 (48.6%)	p=0.73
Female	9602 (48.4%)	10314 (51.1%)	
Age			
Median, (IQR)	75, (62-83)	74, (60-83)	p<0.001
Time of day of call			
00:00 - 5:59	1295 (6.5%)	1415 (7.0%)	p<0.05
06:00-11:59	5565 (28.1%)	5692(28.2%)	
12:00-17:59	7793 (39.3%)	8016 (39.7%)	
18:00-23:59	5173 (26.1%)	5055 (25.1%)	
Call location			
Urban	11252 (56.8%)	11064 (54.8%)	p<0.001
Rural Settlement	2042 (10.3%)	2125 (10.5%)	
Rural	6532 (32.9%)	6989 (34.7%)	
Determinant descriptor			
Abnormal Breathing	1633 (8.2%)	1911 (9.5%)	p<0.001
Breathing Normally <35	20 (0.1%)	15 (0.07%)	
Breathing Normally >=35	929 (4.7%)	836 (4.1%)	
Not Alert	7549 (38%)	7286 (36.1%)	
Stroke Charlie Override	0 (0%)	8 (0.04%)	
Stroke History	364 (1.8%)	314 (1.6%)	
Sudden Loss of Balance or Co-Ordination	617 (3.1%)	738 (3.7%)	
Variable	**Pre-COVID-19 (N=19826)**	**COVID-19 (N=20178)**	

Determinant descriptor continued			
Sudden Onset of Severe Headache	229 (1.2%)	264 (1.3%)	
Sudden Paralysis or Facial Droop	1487 (7.5%)	1380 (6.7%)	
Sudden Speech Problems	3027 (15.3%)	3052 (15.1%)	
Sudden Vision Problems	739 (3.7%)	907 (4.5%)	
Sudden Weakness or Numbness	2920 (14.7)	3205 (15.9%)	
TIA History	196 (1%)	182 (0.9%)	
Unknown Status or NA	116 (0.7%)	80 (0.4%)	
Time Status			
>4 hours	5459 (27.5%)	6182 (30.6%)	p<0.001
<4 hours	13524 (68.2%)	13177 (65.3%)	
Unknown	843 (4.3%)	819 (4.1%)	

*Unknown or missing - patient sex was not entered into the electronic healthcare record by the prehospital practitioner and there was an indexing error in the database, resulting in some records in the dataset not returning a value for sex for November 2018.

During the pandemic, suspected stroke/TIA patients were younger; 74 years (60–83) than pre-pandemic; 75 (62–83), p<0.001. A higher proportion of cases were from rural areas during COVID-19; 6989 (34.6%) than pre-COVID-19; 6532 (32.9%), p<0.001. ***Appendix 4.7*** provides more information on call location during the two periods. Furthermore, more cases presented with abnormal breathing (1911 (9.5%) vs 1633 (8.2%)), and >4 hours after symptom onset (6182 (30.6%) vs 5459 (27.5%)) during the pandemic, p<0.001.

More calls were stopped during the COVID-19 period; 1833 (9.1%) than pre-COVID-19; 1614 (8.1%), p<0.001. More cases presented from 12:00 to 17:59 during COVID-19 8016 (39.7%) than pre-COVID-19; 7793 (39.3%), p=0.04. More calls were made by public access (15 253 (75.6%) vs 14 674 (74%)). There were more amber calls ((7015 (34.8%) vs 6310 (31.8%)) and less red calls (13 163 (65.2%) vs 13 516 (68.2%)) in the COVID-19 period compared with pre-COVID-19, p<0.001.

Appendices 4.8 and 4.9 include information on the number of 999/112 calls and types of resources used during the pre-COVID-19 and COVID-19 period.

Appendix 4.10 provides information on comparing number of resources with time status.

4.6.3 Ambulance time intervals

Allocation performance (n=39 962), mobilisation performance (n=39 936), response time (n=39 604), on-scene time (n=36,4,28), and conveyance time (n=36 419) contained different case numbers due to different resources being stood down at various points on the patient journey[56]. ***Appendix 4.11*** provides further information on the distribution of ambulance time intervals across the study years.

We found an increase in all time intervals during COVID-19 compared with pre-COVID-19 (**table 4.3**, ***appendix 4.12*)**.

Table 4.3 - Mean ambulance time intervals for suspected adult stroke/TIA cases during the pre-COVID-19 and COVID-19 period

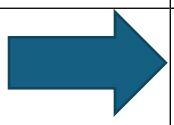
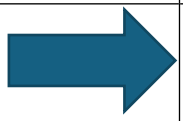
Time Period	Mean Allocation Performance	Mean Mobilisation Performance	Mean Response Time	Mean On Scene Time	Mean Conveyance Time
Pre-COVID-19	38 secs	2 mins	17 mins 25 secs	23 mins 01 second	26 mins 27 secs
COVID-19	1 min 27 secs	2 mins 40 secs	19 mins 3 secs	26 mins 11 seconds	27 mins 30 secs
Difference pre-COVID vs COVID	49 secs	40 secs	1 min 38 secs	3 mins 10 secs	1 min 3 secs
P-value	<0.001	<0.001	<0.001	<0.001	<0.001

Appendix 4.13-4.15 include the distribution of the time intervals in the dataset during the COVID-19 vs pre-COVID-19 periods.

4.6.3.1. Linear regression analyses

Table 4.4 summarises the results of the linear regression analyses. ***Appendix 4.16*** includes full outputs from the regression models.

Table 4.4 - Results of Regression Analyses of Log of Time Intervals: COVID-19 waves compared to pre-COVID-19

Time intervals	Wave 1	Wave 2	Wave 3	Wave 4	Wave 5 (Partial data)
Allocation Time	Increase (p<0.001)	Increase (p<0.001)	Increase (p<.001)	Increase (p<0.001)	Increase (p<0.001)
Mobilisation Time	Increase (p<0.001)	Increase (p<0.05)	 No Change (p=0.24)	Increase (p<0.001)	Increase (p<0.001)
Response Time	Increase (p<0.001)	Increase (p<0.001)	Increase (p<0.001)	Increase (p<0.001)	Increase (p<0.001)
On Scene Time	Increase (p<0.001)	No Change (p=0.09)	Increase (p<0.001	No Change (p=0.12)	Increase (p<0.05)
Conveyance Time	No Change (p=0.60)	 No Change (p=0.08)	Increase (p<0.05)	Increase (p<0.001)	No Change (p=0.13)

*The following variables were held constant: Numdays, Time of Day, Method of Call, Number of Resources Allocated to Call, Urgency of Call, Location Type of Call, AMPDS Descriptor, Time Status, Total Monthly Emergency Calls, Monthly Traffic Volume.

** The p-values from the linear regression models indicate whether the effects of each wave of COVID-19 on each of the ambulance time intervals listed is statistically significant while holding the variables listed under the table constant.

Allocation performance

When all other variables are held constant all the wave numbers show a significant increase ($p<0.001$) in log of allocation performance compared with pre-COVID-19. While the number of days since 1st Jan 2018 (numdays) is significantly negatively associated with log of allocation performance.

Mobilisation performance

When all other variables are held constant all the wave numbers, except for wave 3 show a significant increase ($p<0.001$) in log of mobilisation performance compared with pre-COVID-19. While the number of days since 1st Jan 2018 (numdays) is significantly negatively associated with log of mobilisation performance.

Response time

When all other variables are held constant all the wave numbers, show a significant increase ($p<0.001$) in log of response time compared with pre-COVID-19. While the number of days since 1st Jan 2018 (numdays) is significantly negatively associated with log of response time.

On scene time

When all other variables are held constant waves 1,3 and 5 show a significant increase ($p<0.001$) in log of on scene time compared with pre-COVID-19. While the number of days since 1st Jan 2018 (numdays) is significantly positively associated with log of on scene time.

Conveyance time

When all other variables are held constant, waves 3 and 4 show a significant increase ($p<0.001$) in log of conveyance time compared with pre-COVID-19. While the number of days since 1st Jan 2018 (numdays) is not associated with log of conveyance time.

4.6.4 Call volume for total emergency calls and suspected stroke/TIA

4.6.4.1 Overall emergency weekly call volume

1,028,492 emergency calls, including 40,004 suspected stroke/TIA calls were made from 2018 to 2021. When compared with total emergency call volume (AS1 calls) suspected stroke/TIA calls increased faster than total call volume in late 2020 and in 2021 ***(appendix 4.17)***.

4.6.4.2 Monthly suspected stroke/TIA call volume

As seen in **figure 4.1** and **figure 4.2** monthly suspected stroke/TIA call volume during COVID-19 was gradually increasing until wave 3, when we observed a rapid increase in suspected stroke/TIA call volume. Furthermore, two dips in suspected stroke/TIA call volume occurred in wave 1 and wave 4 (**figure 4.1 and 4.2, *appendices 4.18 and 4.19*)**.

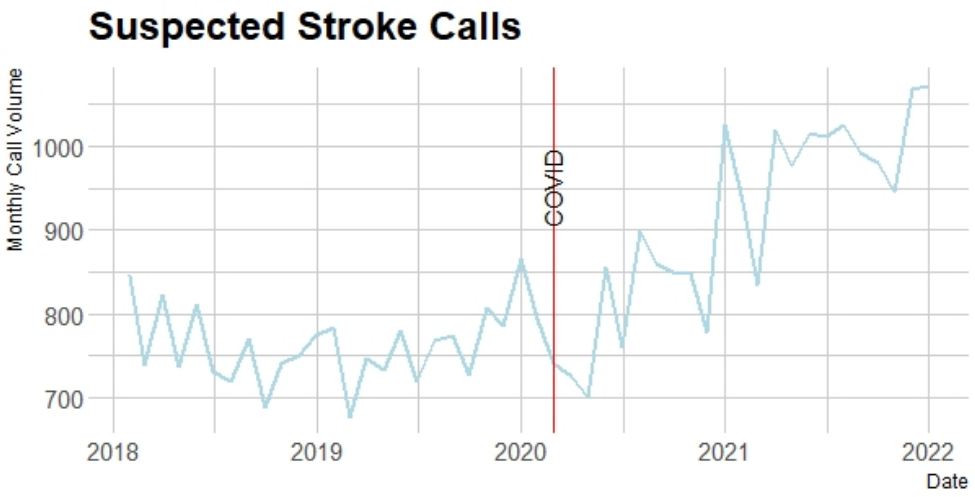


Fig. 4.1 - Monthly time series graph of emergency call volume for suspected stroke/TIA from 2018 to 2021 displaying the COVID-19 period

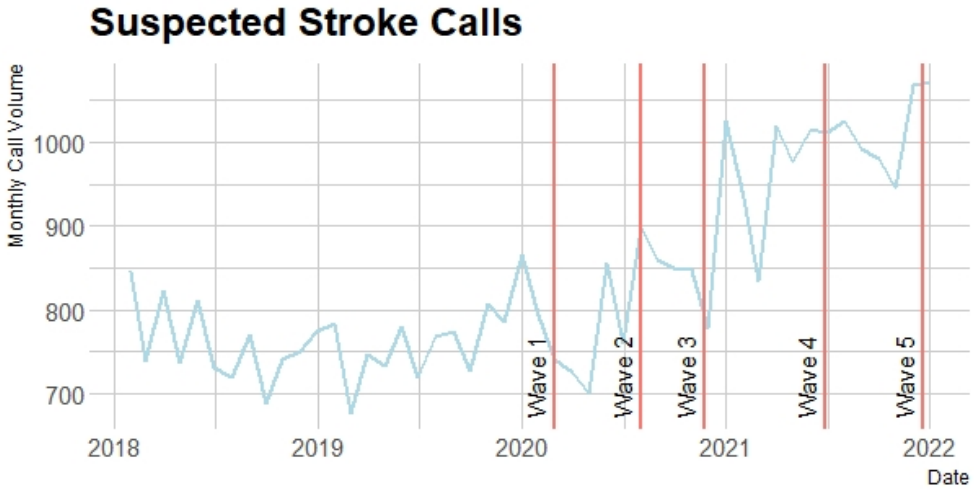


Fig 4.2 - Monthly time series graph of emergency call volume for suspected stroke/TIA from 2018-2021 displaying the COVID-19 waves

4.6.4.3 Daily suspected stroke/TIA call volume

Suspected stroke/TIA call volume increased during COVID-19, with approximately 30 mean calls/day during COVID-19 and approximately 25 mean calls/day during pre-COVID-19. Calls per day during COVID-19 were gradually increasing until wave 3, when we observed a rapid increase in suspected stroke/TIA call volume ***(appendix 4.20)***.

4.6.4.4 Results of the Interrupted time series analysis

The results of the augmented Dickey-Fuller stationarity test (−2.06, p=0.55) indicate that the time series of monthly call data is non-stationary. Taking the first order difference of the suspected stroke call time series results in a stationary time series (Dickey-Fuller=−5.68, p<0.01). After running the auto. arima the model chosen was an ARIMA (0,0,0).

Results of the residuals and autocorrelation ***(appendix 4.21-4.23)*** indicate the model is a good fit to the data. A Box Ljung test of the model residuals gives a result of x squared=0.05, p=0.83 indicating autocorrelation is not present in the data.

This model when fit to the pre-COVID-19 data predicts an increase in suspected stroke calls during March 2020, however, there was a drop in cases that month (predicted=883, actual 726). The number of cases in April 2020 was also below the predicted figure (predicted=792, actual=700). Thereafter the predicted number of cases and actual number are similar until December 2020 when there was a large increase in cases (predicted=857, actual=1025) and an increase of actual cases over

predicted was maintained every subsequent month up to the end of the dataset in December 2021 ***(appendix 4.24)***.

Figure 4.3 visualises the predicted suspected stroke/TIA call volume in the absence of COVID-19 (red), as well as the actual values (blue). Actual and predicted suspected stroke/TIA call volume start to noticeably diverge from wave three onwards.

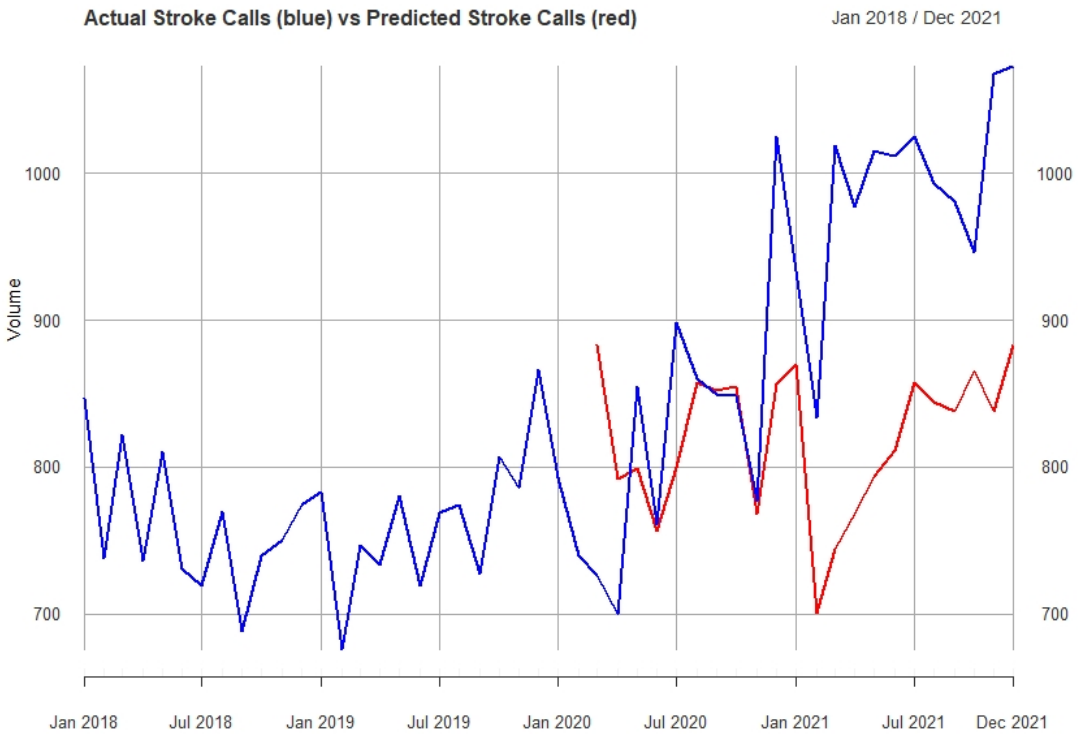


Figure 4.3 - Actual (blue) versus predicted (red) call volume for suspected stroke/TIA for the COVID-19 period.

4.7 Discussion

This analysis of prehospital ambulance time interval data reveals three key findings. Firstly, both ambulance time intervals and the volume of suspected stroke/TIA calls exhibited an increase during the pandemic. Secondly, the most significant alterations in the aforementioned outcomes were observed from wave 3 onward. Finally, during the COVID-19 pandemic, there was a notable increase in terminated calls and a higher proportion of calls with >4 hours since last known well.

4.7.1 Strengths and weaknesses

This national study investigated ambulance time intervals and call volume for suspected stroke/TIA across all pandemic waves and compared a substantial period during and pre-COVID19 to facilitate the tracking of emerging patterns. However, in reality prehospital services come under immense and sustained pressure every winter. Thus, this research also has relevance for routine prehospital service planning.

This study does not include data from the Dublin Fire Brigade so only reflects a portion of the Dublin metropolitan area. This is because both the NAS and the Dublin Fire Brigade provide EMS to Dublin. Second, due to an indexing error in the system there is missing data for sex and age in November 2018. Only approximately two weeks of wave five data were available, preventing a comprehensive analysis of the complete fifth wave. Residual confounding may be present in this study, as the included confounding variables were captured on a national and monthly level,

lacking sufficient granularity for full adjustment. Confirmation of stroke/TIA diagnosis is not included in the study as prehospital and hospital records could not be linked due to the lack of a unique health identifier in the Republic of Ireland. However, whether the diagnosis is verified, the same criteria should have been applied to patients experiencing acute stroke/TIA symptoms at the prehospital stage. Thus, this should not be a significant constraint in interpreting the results, especially trends over time. Finally, COVID-19 is an unprecedented, nuanced and complex phenomenon that impacted on healthcare and healthcare systems. It is not a uniform, discrete intervention. Even defining it as a temporal exposure may be oversimplifying its impact. However, to observe the healthcare system and human behavioural factors during this period we needed to define this time period using evidence based, nationally adopted definitions. Furthermore, we allowed for some nuance by comparing waves of the pandemic.

4.7.2 Comparison with current literature

In terms of time intervals, one study conducted in Hong Kong found a similar increase in their equivalent of conveyance time,[57] whereas a South Korean study found no significant change in this interval[58]. A recent Iranian study found an increase in all time intervals during COVID-19, when investigating all emergency calls[59]. However, an American study found a decrease in response interval and increase in on scene interval at certain points during the pandemic[60]. Two further European studies[61,62] observed an increase in time intervals for stroke/TIA cases during the COVID-19 period. In relation to suspected stroke/TIA call volume, an Australian and American study found a decrease in suspected stroke/TIA call volume during COVID-19[63,64].

Whereas other international studies found an increase in suspected stroke/TIA call volume during the period[65,66]. At the time of writing, literature in acute stroke care during the COVID-19 pandemic was primarily focused on single centre studies set in hospitals, with a lack of papers focusing on the prehospital response[67]. Available prehospital papers focus on either one or more early waves of the COVID-19 pandemic[62,67], and do not investigate emerging patterns over multiple waves. Also, current studies are mainly descriptive in nature, with the minority of studies carrying out analyses that adjusts for potential confounders[67].

4.7.3 Ambulance time intervals

During the COVID-19 period, we observed an increase in ambulance time intervals for suspected stroke/TIA calls. Time intervals displayed the greatest increase in wave four and five of the COVID-19 pandemic. This may be as the peak of the fourth wave was when Ireland's COVID-19 incidence was the highest in the European Union and service demand was higher for COVID-19 and non-COVID-19 indications[68]. As wave four and five also traverse the winter period, which historically means increased pressures for prehospital care service and staff capacity, this may have resulted in prolonged time intervals. Different factors can influence prehospital time intervals, depending on their position within the prehospital phase of care. Members of the NAS were deployed into specific COVID-19 related activities, such as COVID-19 vaccination, swabbing and the COVID-19 response room[69,70]. Additionally, the prehospital workforce was reduced due to COVID-19 isolation/restriction of movements[71]. Thus, at times less ambulance resources may have been available.

Furthermore, donning and doffing of PPE and COVID-19 prehospital disinfection protocols may have resulted in some delay[72,73].

4.7.4 Call volume for suspected stroke/TIA

We observed two dips in suspected stroke/TIA call volume occurring in approximately March 2020 and September 2021. The first dip aligns with the first COVID-19 lockdown in Ireland[74], and the second with the peak of the fourth wave, when Ireland's COVID-19 incidence was the highest in the European Union[68]. This may be indicative of a change in healthcare seeking behaviour of stroke/TIA patients during peak COVID-19 cases and "unexpected" containment measures[75-77].

The increased suspected stroke/TIA call volume from 22nd November 2020 (wave three) onwards is challenging to interpret and attempt to explain. While evidence suggests that a link may exist between COVID-19 and cerebrovascular disease, multiple systematic reviews have indicated that a causal relationship cannot be currently confirmed[78-82]. Furthermore, the Republic of Ireland's stroke audit reflects a similar pattern, as an increase in stroke cases has been seen from 2019 onwards[83]. However, this audit reports confirmed stroke diagnoses only and excludes TIAs. Moreover, the decreased presentations of TIAs during the initial waves of the pandemic might be a contributing factor to the rise in suspected stroke/TIA call volume. This is because routine TIA assessment and treatment aim to prevent subsequent strokes. Thus, the rise in suspected strokes/TIAs may have been prevented if this assessment and treatment was carried out. Finally, the number of

stroke/TIA cases presenting with “abnormal breathing” increased during COVID-19, which may partially explain the increase in suspected stroke/TIA call volume.

4.7.5 Sociodemographic and clinical factors

During the COVID-19 pandemic younger patients, those from rural areas, calling in the early hours of the morning and accessing an ambulance through a 999/112 call increased. The increased number of calls for suspected stroke/TIA survivors in rural areas may be due to the travel restrictions in-place at the time. Rural residents face longer travel distances to hospitals than their urban counterparts. Despite being faced with a medical emergency stroke survivors may have avoided personal car travel during earlier pandemic waves to comply with public health restrictions, including the five km residence limit[68,69,73]. Furthermore, more calls were stopped during the COVID-19 pandemic, with the vast majority of these due to patient factors. These factors included transport refusal, as the largest contributor to non-transports. This phenomenon has been reported on elsewhere and is considered distinct to suspected stroke/TIA survivors not seeking emergency care at all[84].

Crucially, the number of cases with symptom onset to emergency call time of >4 hours (amber calls) increased during the pandemic period. This might suggest delays in calling the ambulance service during the COVID-19 pandemic. This delay could be attributed to suspected stroke/TIA survivors hesitating to make an emergency call. Furthermore, fewer visitors due to public health restrictions decreased the possibility of a bystander witnessing the stroke and raising the alarm. Both occurrences may contribute to missed four-hour treatment windows. This

finding suggests a change in healthcare seeking behaviour of suspected stroke/TIA survivors during the pandemic. Due to the time-sensitivity of acute stroke/TIA management and treatment any delay in the stroke chain of survival could lead to worse clinical and functional outcomes. Other studies have also reported changes in demographic characteristics of those presenting with stroke/TIA during the COVID-19 pandemic,[62,85,86] whereas further studies found no change in demographics, between the two periods[57,67,87].

The COVID-19 pandemic has been noted to impact various acute emergencies, including acute coronary syndrome, psychiatric illness and musculoskeletal presentations[19,88-91]. Thus stroke/TIA are not unique, however the time critical nature of recognition and intervention means they are key indicators of healthcare access and delivery during COVID-19.

This study adopts a quasi-experimental design, which is well-suited to evaluating the effects of interventions in real-world healthcare settings where randomisation is not feasible[92-93]. Within this form of study design, an interrupted time series analysis was selected as it is considered the most robust quasi-experimental approach[94]. Interrupted time series enables evaluation of intervention effects by analysing trends and level changes across multiple time points before and after implementation, strengthening causal inference through temporal sequencing[94]. Alternative quasi-experimental designs such as before-and-after studies or natural experiments were also considered[92,95]. However, before-and-after designs lack the ability to detect changes in trends over time, limiting their inferential strength[92,94]. Natural

experiments, while potentially valuable, often rely on strong and untestable assumptions about selection on unobservable confounders, and are constrained by limited data availability[95]. Thus, interrupted time series was deemed the most appropriate and rigorous method for addressing the study objectives, to investigate the impact of a pandemic consisting of five waves on key aspects of prehospital care.

4.8 Conclusions

Study findings suggest an increase in all five ambulance time intervals from assignment of triage code to arrival at hospital for suspected stroke/TIA during the COVID-19 pandemic. Furthermore, we also found an increase in suspected stroke/TIA call volume between pre-COVID-19 and COVID-19 periods. Future work may explore the potential mechanisms behind the observed trends in this study, conduct qualitative studies to explore stroke/TIA survivor and healthcare professional experiences and compare longer time periods across different healthcare systems during the pandemic.

4.9 Author Contributions

E Burton - Conceptualisation, methodology, formal analysis, investigation, data curation, writing - original draft, visualisation, project administration. **R Quinn - Methodology**, formal analysis, data curation, visualisation, writing – review & editing. **K Crosbie-Staunton -** Methodology, data curation, writing – review & editing. **C Deasy -** Methodology, data curation, writing – review & editing. **S Masterson -** Methodology, data curation, writing – review & editing. **C O'Donnell -** Methodology,

data curation, writing – review & editing. **Á Merwick -** Conceptualisation, methodology, writing – review & editing, supervision, funding acquisition. **D Willis -** Methodology, data curation, writing – review & editing. **PM Kearney -** Conceptualisation, methodology, writing – review & editing, supervision, funding acquisition. **VJC McCarthy -** Conceptualisation, methodology, writing – review & editing, supervision, funding acquisition. **CM Buckley -** Conceptualisation, methodology, writing – review & editing, supervision, funding acquisition.

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Chapter 6a: International comparison of ambulance times terminology and definitions: a benchmarking study

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Burton E, Willis D, Boseley E, Deasy C, Franklin M, Garrison D et al. International Comparison of Ambulance Times Terminology and Definitions: A Benchmarking Study. Annals of Emergency Dispatch & Response. 2023; 11 (1): 12–17. https://www.aedrjournal.org/international-comparison-of-ambulance-times-terminology-and-definitions-a-benchmarking-study-1

6.1 Abstract

Introduction

Ambulance times and intervals are internationally recognised Key Performance Indicators (KPIs) for prehospital care. International benchmarking, by comparing ambulance times and intervals between countries is a valuable method to help to identify strengths and weaknesses across healthcare systems. However, ambulance times and intervals are not standardised across countries. Thus, this study aims to compare terminology and definitions of ambulance times and time intervals from the ambulance services of a range of countries to facilitate international benchmarking.

Methods

We sent a 23-question survey to 19 domestic and international ambulance services, who use the Advanced Medical Priority Dispatch System, asking for the terminology and definitions for times from “call received” to “arrival at hospital”. This included

“clock start” and “clock stop” times. We asked for the ambulance times terms and related variable names in the computer aided dispatch/reporting system. We piloted the questions on members of international emergency care organisations before sending them to representatives from international ambulance services. We engaged with clinical stakeholders and Patient and Public Involvement contributors throughout the process.

Results

We gathered information from ten international ambulance services, representing nine countries, and three continents. Some countries, such as those in the United Kingdom have standardised their ambulance times and intervals terminology and definitions. However, in most cases terminology differed greatly between countries, and at times within countries and between official reports within services. Definitions of ambulance times and intervals varied between countries, with some having different clock start and stop times and others not collecting data on the same time periods.

Conclusion

The current level of variation in international terminology and definitions for ambulance times and intervals poses a challenge for international benchmarking and research. International consensus or harmonisation of language and definitions would result in more efficient and accurate global comparison. On a smaller scale, defining terms in publications and reports would begin facilitating this process.

6.2 Introduction

Ambulance times and intervals are internationally recognised KPIs for prehospital care[1]. However, the terminology and definitions surrounding ambulance times and time intervals are not standardised across countries[1-3]. This can pose challenges for clinicians and researchers when synthesising international evidence or comparing countries/regions in this context. Standardisation or alignment of terminology and definitions would accommodate more accurate international comparisons.

International benchmarking, by comparing ambulance times and intervals between countries is a valuable method to help to identify strengths and weaknesses across healthcare systems[4]. Benchmarking has a long history of being used in the healthcare sector to compare outcomes across organisations[4]. It also facilitates shared learning and application of best practice[4]. If applied correctly, benchmarking can highlight unnecessary variation and work to reduce its occurrence[4].

Thus, this study aims to compare terminology and definitions of ambulance times and intervals from the ambulance services of a range of countries to facilitate international benchmarking.

6.3 Methods

6.3.1 Terminology versus definition

In the context of this study, we consider "terminology" as the term used to describe an ambulance time or ambulance time interval. Whereas a "definition" includes the variable(s) that constitutes the time or time interval in the computer aided dispatch (CAD) system.

6.3.2 Ambulance times and ambulance time intervals

An ambulance time is *"a specific event within the EMS response"*, such as at scene time[5]. Whereas an ambulance time interval is *"the temporal distance between two times"*, such as response time interval[5].

In this study we were interested in key points of the patient journey from "time call commenced" to "arrival at the hospital"[6]. These times and intervals were chosen due to their clinical significance and as they are commonly reported in the EMS response literature[2,3,7]. Ambulance time intervals used by different EMS organisations can be measured from alternate starting points to "time calling taking commenced", when reporting to standards authorities[1]. This can include the "T5" time, when the AMPDS code[8] is assigned to the call. However, in the EMS response literature, the patient-centered perspective is commonly taken, where the prehospital response begins at "time calling taking commenced"[1-3].

The benchmark used for this international comparison were the terminology and

definitions for ambulance times and intervals used by the Republic of Ireland National Ambulance Service **(Table 6.1)**[1]. The definitions used in the study are those used when discussing the prehospital care pathway from the patient perspective. However, when reporting KPIs to the relevant regulator, NAS use slightly different definitions. One key difference, as mentioned above, is that clock start time begins with T5 time (time the AMPDS code is allocated by the call-taker).

EB formed the Prehospital Care of Stroke (PHoCoS) consortium in 2022. Within this consortium, the long-term plan was to compare ambulance times and intervals from the Republic of Ireland with other participating countries **(Chapter 6B)**, to compare stroke responses during COVID-19. Thus, the alignment of terminology and definitions needed to be explored within the consortium prior to further work.

Table 6.1 - Ambulance times and ambulance time intervals used by the Republic of Ireland National Ambulance Service (from the patient perspective)[1]

Ambulance time (Republic of Ireland)	Ambulance time interval (Republic of Ireland)
Time call taking commenced	Resource mobile minus time call taking commenced
Mobile time	Response time (time resource arrived at scene **minus** mobile time)
At scene time	Transport time (time resource left scene to time resource arrived at destination)
Left scene time	Time resource arrived at scene to time resource arrived at destination
At destination	

6.3.3 Questionnaire

Two authors (EB and DW) composed a 23-item questionnaire using expert stakeholder engagement and relevant literature **(appendix 6.1)**. We included the ambulance times and ambulance time intervals in **table 6.1** as the basis for these questions. We provided the ambulance time and interval and then asked for the term and definition used for that time and interval in the respondents CAD system. The questionnaire also included “clock start” and “clock stop” times and the name of the authority which sets these times and intervals for the service.

We piloted the questionnaire on two members of two international EMS organisations before sending them to representatives from international ambulance services who are part of the PHoCoS consortium.

6.3.4 Participants

We sent the questionnaire to members of the PHoCos consortium using the Microsoft Forms platform. This is a group of international prehospital care professionals and researchers. The services in this group all use the AMPDS system, are internationally representative and agreed to engage with the researchers on this project, as it would require frequent communication to align definitions and terminology.

6.3.5 Aligning the terminology and definitions

EB aligned the international terminology and definitions with the Republic of Ireland definitions using Microsoft Excel. This process was carried out in discussion with KCB and DW. A "traffic light system" **(table 6.2 and 6.3)** was devised to consistently visually represent observed differences between the terminology and definitions used among the services. This method was chosen as colour coding systems, using the selected colour palette, are frequently used within the prehospital response. Furthermore, when working to build consensus, using tools like this, which are familiar to participants can optimise the benchmarking process[10].

Table 6.2 - Traffic light coding system for the terminology used for ambulance times and ambulance time intervals

	Complete mismatch (no word matches)
	Near match (at least one-word matches)
	Complete match (all words match)
	Not reported

Table 6.3 - Traffic light coding system for the definitions used for ambulance times and ambulance time intervals

	Complete mismatch (no ambulance time within the interval matches)
	Near match (at least one ambulance time within the interval matches)
	Complete match (both ambulance times within the interval match)
	Not reported

After initial coding was carried out by EB, KCB and DW then independently coded the data. Each participating service was then provided with their preliminary results in a Microsoft Excel file. The file included terminology and definitions from both the Republic of Ireland compared against those of their own service. This was a confirmatory exercise, to ensure each service agreed with the assigned colour codes. EB then engaged with a representative from each service to check if the representative was satisfied with the assigned colour code. If consensus was not reached at that time, or there were outstanding questions, at least one member of the core coding team (EB, DW, or KCB) would meet with a representative from that service. The purpose of the meeting was to reach a final consensus on alignment of terminology and definitions.

6.3.6 Stakeholder Involvement

Stakeholder involvement was included throughout this study in the form of PPI and involvement from policy and practice stakeholders.

6.3.6.1 PPI Contributors

A panel of thirteen stroke/TIA survivors and caregivers of a stroke or TIA survivor were involved in this study from the point of research question development to dissemination. This panel was formed by EB to help shape her doctoral research, focused on aspects of prehospital care for suspected stroke/TIA during the COVID-19 pandemic.

Early in the process of this study, EB discussed the challenges in comparing international terminology and definitions with the group. EB also asked the group about their priorities in this context, as well as their perceptions of the significance and interpretation of different international terms and definitions. The group believed that international studies are always worth carrying out to see where the Republic of Ireland sits on the global stage. The group believed this exercise would also give insight into how EMS operate in other regions. The PPI contributors were also involved in selecting which countries would be appropriate to compare in this context.

Subsequently, EB presented the group with an overview of the study aims and objectives and a summary of the key findings. The group discussed the importance of being able to compare KPIs between countries to facilitate continuous improvement for patients. They further emphasised the importance of shared learning between countries. The group commented on the heterogeneity of international terminology and definitions. They all believed that standardised definitions and terminology are required. They believed current challenges when comparing different countries could be overcome if language was harmonised. They suggested that using the same terminology would be helpful for identifying trends and patterns. This consistency would support researchers, policymakers, and clinicians in setting priorities and making informed decisions.

6.3.6.2 Prehospital clinical and policy stakeholders

Stakeholder involvement has been a key focus of this body of work from the beginning. EB initiated and led on all stakeholder involvement activities. The motivation and conceptualisation of this topic was co-designed by members of the Republic of Ireland National Ambulance Service and The International Academes of Emergency Dispatch. All of the comparisons and methods for this work were co-designed and co-created with this expert group. Input on the conceptualisation and methodology was also sought from representatives of international ambulance services.

Furthermore, the questionnaire used to collect information on the terminology and definitions was composed in collaboration with domestic and international ambulance services. Subsequently the questionnaire was pilot tested by two members of international EMS organisations.

On an international level, members of an international consortium focused on prehospital care of stroke were involved in the comparison of terminology and definitions. The PHoCoS Consortium comprises an international group of prehospital researchers and practitioners from ten ambulance services, nine countries and three continents. This group was involved in aligning the definitions and terminology of the ambulance times and time intervals in **table 6.1**. As this is a specialised area within prehospital response, constant engagement with members of these services was required to ensure accuracy and precise alignment of terminology and

definitions.

The group of prehospital care professionals involved in this body of work were involved in all stages of the process. They all imparted their clinical and research expertise to contribute to this international project.

Furthermore, EB developed and recorded a podcast on this topic with the International Academies of Emergency Dispatch. The "Dispatch in Depth"[11] podcast entitled " Speaking the Same Language" is available on various podcast hosting services Speaking the Same Language with Edel Burton - AEDR Journal. Furthermore, a policy brief was developed with stakeholders and circulated to relevant audiences. ***Appendix 6.2*** includes all outputs from this study.

6.4 Results

6.4.1 Regions/countries

We gathered information from ten international ambulance services, representing nine countries, and three continents. All of the included ambulance services use the AMPDS system. When discussed in this section, services will be represented by their corresponding country, However, the terminology and definition presented only reflects that service, not the entire region/country.

6.4.2 Terminology and definitions

In most cases terminology differed greatly between countries, and at times within countries and even between reports. Table **6.4-6.7** displays the terminology and definitions used for ambulance times and time intervals in the ten services.

Table 6.4 - Terminology used for ambulance times by the international services included in this study

	Time call taking commenced	Mobile time	At scene time	Left scene time	At destination
Ireland	Accepted call time	Time ambulance on way	Time at place of appointment	Time to drop off point	Time at drop off location
Austria	Call received	Enroute	At scene	Depart scene	Arrive at destination
Australia	T0	T3	T4	T5	T6
Canada	Call pick up time	Enroute time	Time arrived at scene	Depart scene time	Time arrive destination
New Zealand	Time call taking commenced	Mobile time	At scene time	Left scene time	At hospital time
Northern Ireland	Call time	Time mobilised	Arrival time	Time left scene	Time arrived at destination
Scotland	Time start call taking	Time of start ambulance run	At scene time	Left with patient time	Arrival at destination
The Netherlands	1st Keystroke	Responding	On-scene	Transporting	At destination
United States of America (Texas)	Phone Answer Time	Unite enroute	Unit arrived	Transporting	At destination
United States of America (Richmond)					

Table 6.5 - Definitions used for ambulance times by the international services included in this study

	Time call taking commenced	Time resource mobile	Time resource arrived at scene	Time resource left scene	Time resource arrived at destination
Republic of Ireland	Call_accepted	ZBO	BO	ZAO	A0
Austria	D_Received	D_Enroute	On-scene	D_Depart_scene	D_at_destination
Australia	Phone pick up	Enroute	Arrive_scene	Depart scene	Arrive destination
Canada	Time phone pick up	Time first unit enroute	Time first unit arrived	Depart scene	Arrive_destination
New Zealand	Time call taking commenced	Time resource mobile	Arrived at scene	Resource_left_scene	Time resource arrived at destination
Northern Ireland	Call_started_date_time	Resource_mobilised_date_time	Resource_arrived_scene	Resource_left_scene	Resource_arrived_destination_date time
Scotland	Time start call taking	Time of start ambulance run	Time of arrival at patient location	Left with patient	Time of arrival at destination
The Netherlands	1st Keystroke	Responding	On-scene	Transporting	At destination
United States of America (T...					

Table 6.6 - Terminology used for ambulance time intervals by the international services included in this study

	Resource mobile - call taking commenced	Response time	Transport time	Time resource at scene to resource arrived at destination
Ireland	Time of disposition	Time on the way to the medical emergency location of the patient	Time at drop off location	Not reported
Austria	Not reported	Travel time	Transport time	Prehospital interval

Table 6.7 - Definitions used for ambulance time intervals by the international services included in this study

	Resource mobile - call taking commenced	Time resource arrived at scene - time resource mobile	From time resource left scene to time resource arrived at destination	Time resource arrived at destination - time resource arrived at scene
Republic of Ireland	DP	Arriving at patient	A0	A0
Austria	Not reported	Not reported	Not reported	Not reported
Australia	Not reported	First arrived - enroute	Not reported	Not reported
Canada	Not reported	Not reported	Arrive destination - Depart scene	Arrive destination- First unit arrive
New Zealand	From time call taking commenced to time resource mobile	Time resource mobile to time resource arrived at scene	From time resource at destination- Time resource left scene	Time resource arrived at destination - Time resource arrived at scene
Northern Ireland	Time mobilised - time allocated	Time arrived - time mobilised	Time left scene- time arrived at scene	Time arrived at destination - time arrived at scene
Scotland	Time resource starts driving to the patient - Time resource is allocated to the call in CAD	Time of arrival at scene - Time of ambulance receiving dispatch order	Time resource is at the destination - Time resource starts driving to the destination	Time resource is at the destination - Time resource is at the patient location
The Netherlands	Responding - 1st Keystroke	On scene - responding	At destination - transporting	Not reported
United States of America (Texas)	1st enroute – time case initiated in PROQA	Vehicle response time	Transport time	Not reported
United States of America (Richmond)				

Services can have different terms for the same ambulance times and time intervals depending on the context and use. Some countries, such as those in the United Kingdom[12] have worked to standardise their terminology and definitions for ambulance times and intervals. However, the variation in terminology across this cross-section of countries is evident. Variation also exists between definitions. However, this is not as apparent or frequent as the variation seen in terminology. Notably, some services/countries do not collect data on the same time periods.

Clock start and stop times are largely similar between the included services **(table 6.8)**.

Table 6.8 - Clock start and stop times for included ambulance services

	Time calling taking commenced	Time resource clear
Ireland		
Austria	Call comes through on phone line	Call has ended
Australia	Time ambulance service answers the call	Clear case
Canada	Phone pick up	Call complete (cancellation, completion, offload)
New Zealand	Time phone call picked up in the communication centre	Time the assigned ambulance is cleared from the incident
N. Ireland	From call connect	At hospital time
Scotland	Time of call	Discharged from the service
Netherlands	Time 112 call is answered in ambulance triage and dispatch centre	Time resource status is free
United States of America (Richmond)	1st Keystroke in Medstar PSAP system	Resource available
United States of America (Texas)	Call created in CAD	First arriving EMS unit

In order to synthesis the differences in the terminology and definitions, table **6.9** and table **6.10** reflect the times and intervals collected by all services included in this study.

Table 6.9 - Number of different terms used for ambulance times and intervals reported by all included services

Ambulance Time	Number of different terms
Time call taking commenced	8
Mobile time	8
At scene time	6
Left scene time	9
At destination	8
Ambulance Time Interval	**Number of different terms**
Response time	4
Transport time	4

Table 6.10 - Number of different definitions used for ambulance times

Ambulance Time	Number of different definitions
Time call taking commenced	2
Mobile time	1
At scene time	2
Left scene time	2
At destination	1

6.5 Discussion

It is evident from the above results that there is a lack of standardisation of terms commonly used among the participating ambulance services.

This cross-section of international ambulance services shows that, currently, there is no standardized definition for ambulance time intervals used by the group. Thus, this limits the capacity for international comparison in this context. However, as clock start and stop times generally align, there is the basis for establishing harmonisation.

A benchmarking approach, using a questionnaire disseminated within the PHoCoS consortium, was selected as the most appropriate methodology for this study. This approach enabled the direct collection and comparison of time interval terminology and definitions used in routine practice across international ambulance services. An alternative method—conducting a scoping review—was considered to map existing definitions and terminology. However, this would primarily capture information from peer-reviewed literature, which does not typically include the operational language embedded in non-public dispatch protocols. Given that the terminology in use often resides within internal documents and local practice, engaging directly with consortium members allowed for a more accurate and meaningful comparison. Additionally, this collaborative approach ensured clarity around the interpretation and intended meaning terms, strengthening the relevance and applicability of findings across different service contexts.

As English is not the first language of some of these countries, terminology and definitions were translated into English from the native language. At times it was challenging to translate local assumptions and meaning. Thus, constant stakeholder engagement was required throughout the process to optimise accuracy.

This work could be viewed as a semantic exercise comparing words and meanings. However, language matters and the current level of variation in international terminology and definitions for ambulance times and intervals poses a challenge for international benchmarking and research. International consensus or harmonisation of language and definitions would result in more efficient and accurate global comparison. On a smaller scale, defining terms in publications and reports would begin facilitating this process.

6.6 Author Contributions

E Burton - Conceptualisation; data curation; formal analysis; investigation; methodology; project administration; visualisation; writing – original draft preparation. **D Willis -** Conceptualisation, methodology, data curation, writing – review and editing, visualisation. **E Boseley -** Methodology, data curation, writing – review and editing. **C Deasy -** Methodology, data curation, writing – review and editing. **M Franklin -** Methodology, data curation, writing – review and editing. **D Garrison -** Methodology, data curation, writing – review and editing. **C Henderson -** Methodology, data curation, writing – review and editing. **H Hutchinson -** Methodology, data curation, writing – review and editing. **PM Kearney -** Conceptualisation; funding acquisition; methodology; supervision; writing - review and editing. **M Krammel -** Methodology, data curation, writing – review and editing. **A Lloyd -** Methodology, data curation, writing – review and editing. **W Loudon -** Methodology, writing – review and editing. **R Quinn -** Methodology, writing – review and editing. **S Masterson -** Conceptualisation, methodology, data curation, writing – review and editing. **VJC McCarthy –** Conceptualisation, funding acquisition, methodology, supervision, writing – review and editing. **Á. Merwick -** Conceptualisation, funding acquisition, methodology, supervision, writing - review and editing. **C O'Donnell -** Methodology, data curation, writing - review and editing. **J Overton -** Conceptualisation, methodology, data curation, writing - review and editing. **H Van de Pas -** Methodology, data curation, writing - review and editing. **JH Wolfe -** Conceptualisation, methodology, data curation, writing - review and editing. **M Zavadsky -** Methodology, data curation, writing - review and editing. **K. Crosbie-**

Staunton - Conceptualisation, methodology, data curation, writing - review and editing**. CM Buckley -** Conceptualisation; funding acquisition; methodology; supervision; writing - review and editing.

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Chapter 7: Discussion

7.1 Overview

This final chapter of the thesis presents three main findings on the resilience of the acute stroke/TIA pathway to a “shock”, such as the COVID-19 pandemic. These findings are framed within a multi-level triangulation design mixed methods approach[1], informed by the "Resilient Health System as a Conceptual Framework for Strengthening Public Health Disaster Risk Management"[2].

The strengths and limitations of the thesis are then discussed, followed by the potential implications for research, policy, and practice. These implications are examined through the lens of the WHO’s "building blocks of the healthcare system,"[3] which is a central element of the theoretical framework employed in this thesis. The chapter ends with a conclusion statement.

7.2 Summary and Interpretation of Research Findings

The overall aim of this thesis was to investigate the impact of a "shock", such as the COVID-19 pandemic on prehospital emergency care for exemplar time-sensitive conditions; stroke and TIA, with the goal of exploring potential implications for future policy and service delivery. This aim was addressed using the "Resilient Health System as A Conceptual Framework for Strengthening Public Health Disaster Risk Management"[2] approach embedded within a multi-level triangulation mixed methods design[1]. This approach enabled the capture of impacts on the acute stroke/TIA pathway **(structure)** across various system levels **(regional, national and international)** considering both the healthcare system's response and user interaction with the system **(mechanisms)**[1,2].

The main findings of the thesis are discussed within the context of the aforementioned framework nested within the multi-level mixed methods design[1]. The WHO's "building blocks of the healthcare system"[3] are central to the chosen framework. They are used to explain how components at each level influenced two important and internationally recognised KPIs of prehospital care: ambulance time intervals **(system response)** and call volume **(access and interaction with the system)**. The "building blocks of the healthcare system"[3] are also used to structure the implications of this thesis for policy, practice and research.

The three main findings of this thesis are:

1. The healthcare system response: while the integrity of the emergency phase of the acute stroke and TIA pathway was maintained, significant prehospital delays were identified across the stroke chain of survival.

2. Interaction with the healthcare system: a shift in healthcare-seeking behaviour among stroke and TIA survivors was observed during the pandemic, evidenced by delays or decreases in the number of individuals seeking care for these conditions.

3. Shared understanding of the patient journey: this research highlights the differing opinions of various stakeholder groups on key aspects of the patient journey. It also reveals how heterogeneity in current international terminology and definitions for ambulance times and intervals limits effective international benchmarking of KPIs, tracking the patient journey.

7.2.1 The healthcare system response

Throughout this thesis, ambulance time intervals were used as an indicator of the healthcare system's capacity to respond to time-sensitive conditions during a period of increased pressure. Key bottlenecks in the prehospital pathway for stroke/TIA during the pandemic were identified in the systematic review **(chapter 3)**, Republic of Ireland temporal trends study **(chapter 4)** and international comparative study **(chapter 6)**. Potential reasons for these bottlenecks were provided by participants in the qualitative study **(chapter 5)**.

The response time interval was the only prehospital interval that increased during the COVID-19 pandemic across all quantitative studies in this thesis **(Chapters 2, 4,**

and 6b). However, on-scene time increased across all seven countries in the international study **(Chapter 6b)**, followed by the response interval, which increased in six services during the COVID-19 pandemic. A study using the same pre-COVID-19 and COVID-19 periods as **Chapters 4 and 6b** also observed increases in response time interval and on-scene time for suspected stroke/TIA during COVID-19[4]. A Polish study found an increase in response time interval for stroke/TIA during COVID-19[5]. While a Spanish study found an increase in on-scene time only[6]. Furthermore, while the studies in the systematic review **(chapter 3)** mainly focused on the first pandemic wave, **Chapters 4 and 6** covered two years of the pandemic. This extended period provides a stronger basis for assessing the responsiveness and resilience of the healthcare system in this context. Allocation performance and response time were the only intervals to increase over the five Republic of Ireland COVID-19 waves **(chapter 4)**. Whereas the impact of each wave on the remaining intervals varied **(Chapter 4)**. The international comparative study did not examine the impact of each wave individually, on the time intervals, due to variation in the number and timing of waves across the countries. However, the two-year period investigated acted as a temporal proxy, representing changes in COVID-19 public health measures over time. Previous studies were typically limited to examining one or two early pandemic waves, making it impossible to track time intervals for time-sensitive conditions across different stages of COVID-19 restrictions. This thesis provides a unique contribution by enabling the analysis of performance times throughout multiple pandemic waves, offering insights that were previously unattainable.

The structure of a healthcare system and the strengths and weaknesses of its "building blocks"[3] can influence the system's ability to respond during a crisis. In the international study **(Chapter 6)**, the Australian service experienced increases in all five-time intervals on the stroke/TIA pathway during COVID-19. Whereas services in the Republic of Ireland, Scotland, and Northern Ireland experiences delays in four of the five-time intervals investigated[7-10]. These services operate nationally or statewide, unlike Austria[11] and the Netherlands[12], which have regional services. This suggests that a greater pool of shared resources, including staff and vehicles, may provide more resilience during increased pressure. Furthermore, New Zealand[13], which had the strictest COVID-19 management strategy - elimination[14], saw improved efficiency in entry to the prehospital pathway and review by practitioners during the pandemic. This strict COVID-19 management strategy likely enhanced its capacity to respond to suspected stroke/TIA calls more effectively than other services. Services with the greatest number of increased time intervals were found in countries with either national healthcare systems or COVID-19 management strategies other than elimination. As a result, these aspects of the healthcare systems in affected countries may represent appropriate targets for "futureproofing" interventions to enhance resilience in future public health crises.

Healthcare professionals in the multi-stakeholder qualitative study **(Chapter 5)** discussed how workforce issues during COVID-19 may have compromised the timely operation of the acute stroke pathway. Prehospital and hospital-based healthcare professionals noted increased time intervals at each stage of the stroke chain of survival[15,16]. They further believed that staff shortages during COVID-19 resulted in

fewer available ambulances, reducing system capacity. Additionally, redeployment led to non-specialist or less experienced staff caring for stroke/TIA survivors[17]. Interview participants from prehospital care believed that COVID-19 cleaning protocols and PPE contributed to increased response and on-scene intervals. International evidence supports that these factors contributed to prehospital delays during the pandemic[4-6,18]. Prehospital participants also believed current stroke/TIA triaging protocols limited the effectiveness of the prehospital response during the pandemic. The highest acuity level for a stroke on AMPDS, the prehospital triage tool used by all countries in **Chapter 6**, is classified as a Charlie call[19-21]. A Charlie call is categorised as serious but not life-threatening yet warrants an immediate response[20-21]. Participants perceived this as a prehospital care issue because calls triaged higher than stroke would receive priority. This could potentially delay urgent intervention, which could impact patient outcomes, especially under increased system pressures[22]. The triage level of suspected stroke/TIA did not change during the pandemic. However, the pandemic highlighted that the current triage approach does not match the urgency and time-sensitivity inherent in stroke/TIA calls. Review of this protocol may be required to ensure a timey prehospital response for stroke/TIA in ordinary and extraordinary circumstances. Furthermore, educational support may be required for prehospital staff to understand the implications of a delay to such calls regardless of system pressures.

7.2.2 Interaction with the healthcare system

In this thesis service user interaction with the acute stroke pathway was operationalised using two metrics: 1) emergency call volume for suspected stroke/TIA and 2) time since last known well.

Emergency call volume indicates demand for prehospital care services[23]. The systematic review **(Chapter 3)**, Irish study **(Chapter 4)**, and international comparative study found that calls for suspected stroke/TIA declined at the onset of the COVID-19 pandemic. **Chapters 4 and 6** observed smaller declines in later stages of COVID-19, with a significant dip during wave 4 noted in **Chapter 4**. This corresponded to when Ireland's COVID-19 incidence was the highest in the European Union[24]. This finding suggests that during peaks in COVID-19 incidence, stroke and TIA survivors may have avoided healthcare settings due to fears of contracting the virus. All stakeholder groups in **Chapter 5** also perceived that a decreased number of stroke/TIA presentations or delays in seeking care tended to occur during COVID-19 surges. The patient journey maps support this, showing the longest "symptom onset to hospital arrival" and "medical assessment to hospital arrival" intervals occurred in wave 1 **(chapter 5)**. Most other intervals were longest during wave 4. However, "time to imaging" was longest during wave 3. This trend was echoed by a recent systematic review on stroke care during the COVID-19 pandemic[25]. A Canadian study showed hospital admissions and presentations for ischemic stroke dropped in Wave 1[26]. They increased during the lull period but didn't reach pre-pandemic levels[26]. By Wave 3, they had declined further[26].

However, **chapter 4** and **chapter 6b** noted increases in suspected stroke/TIA call volume during the entire COVID-19 period in all countries except the Netherlands. Some prehospital care practitioners in **chapter 5** also discussed a perceived increase in suspected stroke/TIA calls as the pandemic progressed. This echoes the results of three further studies[27-29]. This may be because stroke/TIA survivors were more inclined to contact EMS in medical emergencies during COVID-19 rather than travel to hospitals themselves or rely on relatives for transport[4,30,31]. However, in the qualitative study equal numbers of participants arrived at hospital by ambulance and car. Hospital-based healthcare professionals in **chapter 5** noted that increased stroke presentations later in the pandemic may be explained by the reduction in TIA presentations during the early COVID-19 period. The primary goal of TIA assessment and treatment is to prevent subsequent strokes[32,33]. Thus timely intervention for TIAs may have potentially averted the observed rise in suspected strokes/TIA calls,[32,33]. Similar trends were documented in a recent systematic review, which reported a 34% decrease in TIA admissions during the pandemic[34].

Another metric which indicated changes in healthcare utilisation was "time since last known well". This is a clinical indicator captured within the AMPDs stroke code protocol[19]. **Chapters 4 and 6a** documented an increase in suspected stroke/TIA cases falling outside the defined treatment window, during COVID-19. Simultaneously more cases with unknown onset times occurred during the pandemic in Northern Ireland **(chapter 6)**. The findings across these chapters have two major implications. Firstly, if the survivor has experienced an ischaemic stroke, they now fall outside the thrombolysis time window. Secondly, falling outside of this time window

automatically reduces the triage level of the call[20,21] **(chapter 4)**, possibly compounding prehospital delays. Healthcare professionals in the qualitative study **(Chapter 5)** supported these findings. They noted that stroke survivors presented later during COVID-19. There also appeared to be an increase in the number of more severe stroke's presentations during COVID-19. Some studies report an increase in severe strokes during COVID-19, while others find no change[25,35]. It is noteworthy that the reduction in presentations of strokes with milder symptoms may distort the perception of an increase in severe strokes[35].

One possible explanation for the reluctance to seek care during the COVID-19 pandemic, illustrated by dips in call volume and increased "time since last known well" **(Chapters 3, 5, 6b)**, may be fear **(Chapter 5)**. Another potential explanation may be perceived compliance with COVID-19 public health advice. Thus, the findings of chapter **3-6** are indicative of a change in healthcare seeking behaviour of stroke/TIA survivors. With this observation being particularly obvious during peak COVID-19 cases and "unexpected" containment measures[36-38]. This change in healthcare-seeking behaviour, called healthcare avoidance, was widely noted during the pandemic[39]. Individuals facing urgent medical emergencies often avoided services due to contagion fears[39]. Furthermore, public health messaging to "stay at home" may have been strictly followed, evening in the content of emergencies, like a stroke or TIA. Since approximately two million brain cells die per minute during severe ischemic strokes, care avoidance and delays can have severe consequences for stroke/TIA survivors[40-43].

7.2.3 Shared understanding of the patient journey

This PhD project examined the COVID-19 pandemic's impact on all stages of the patient journey, from symptom recognition to early hospital care. The patient journey was tracked using a quantitative approach in **Chapters 3,4,6**. Whereas **Chapter 5** explored this journey using qualitative methodology.

The systematic review **(Chapter 3)** and benchmarking study **(Chapter 6a)** found significant heterogeneity in ambulance time and interval terminology and definitions worldwide. This limits the ability to accurately compare prehospital times across the patient journey in different countries. This may explain why, before this thesis, there were no international studies on prehospital stroke care during COVID-19 and very few in the prehospital space overall. The benchmarking study **(chapter 6a)** facilitated accurate cross-national comparison of ambulance time intervals across seven international services **(chapter 6b)**. Although this approach is a positive first step, standardising international terminology and definitions would facilitate consistent international benchmarking[44]. The use of internationally standardized terminology and definitions could facilitate the development of quality measures across different healthcare systems[44]. This would enable cross-country benchmarking, ultimately aiming to improve patient outcomes[44].

The qualitative study **(Chapter 5)** also explored the provision and receipt of care during the pandemic from the perspectives of multiple stakeholders. The patient

journey was further illustrated using the novel patient journey mapping[45-50]approach.

The prehospital and hospital-based healthcare professionals interviewed focused on the maintenance of the integrity of the acute stroke pathway during the pandemic. Whereas the stroke/TIA survivors and caregivers focused more on the user experience. The patient journey maps give insight into the very varied experiences of the stroke/TIA survivors and family members included in this study during the pandemic. However, only one nurse out of fifteen healthcare professionals interviewed even mentioned the patient experience. There seems to be a conflict here in terms of priorities, with healthcare professionals focusing on how modifications to the acute stroke pathway may have resulted in bottlenecks in the chain of survival[15,16]. Whereas, survivors and family members focused on communication with healthcare professionals and loved ones. They also emphasized the need for more information on navigating the acute stroke pathway. These findings, including conflicting priorities between healthcare professionals and survivors/family members, are reflected in two recent qualitative studies[50,51]. Although this thesis focused on care provision during COVID-19, the conflicting perspectives on priorities throughout the patient journey is a finding that can be applied to routine care. The emphasis on process versus patient experience, whether in a healthcare crisis or not, highlights a significant disconnect between the viewpoints of service providers and service users. Investigating care experiences for acute time-sensitive conditions during COVID-19, highlighted this divergence of perspectives. Going forward, methods and strategies to better understand and

potentially bridge this gap should be explored, with the goal of making care truly patient-centred.

However, participants across all groups in the qualitative study **(Chapter 5)** believed that "COVID-19 superseded everything". A fact that seemed to be supported by the quantitative evidence found in chapters **3,4,6**, due to prehospital delays and evidence of potential changes in healthcare seeking behaviour. Healthcare providers believed that COVID-19 overshadowed the importance of other conditions. Stroke survivors and caregivers discussed how COVID-19 limited access to healthcare. This included primary or preventative care, and also timely access to time-dependent therapies. However, all groups had a shared understanding that COVID-19 visitor restrictions were challenging for all stakeholders. Healthcare professionals and survivors/family members all believed that these restrictions affected survivors both personally and clinically. Family members are a key support system for the stroke/TIA survivor.[52,53] Furthermore the witness (frequently a family member) is a key source of information for the stroke team[52,53]. All groups understood the importance of the presence and adherence to COVID-19 interventions for public health. However also the implications of these restrictions on care experiences. Thus, it is necessary to consider how healthcare professionals can meet individuals' needs during times of heightened demand on the healthcare system.

7.3 Implications of the Findings

This PhD project, utilising a multi-level mixed methods[1] approach to explore healthcare system resilience amidst a "shock"[54] has many potential implications for policy, practice and research. Collectively, these implications map to all six WHO "building blocks of the healthcare system"[3]. **Table 7.1** summarises the policy, practice and research implications of this thesis.

Table 7.1 - Policy, practice and research implications of this thesis research, mapped to the WHO "Building Blocks of the Healthcare System"[3]

(A) Policy Implications		
Health service delivery	**Leadership/governance**	**Health information**
• Standardisation of international terminology and definitions for ambulance times and intervals	• Evaluation of how different COVID-19 management strategies were implemented and how they impacted care for acute time-sensitive conditions	• Consider introducing a prehospital stroke register in countries without one
• More frequent stroke awareness campaigns		
• Targeted communication advising the public to continue to present to hospitals during healthcare crises with conditions such as stroke/TIA		

(B) Practice Implications				
Health service delivery	**Healthcare workforce**	**Leadership/governance**	**Health financing**	**Medicines, vaccines and technologies**
• Focus on processes to preserve response and on-scene intervals for suspected stroke/TIA during future crises	• Need for continued access to specialist stroke teams across the continuum of care	• Review of employment policies during healthcare crises to maximise ability to preserve staffing levels and skill mix	• Strengths and weakness of prehospital service design during crises	• Consideration to upgrade the triage status of a suspected stroke/TIA from a "Charlie" call

(C) Research Implications	
Health service delivery	**Health information**
• Patient journey mapping used to visualise complex interactions of service users with the healthcare system	• Encourage authors to define and cite source for ambulance times and intervals in all outputs
• Novel benchmarking approach can be used to compare current international ambulance times and intervals	
• This thesis further highlights the need for standardised terminology and definitions for ambulance times and intervals on a global scale	
• Encourage other prehospital and stroke researchers to include PPI and other forms or stakeholder involvement throughout their studies	

7.3.1 Policy Implications

7.3.1.1 Terminology and definitions for ambulance times and intervals

The cross-section of countries represented by this thesis **(chapter 3,4,6)** reveals a lack of standardised and consistent terminology and definitions for ambulance times and intervals. The existing variation in terminology and definitions presents a challenge for international benchmarking and research[21,44, 55,] In the interim, defining terms in publications and reports would begin to facilitate meaningful comparison. However, the proposed methodology for benchmarking these intervals included in this thesis **(chapter 6)** offers a temporary solution to conducting accurate and appropriate international prehospital time intervals research. A permanent solution would involve the development and uptake of internationally standardised terminology and definitions for ambulance times and intervals.

7.3.1.2 Public Awareness of stroke

This PhD research indicates possible healthcare avoidance during the pandemic. This is evidenced by changes in call volume for suspected stroke/TIA and prolonged intervals from "time since last known well" to raising the alarm **(Chapters 3-6)**. Delayed acute stroke/TIA treatment can lead to significant complications, higher mortality rates, and substantial costs for individuals, their families, and the healthcare system as a whole[56]. Additionally, delays in recognising and transferring patients to hospital contributes to prehospital mortality[57]. This highlights the need for nuanced public health messaging about seeking care for medical emergencies during healthcare crises. Participants across all groups interviewed in Chapter 5

emphasised the need for more frequent and continuous stroke public awareness campaigns, such as the F.A.S.T. campaign run by the Irish Heart Foundation[58,59]. They recommended these campaigns include specific references to the advantages of calling an ambulance rather than traveling to the hospital by private car. However, as these campaigns can be costly, a cost-benefit analysis may be required before further campaigns can be considered[58,59].

7.3.2 Practice Implications

7.3.2.1 Ambulance time intervals responsible for prehospital delays during COVID-19

Chapters 3, 4, and **6** of this thesis found that the "response" interval and "on-scene time" were the most commonly implicated in prehospital delays during COVID-19. System evaluations should identify modifiable factors to preserve these times during routine stroke/TIA care and public health crises[41-43]. This approach would enhance preparedness and learning for future crises, leading to a more resilient healthcare system[54]. As prehospital services come under intense pressures each winter, these findings have relevance for both routine and crises prehospital services planning.

7.3.2.2 Need for specialist and consistent stroke healthcare workforce

Interview participants in **Chapter 5** highlighted COVID-19-related workforce issues, which appeared to contribute to the prehospital delays observed in **Chapters 3, 4, and 6**. Redeployment of prehospital practitioners and stroke team members to COVID-19 related activities resulted in non-specialist healthcare professionals caring

for stroke survivors. Stroke care requires access to specialist multidisciplinary teams for optimal patient outcomes[50,51]. Thus, a review of staffing policies during healthcare crises may be required to optimise the ability to maintain staffing levels and ensure an appropriate skill mix within acute stroke services.

7.3.3.3 Prehospital triage of suspected stroke/TIA

Prehospital practitioners in **Chapter 5** highlighted the need to review the current triaging protocol for suspected stroke/TIA within the AMPDS system[19-21]. This could be a contributing factor to increased prehospital delays during COVID-19; specifically for entry into and advancement through the prehospital pathway (activation, mobilisation and response time intervals[21]).

7.3.3 Implications for Research

7.3.3.1 Patient Journey Mapping Approach

This PhD project used the novel "patient journey mapping"[45-50] approach to visualise the complex interactions of stroke/TIA survivors with the acute stroke pathway during a pandemic period. This method illustrated the bottlenecks that were quantitatively summarised in Chapter 3, 4, and 6. Furthermore it captures the heterogeneity of survivor and caregivers' experiences. Utilising this method in this manner may encourage other researchers to adopt this approach. This approach may further inform HCPs, so they can meet survivors and caregivers needs[45-50]. As seen in this work, perspectives can differ between service users and providers, with

HCPs often focusing on different aspects of care to survivors and caregivers. Patient-reported outcomes are increasingly valued by HCPs and can significantly impact quality of life, symptom burden, and health behaviors[45-50]. Fully understanding the patient journey is crucial for HCPs to provide effective care, both during crises and in routine care settings.

7.3.3.2 Novel method for comparing ambulance times and intervals across countries

The methodology outlined in **Chapter 6a** to compare ambulance times and intervals across services was co-developed with members of the Prehospital Care of Stroke Consortium. While the ultimate goal is to develop and adopt standardized international definitions and terminology for ambulance times and intervals, this method can facilitate international benchmarking and quality improvement projects in the interim.

7.3.3.3 Encouraging increased inclusion of stakeholder engagement in prehospital research

Patient and Public Involvement is a concept that is considered novel and a very recent condition to prehospital research in the Republic of Ireland. PPI was embedded within all aspects of this PhD work, throughout all stages of the research cycle[60,61]. The PPI panel played a crucial role in shaping and co-developing this study across all phases. The goal was to involve the panel at every possible stage to enrich the research by incorporating their lived experiences. This approach proved highly

beneficial, as integrating the perspectives of stroke/TIA survivors greatly enhanced the study's purpose, impact, and overall implications. Thus, this may enhance the knowledge of prehospital researchers of PPI and encourage further inclusion of PPI contributors in prehospital stroke research.

7.4 Directions for Future Research

7.4.1 International consensus on terminology and definitions for ambulance times and intervals

This PhD project laid the foundation for alignment of terminology and definitions for ambulance times and intervals across countries and regions. However larger multi-stakeholder consensus studies conducted on a broader range of countries would be required to achieve standardisation. Thereafter standardisation will enable more accurate comparisons within the same health system over time, between different healthcare systems, or across regions or nations[44,62].

7.4.2 Longer term impact of delayed care for suspected stroke/TIA

This thesis indicates that there was a change in healthcare seeking behaviour amongst stroke/TIA survivors during the COVID-19 pandemic. Thus, research is required to investigate longer term outcomes of stroke/TIA survivors who delayed seeking treatment during the COVID-19 pandemic.

This research further highlighted the need for a prehospital stroke register in Ireland. Currently the INAS is not linked with prehospital data, and without a unique health identifier in Ireland it is currently not possible to follow the patient through their entire stroke pathway of care. Initially, presenting the cohesive findings of this research to key stakeholders could demonstrate the value of collecting data across the entire stroke chain of survival.

7.4.3 Prehospital stroke/TIA care before, during and after the COVID-19 pandemic

This work focused on comparing time intervals pre-COVID-19 and during COVID-19. Future work may consider furthering this analysis but also conducting a comparison with a post-COVID-19 period. The current analysis included post-lockdown periods. However, considering periods after the lifting of all restrictions in a region would identify whether the system is resilient, and has returned to its pre-COVID-19 state, or learnt lessons and improved.

7.4.4 Potential reasons for increased suspected stroke/TIA call volume during COVID-19

Further studies are required to investigate reasons behind the notable increase in suspected stroke/TIA call volume across countries during the COVID-19 pandemic. Prior research indicates that the systemic inflammation triggered by COVID-19 could elevate the risk of experiencing a stroke[63]. Although this thesis has identified the changing patterns of call volume during COVID-19 and potential reasons for these

observations, robust evidence on a causal link between COVID-19 and stroke is currently lacking[63].

7.4.5 Context specific evaluation of prehospital delays during COVID-19

Apart from the response interval and on-scene time, there was significant heterogeneity in the impact of COVID-19 on ambulance time intervals in this thesis. Therefore, context- and country-specific evaluations are necessary to identify the strengths and weaknesses of the building blocks of each country's healthcare system[2,3].

7.5 Strengths and Limitations

7.5.1 Strengths

Firstly, this PhD thesis uses a multilevel mixed methods approach[1], involving the integration of qualitative and quantitative strands of investigation. Thus, this approach confers rich, meaningful, and reliable results. The Irish temporal trends analysis and the international comparative study quantify the impact of the COVID-19 pandemic on prehospital stroke/TIA care. Whereas the qualitative study provides multistakeholder meaningful insights into access and provision of acute stroke/TIA care during the COVID-19 pandemic. When combined, both approaches provide a comprehensive and holistic overview of the stroke/TIA survivor journey through acute stroke care during the COVID-19 pandemic[15,16].

Secondly, stakeholder involvement was integral to this project, including Patient and Public Involvement as well as stakeholders from neurology, stroke, emergency medicine, and prehospital care. Their participation spanned from the refinement of the research question to the dissemination of findings. The creation of two international prehospital consortia, arising from this PhD project is testament to the quality of stakeholder involvement engaged throughout.

Thirdly, the qualitative study in this PhD thesis included healthcare professionals from both prehospital and hospital settings, as well as stroke/TIA survivors and caregivers. This multistakeholder approach provided a comprehensive view of the stroke/TIA survivor journey through the healthcare system during a public health

crisis. Additionally, it offered a platform to highlight the presence or absence of shared understanding among the included groups.

Fourthly, this thesis employed novel methodology to compare terminology and definitions for ambulance times and intervals across a cross-section of international ambulance services. This facilitated an international comparative study involving seven international services. This approach enabled a robust assessment of the resilience of the prehospital stroke pathway during a public health crisis, with learnings across systems with different “building blocks”.

7.5.2 Limitations

Firstly, within this PhD project, suspected stroke is being investigated rather than confirmed stroke diagnoses. However, whether the diagnosis is verified, the same criteria should have been applied to patients experiencing acute stroke symptoms at the prehospital stage. Therefore, this limitation shouldn't significantly hinder interpreting the results, particularly trends over time. Additionally, the number of stroke/TIA cases presenting with "abnormal breathing" increased during COVID-19 among three of the seven countries studied in the international comparative study which may partially account for the rise in suspected stroke/TIA call volume, in those instances.

Secondly, although robust regression analyses were conducted in the national and international studies on time intervals, the methods themselves have limitations [64]. In the multivariable linear regression models, adjustments could only be made for observed confounders[64]. The R^2 values indicate that the included independent variables only explain a modest percentage of the variance in the dependent variables (prehospital time intervals). Also, further potential confounders, such as traffic volume was included in the intervals analysis for the Irish study. However, due to data availability and resource constraints was not included for the international comparative study[64]. All covariates included in these models were chosen on a priori based on existing literature and clinical judgment, supported by stakeholder involvement[64]. This thoughtful selection of covariates was essential in generating minimally biased results[64].

In terms of the emergency call volume analysis in **Chapter 4** ARIMA modelling typically requires relatively long time series, with a common rule of thumb being at least 50 observations to estimate seasonal components[65]. Due to limitations in data access at the time of this study (2022 data not being available until 2023) this may limit the acceptability of ARIMA models in this instance. Secondly, the described model estimation process involves fitting a model form, particularly determining the order of autoregressive and moving average terms, to the observed data[65]. While this is effective in depicting the observed time trend, such an approach may restrict the model's usefulness in characterising trends in alternative contexts[65]. Finally, like all models, ARIMA models should be considered as one potential model and subjected to scrutiny[65]. However, ARIMA has been used widely in COVID-19 analyses, as enables the incorporation of relationships between observations[65]. ARIMA models are capable of investigating changes relative to the underlying background trends in the data[65]. This is particularly important in a study comparing outcomes pre-COVID-19 and during COVID-19.

Thirdly, COVID-19 represents an unprecedented, multifaceted phenomenon that has profoundly affected healthcare and healthcare systems. It is not a uniform, discrete intervention, and even categorising it as a temporal exposure may oversimplify its impact. However, to examine the effects on healthcare systems and human behaviour during this period, we required a defined time frame based on nationally and internationally adopted definitions[66]. Moreover, accommodations for this complexity were made by comparing different waves of the pandemic in **Chapters 4 and 5**[66].

Fourthly, although the datasets used in the quantitative analysis were accurate and complete in terms of the main outcomes, there was some missing and incomplete datasets for other variables. Due to data warehousing systems and retention policies of the Northern Ireland Ambulance Service, limited data was available for 2018 and 2019. Thus, ambulance time intervals could not be analysed for those two years for that service. Additionally, it is important to note that the data utilised in the study was gathered by practitioners during their routine work, thus various reasons may contribute to the missing or incomplete nature of some of the data[67].

Lastly, since participant interviews took place between April and August 2023, recall bias may have influenced the accuracy of their accounts regarding experiences during COVID-19 events. The WHO did not declare that COVID-19 was no longer classed as a pandemic until 5th May 2023[68]. However, most public health restrictions in the Republic of Ireland were lifted by the end of February 2022[69]. Thus, up to three years could have elapsed since participants or their family member had their stroke/TIA. This phenomenon may also have affected HCPs. Thus, participants may experience memory decay, where they fail to recall events entirely[70]**.** The degree of this phenomenon often correlates with the length of the recall period[71-73]. For instance, a longer recall period, such as over 12 months compared to 6 months, may result in a greater quantity of information being forgotten over time[71-73]. However, salient, and less frequent healthcare utilisation events, like hospitalisations and specialist visits, are more accurately self-reported in comparison to more routine and frequent events, such as GP visits[71-73]. Furthermore, stroke/TIA survivors who believed they may miss or forget pertinent information selected to be interviewed

in a dyad. Also, ample time was given between recruitment and the interview, so that survivors and caregivers could reflect on their past experiences or refer to diaries or otherwise. Additionally, the inclusion and exclusion criteria used for the qualitative interviews may have introduced selection bias. Stroke survivors who could not provide informed consent and those with communication impairments that could impede their engagement were excluded from the study. This also meant excluding those with very severe stroke-related disabilities or who died of stroke during the pandemic. Consequently, the caregivers of these stroke patients were also excluded. Although this study achieved variation in stroke survivor journeys through "maximum variation sampling"[74-78], the potentially distinct experiences of the excluded participants were not captured, leaving those perspectives unrepresented.

7.6 Conclusion

This thesis used a multistakeholder mixed methods approach to investigate the resilience of the acute stroke pathway during a public health crisis. The prehospital management of patients with suspected stroke remains a crucial aspect of the stroke chain of survival and is a target for enhancing the timeliness of stroke care delivery and patient transport. This body of work highlighted prehospital delays, particularly prolonged response and on-scene intervals, during COVID-19. Additionally, this research indicates potential care avoidance by stroke/TIA survivors during the pandemic. It also identified a lack of shared understanding of international terminology and definitions for ambulance times and intervals, as well as the importance of the patient journey. Other factors relevant to routine acute stroke/TIA care, such as lack of public awareness of stroke symptoms and failures to involve EMS, were also noted. Therefore, concerted efforts are required across all stakeholder groups to optimise all aspects of the stroke chain of survival. Further studies are needed to investigate the long-term impacts of the COVID-19 pandemic on emergency stroke/TIA care.

7.7 References

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Chapter 8: Appendices

Chapter 2 Appendices

Conferences

Title	Conference	Date	Type	Authors
Embedding Patient and Public Involvement (PPI) in a PhD Project: Key Turning Points in the Research Trajectory	Global Evidence Summit	September 2024	Poster	Burton E Racine E Fleming A Hartigan I Kearney PM McCarthy VJC Merwick Á Buckley CM
Stakeholder Involvement Throughout a PhD Programme: Principles, Purpose and Process	Global Evidence Summit	September 2024	Oral	Burton E Willis D Crosbie-Staunton K Deasy C Masterson S O'Donnel C Overton J Quinn E Merwick Á Kearney PM McCarthy V Buckley CM Prehospital Care of Stroke (PHoCoS) Consortium
Embedding Patient and Public Involvement (PPI) Throughout A Structured Doctoral Programme	Trinity Health and Education International Research Conference 2023 (THEconf2023)	March 2023	Oral (Co-delivered with PPI Contributor Mr. Larry	Burton E Carvalho M Haseldine C Dunne P

			Masterson)	Gibson I Kenny E Meade O Leadership team of the Collaborative Doctoral Programme in Chronic Disease Prevention (CDP-CDP)
Development Of a Public and Patient Involvement (PPI) Guidance Document to Support Doctoral Research in Cardiovascular Disease and Diabetes Prevention	Structured Population and Health Services Research Education (SPHeRE) Conference	March 2023	Oral	Dunne P Gibson I Kenny E Burton E Carvalho M Haseldine C Meade O PPI Contributors CDP-CDP Readership team
Advancing Research in Cardiovascular Disease and Diabetes Prevention Through Public and Patient Involvement (PPI)	National Institute for Prevention and Cardiovascular Health	November 2022	Poster	Dunne P Gibson I Kenny E Burton E Carvalho M Haseldine C Meade O PPI Contributors CDP-CDP Leadership Team

Reports or guidelines

Title	Date of publication	Authors	Link
Guidance Document for Patient and Public Involvement within the Collaborative Doctoral Programme in Chronic Disease Prevention (CDP-CDP)	October 2022	Burton E Carvalho M Dunne P Gibson I Haseldine C Kenna E	https://www.universityofgalway.ie/cdp-cdp/ourresearch/ppi/

Other presentations

Title	Presenters	Event	Date
Patient And Public Involvement in Health and Social Care Research	Racine E Burton E	Health Services Research and Pharmacy Practice Conference	April 2024
How To Include Patient and Public Involvement in A PhD	Burton E Masterson E	Online – SPHeRE training session for PhD students	December 2023
PPI In Different Postgraduate Journeys (Session Co-Developer and Organiser)	Burton E Dunne P Haseldine C Leocadio P	PPI Ignite Festival 2023	October 2023
How To Include Patient and Public Involvement in A PhD	Burton E Masterson L	Online – SPHeRE training session for PhD students	December 2022
Terms Of Reference for Patient and Public Involvement in A Chronic Disease Prevention Phd Progamme	Burton E Carvalho M Dunne P Gibson I Hasedline C Kenny E	PPI Ignite Festival 2022	October 2022

Title	Presenters	Event	Date

How To Include Patient and Public Involvement in A PhD (Asked by the National Director of PPI Ignite to record this presentation for the website as a resource to help other PhD students)	Burton E Masterson L	Online – SPHeRE training session for PhD students Video on PPI Ignite website: PPI in my PhD: Impact of COVID-19 on ambulance times for suspected strokes/TIA in Ireland • PPI Ignite Network (ppinetwork.ie)	December 2021
Patient And Public Involvement in My PhD	E. Burton	SPHeRE Online Peer Learning Event	June 2021

Title	Blog site	Date	Author(s)

Blog

Developing Terms of Reference for Patient and Public Involvement in the Collaborative Doctoral Programme for Chronic Disease Prevention (CDP-CDP)	Structured Population and Health services research education (SPHeRE) Blog series Developing Guidance for Patient and Public Involvement in the Collaborative Doctoral Programme for Chronic Disease Prevention (CDP-CDP) | The SPHeRE Programme | Structured Population and Health-services Research Education	December 2022	Burton E. Carvalho M. Dunne P. Haseldine C. Gibson I. Kenny E.

Workshops

Title	Presenters	Event	Date
Planning Your PPI Approach	Burton E Dunne P	PPI Ignite – Ignite Insight: PPI in PhD Research Symposium	October 2024
PPI in Doctoral Studies- Guidance from the Collaborative Doctoral Programme in Chronic Disease Prevention	Burton E Dunne P	PPI Ignite - University of Limerick PPI Summer School	June 2024

Chapter 3 Appendices

Appendix 3.1 - Systematic review protocol on PROSPERO

Appendix 3.2 - Peer Review in Electronic Search Strategy Criteria Checklist

Translation of the research question	PubMed (Yes/No)
Has the research question been translated correctly into search concepts (e.g., PICO) i.e. does the search strategy match the research question?	
Are the search concepts clear?	
Are there "too many" search concepts?	
Are any of the search concepts too narrow or too broad?	
Does the search appear to retrieve too many or too few records?	
Boolean and proximity operators	
Are there any mistakes in the use of Boolean or proximity operators?	
Are there any mistakes in the use of nesting with brackets?	
If NOT is used, is this likely to result in any unintended exclusions?	
Could precision be improved by using proximity operators (e.g., adjacent, near, within instead of AND?	
Is the width of any proximity indicators, correct?	
Subject headings	
Are the subject headings relevant?	
Any subject headings missing?	
Are any subject headings too broad or too narrow?	

Are subject headings exploded where necessary and vice versa?	
Are sub-headings attached to subject headings (floating subheadings may be preferred)	
Are subheadings used instead of relevant subject headings and vice versa?	
Are both subject headings and natural language terms (see below) used for each concept? If there is a reason provided for not doing so, does the reason appear sound?	
Natural language (also free-text or text-word)	
Does the search miss any spelling variants in free text?	
Does the search miss any synonyms?	
Does the search miss truncation or truncate at the wrong point?	
If an acronym or abbreviation if used, is the full term also included?	
Are apparently irrelevant or excessively broad natural language terms used?	
Spelling, syntax, and line numbers	
Are there any spelling errors?	
Are there any errors in system syntax or wrong line numbers?	
Limits and filters	
Do any of the limits used seem unwarranted?	
Are any filters used appropriate for the topic?	
Are any potentially useful limits or filters missing?	
Is starring (restrict to focus) used and if so, is there adequate justification for this?	

Search strategy adaptations	
Does the searcher indicate that the search strategy has been adapted for additional databases and/or interfaces?	
Are the adaptations available for review, and correct?	

Appendix 3.3 - Database Search Terms for 31.05.2022 and 26.04.2023 Searches

PubMed terms:

(((("COVID-19"[Title/Abstract] OR covid [Title/Abstract] OR coronavirus*[Title/Abstract] OR "novel coronavirus*"[Title/Abstract] OR lockdown*[Title/Abstract] OR pandemic*[Title/Abstract]) OR (SARS-CoV-2[MeSH Terms]))
AND
(("cerebrovascular accident*"[Title/Abstract] OR "cerebrovascular disease*"[Title/Abstract] OR "transient ischaemic attack*"[Title/Abstract] OR "transient ischemic attack*"[Title/Abstract] OR "TIA"[Title/Abstract] OR "cerebrovascular event*"[Title/Abstract]) OR (stroke*[MeSH Terms])))
AND
(("pre hospital"[Title/Abstract] OR prehospital[Title/Abstract] OR "pre-hospital"[Title/Abstract] OR EMS[Title/Abstract] OR ambulance*[Title/Abstract] OR "emergency care"[Title/Abstract] OR paramedic*[Title/Abstract] OR 999[Title/Abstract] OR 112[Title/Abstract] OR 911[Title/Abstract] OR "emergency department*"[Title/Abstract] OR "out-of-hospital"[Title/Abstract] OR emergenc*[Title/Abstract] OR "hospital referral*"[Title/Abstract] OR "emergency admission*"[Title/Abstract] OR "time-to-treatment"[Title/Abstract] OR "acute stroke care"[Title/Abstract] OR "acute stroke therapy"[Title/Abstract]) OR (emergency medical services[MeSH Terms]))

Embase search terms:

'emergency care'/exp OR'emergency medical service*':ab,ti OR ems:ab,ti OR ambulance*:ab,ti OR paramedic*:ab,ti OR 999:ab,ti OR 911:ab,ti OR 112:ab,ti OR 'pre hospital':ab,ti OR prehospital:ab,ti OR 'emergency department*':ab,ti OR 'out-of-hospital':ab,ti OR 'acute stroke care':ab,ti OR 'acute stroke therapy':ab,ti OR 'time-to-treatment':ab,ti OR 'emergency service*':ab,ti OR emergenc*:ab,ti
AND
'Cerebrovascular accident'/exp OR stroke*: ab, ti OR 'transient ischaemic attack*': ab, ti OR 'transient ischemic attack*': ab, ti OR tia: ab, ti OR 'cerebrovascular disease*': ab, ti OR 'cerebrovascular event*': ab, ti
AND
'Coronavirus disease 2019'/exp OR 'covid-19': ab, ti OR 'sars-cov-2': ab, ti OR covid: ab, ti OR 'novel coronavirus19': ab, ti OR coronavirus*: ab, ti OR lockdown*: ab, ti OR pandemic*: ab, ti

ProQuest Central search terms:

(((AB,TI("emergency medical service*") OR AB,TI(EMS) OR AB,TI(ambulance*) OR AB,TI("emergency care") OR AB,TI(paramedic*) OR AB,TI(999) OR AB,TI(911) OR AB,TI(112) OR AB,TI("emergency department*") OR AB,TI("out-of-hospital") OR AB,TI (emergenc*) OR AB,TI("hospital referral*") OR AB,TI("emergency admission*") OR AB,TI("acute stroke care") OR AB,TI("acute stroke therapy") OR AB,TI("time-to-treatment") OR AB,TI("emergency service*") OR AB,TI ("pre hospital") OR AB,TI(prehospital) OR AB,TI("pre-hospital")) AND PEER(yes)) OR (mainsubject.Exact("emergency services") AND PEER(yes)))
AND
((mainsubject. Exact("stroke") AND PEER (yes)) OR ((AB, TI ("cerebrovascular accident*") OR AB, TI ("transient ischaemic attack*") OR AB, TI ("transient ischemic attack*") OR AB, TI(TIA) OR AB, TI ("cerebrovascular disease*") OR AB, TI ("cerebrovascular event*")) AND PEER (yes)))
AND
((mainsubject. Exact("covid-19") AND PEER (yes)) OR ((AB, TI("SARS-CoV-2") OR AB, TI (coronavirus*) OR AB, TI ("novel coronavirus19") OR AB, TI (covid) OR AB, TI (lockdown*) OR AB, TI (pandemic*)) AND PEER (yes)))

Web of Science search terms:

TS= ("prehospital" OR "pre-hospital" OR prehospital OR "emergency medical service*" OR "emergency care" OR EMS OR ambulance* OR paramedic* OR 999 OR 911 OR 112 OR "emergency department*" OR "out-of-hospital" OR emergenc* OR "hospital referral*" OR "emergency admission*" OR "time-to-treatment" OR "acute stroke care" OR "acute stroke therapy")
AND
TS= (stroke* OR "cerebrovascular accident*" OR "transient ischaemic attack*" OR "transient ischemic attack" OR TIA OR "cerebrovascular disease*" OR "cerebrovascular event*")
AND
TS= ("COVID-19" OR "SARS-CoV-2" OR covid OR coronavirus* OR "novel coronavirus*" OR lockdown * OR pandemic*)
TS - topic - title/abstract/keywords

Scopus search terms:

TITLE-ABS ("pre hospital") OR TITLE-ABS ("pre-hospital") OR TITLE-ABS (prehospital) OR TITLE-ABS ("emergency medical service*") OR TITLE-ABS ("emergency care") OR TITLE-ABS (ems) OR TITLE-ABS (ambulance*) OR TITLE-ABS (paramedic*) OR TITLE-ABS (999) OR TITLE-ABS (911) OR TITLE-ABS (112) OR TITLE-ABS ("emergency department*") OR TITLE-ABS ("out-of-hospital") OR TITLE-ABS (emergenc*) OR TITLE-ABS ("hospital referral*") OR TITLE-ABS ("emergency admission*") OR TITLE-ABS ("time-to-treatment") OR TITLE-ABS ("acute stroke care") OR TITLE-ABS ("acute stroke therapy") ARTICLE

AND

TITLE-ABS (stroke*) OR TITLE-ABS (“cerebrovascular accident*”) OR TITLE-ABS (“transient ischaemic attack*”) OR TITLE-ABS (“transient ischemic attack*”) OR TITLE-ABS (tia) OR TITLE-ABS (“cerebrovascular disease*”) OR TITLE-ABS (“cerebrovascular event*”) ARTICLE

AND

TITLE-ABS (“COVID-19”) OR TITLE-ABS (“SARS-CoV-2”) OR TITLE-ABS (covid) OR TITLE-ABS (coronavirus*) OR TITLE-ABS (“novel coronavirus*”) OR TITLE-ABS (lockdown*) OR TITLE-ABS (pandemic*) ARTICLE

Wiley search terms:

"stroke* OR "cerebrovascular accident*" OR "transient ischaemic attack*" OR "transient ischemic attack" OR TIA OR "cerebrovascular disease*" OR "cerebrovascular event*"" anywhere

AND

""COVID-19" OR "SARS-CoV-2" OR covid OR coronavirus* OR "novel coronavirus*" OR lockdown * OR pandemic*" anywhere

AND

""prehospital" OR "pre-hospital" OR prehospital OR "emergency medical service*" OR "emergency care" OR EMS OR ambulance* OR paramedic* OR 999 OR 911 OR 112 OR "emergency department*" OR "out-of-hospital" OR emergenc* OR "hospital referral*" OR "emergency admission*" OR "time-to-treatment" OR "acute stroke care" OR "acute stroke therapy" anywhere

Appendix 3.4 - Form Used for Input from Expert Stakeholders

Paper number	Author	Outcome(s)	Location	EB comment	SM comment	AM comment
Primary outcome (ambulance time intervals)						
Secondary outcome (call volume) only						
Primary outcome (ambulance time intervals) and secondary outcome (call volume)						

Appendix 3.5 - Data Extraction Form Used in This Systematic Review and Meta-analysis

Author(s), month, year of publication, country	Aims/purpose	Stroke/TIA	Study design	Country/region	Income level of country	Sample size in studies, sex, age	COVID-19 cases numbers/ICU numbers/hospitalizations

EMS system	Definition of EMS call volume	Activation time interval before and during the pandemic	Total prehospital time interval	Response time interval before and during the pandemic	Patient care time interval before and during pandemic	Call volumes before and during the pandemic	Time period (pre and during COVID-19 pandemic)	Method of stroke/TIA diagnosis	Total calls during pandemic

Appendix 3.6 - Patient and Public involvement in this review reported using The GRIPP2 checklist (short version)

1. Aim – Report the aim of PPI in this study

The aim of PPI in this study was to ensure those with lived experience of stroke/TIA helped to shape the review, from research question development to dissemination.

2. Methods - Provide a clear description of the methods used for PPI in the study

We worked with a PPI panel of 5 stroke survivors (2 female, 3 male) from a stroke support group to refine the research question, develop the protocol[58] and disseminate review results. EB facilitated three face-to-face meetings with the PPI panel. Firstly, the panel were consulted on their language preferences surrounding people who have had a stroke/TIA. The PPI contributors were asked to suggest synonyms were "stroke" and "TIA" to be included in the search strategy. The group were also asked to identify key outcomes that were important to them in the prehospital phase of their stroke/TIA journey. The group were also involved in the interpretation of findings as EB presented the group with key findings to discuss and identify potential gaps. Finally, the panel were tasked with identifying key stakeholder groups to target for dissemination.

3. Study results – Outcomes - Report the results of PPI in the study, including both positive and negative outcomes

The PPI contributors advised that they prefer the term "stroke/TIA survivor" over "stroke/TIA patient" or "stroke/TIA victim." They also suggested synonyms such as

"mini stroke" and "brain attack" for potential inclusion in the search strategy. In terms of dissemination, the group identified key relevant policy and practice stakeholders for dissemination, as well as compiling a lay summary which is displayed on the stroke support group's website Ambulance times and calls for suspected stroke and TIA (mini-stroke) during the COVID-19 pandemic : What's in the papers? - Cork Stroke Support. They suggested that healthcare professionals, including the ambulance services, and policy makers should be aware of study findings. The PPI panel also stressed that stroke/TIA survivors and their families/caregivers needed to be informed of study results.

4. Discussions and conclusions – Outcome - Comment on the extent to which PPI influenced the study overall. Describe positive and negative effects

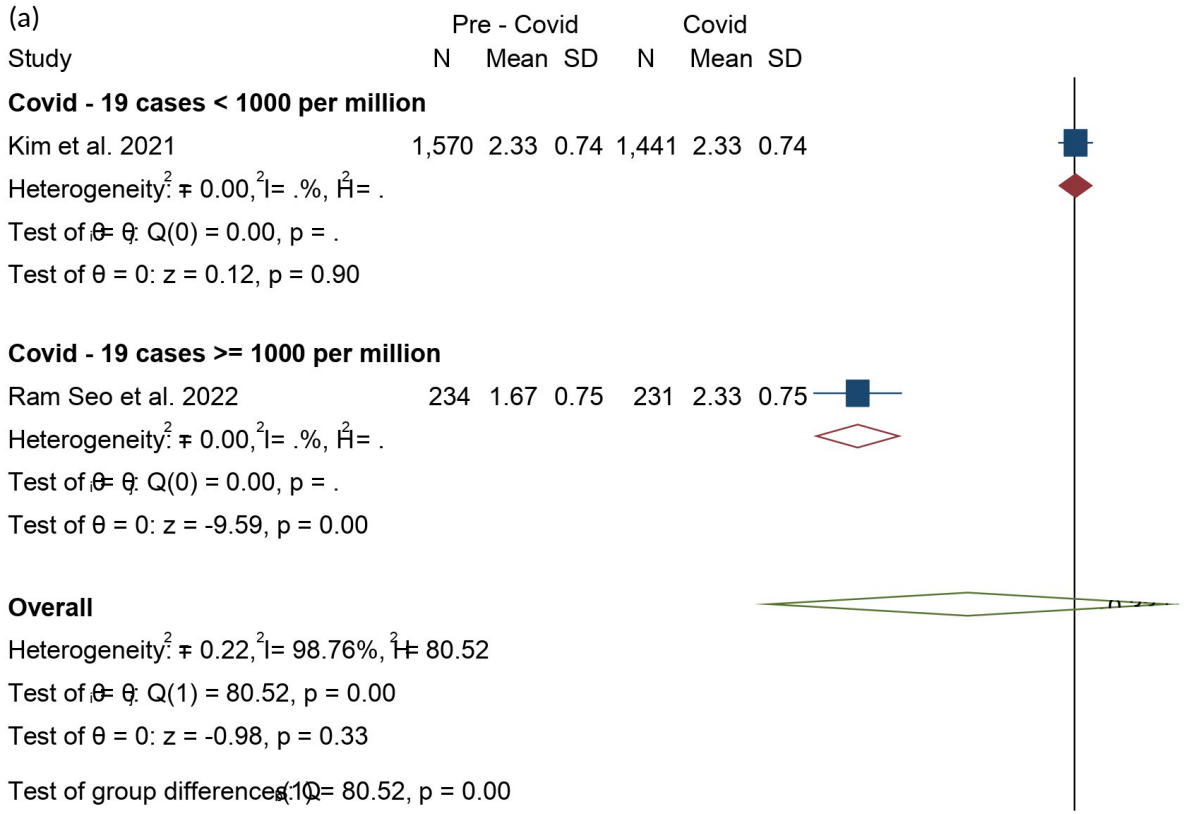
The PPI panel were involved in the development of the research question that inspired this review. We wished to include the panel as much as possible throughout the study. However, due to time constraints and training requirements we did not involve PPI contributors in the title/abstract screening process.

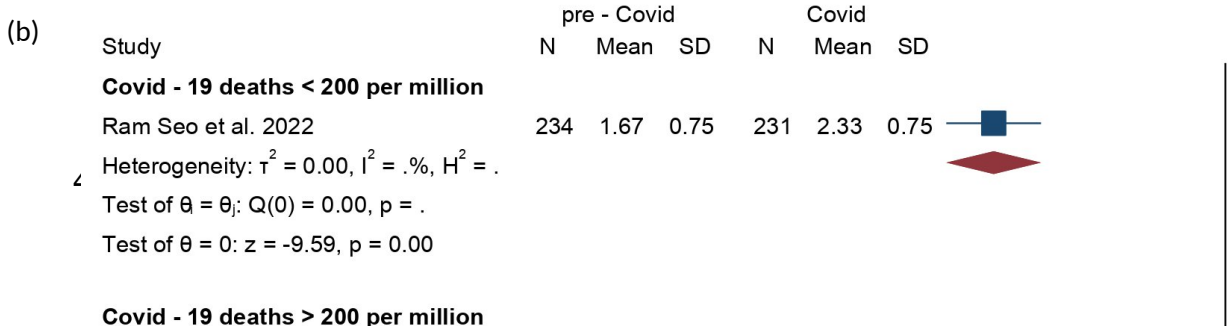
5. Reflections/critical perspective - Comment critically on the study, reflecting on the things that went well and those that did not, so others can learn from this experience

Overall, the inclusion of PPI throughout this review was a positive experience. We believe the purpose, impact and implications of the review were enriched by the

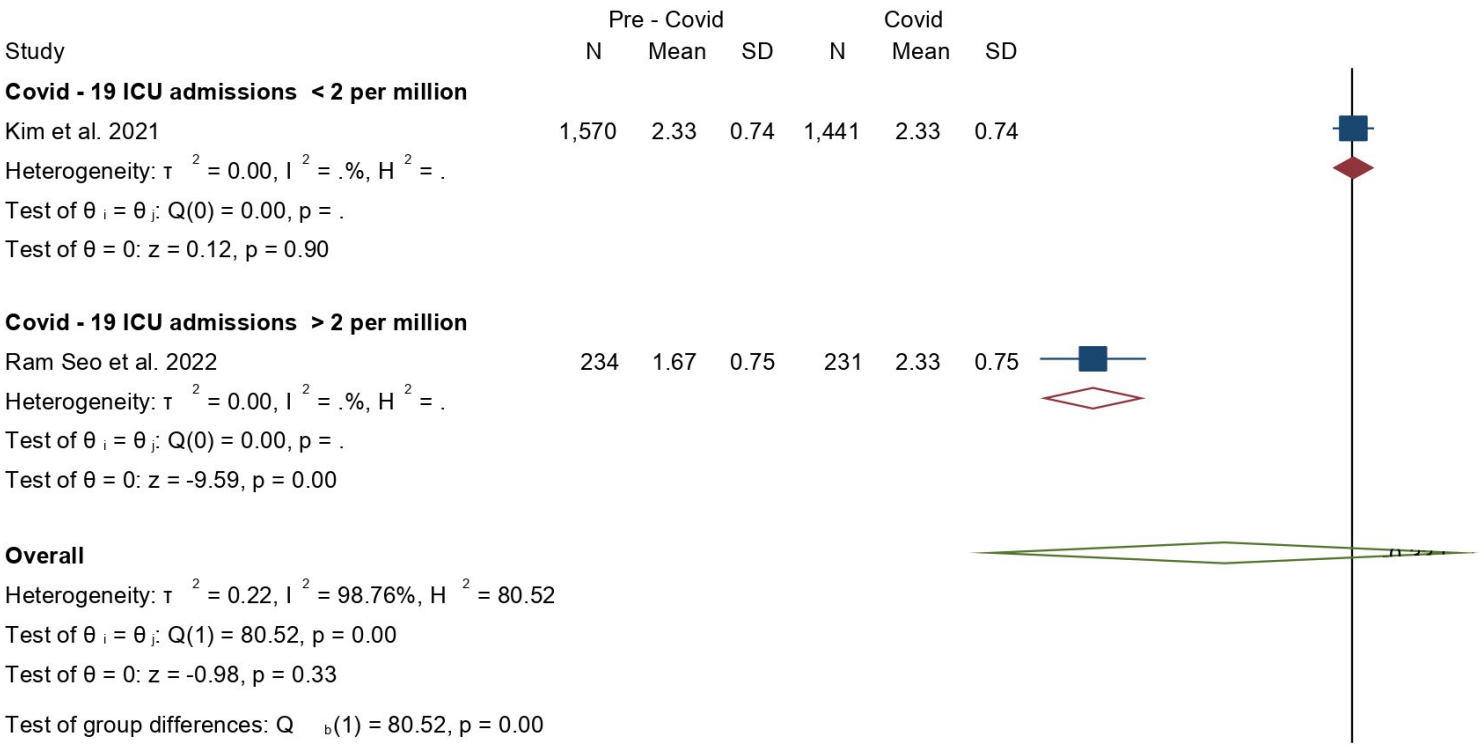
inclusion of the lived experience of stroke/TIA. However effective PPI requires time and other resources. Thus, within the confines of a PhD it can be challenging to include optimal levels of PPI.

Appendix 3.7 - Forest plots of subgroup analyses for activation time interval



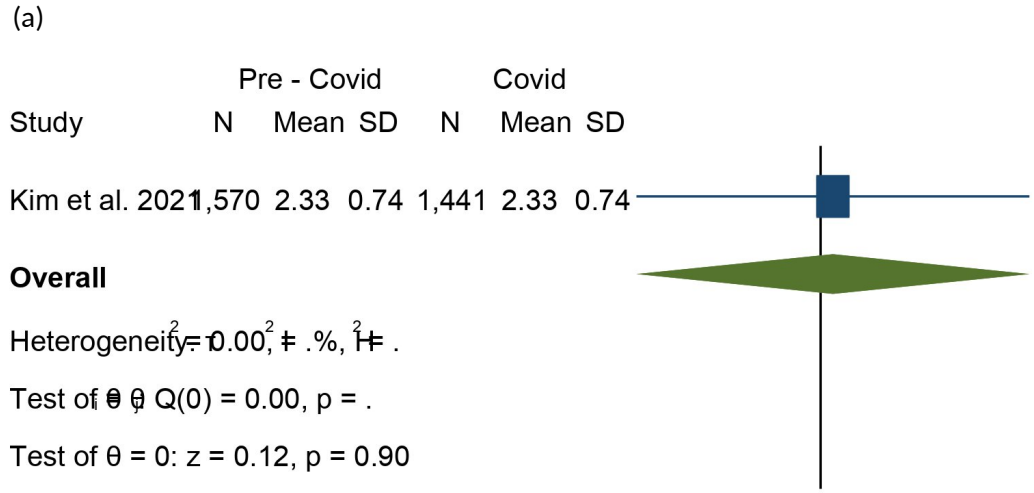


(c)



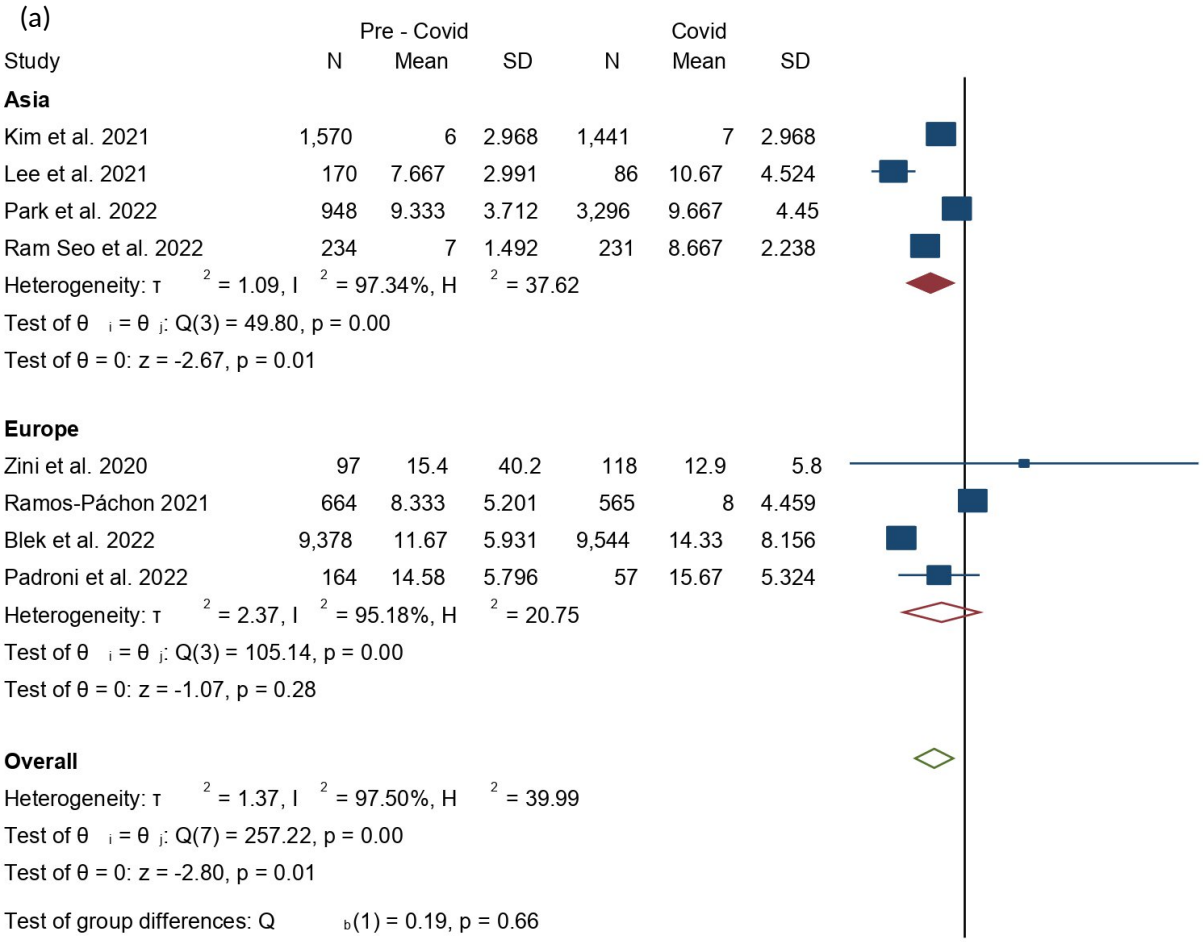
Appendix figure 3.7(c) - Subgroup analysis of activation time interval by COVID-19 ICU admissions per million

Appendix 3.8 - Forest plots of sensitivity analysis for activation time interval



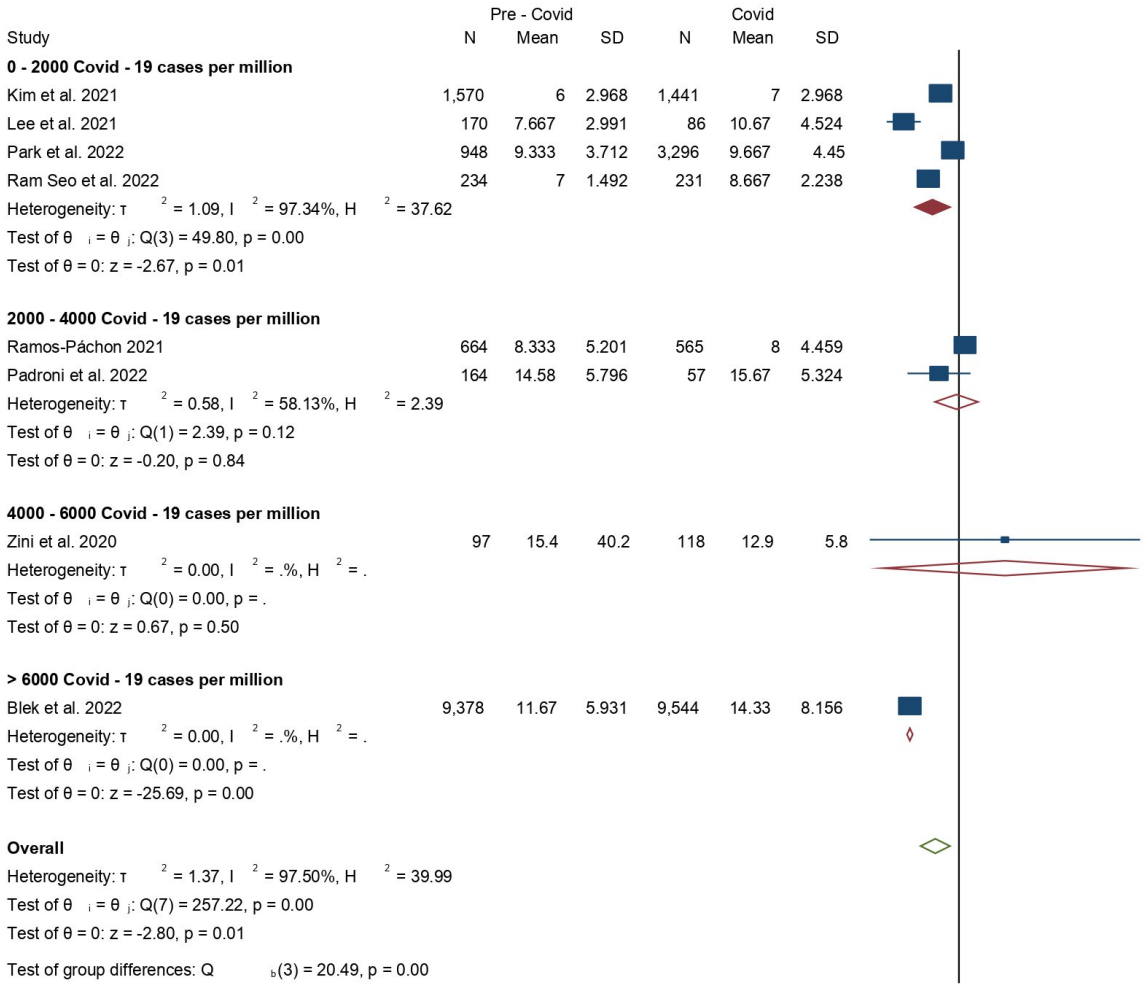
Appendix figure 3.8(a) - Sensitivity analysis of activation time interval by its definition

Appendix 3.9 - Forest plots of subgroup analyses for response time interval



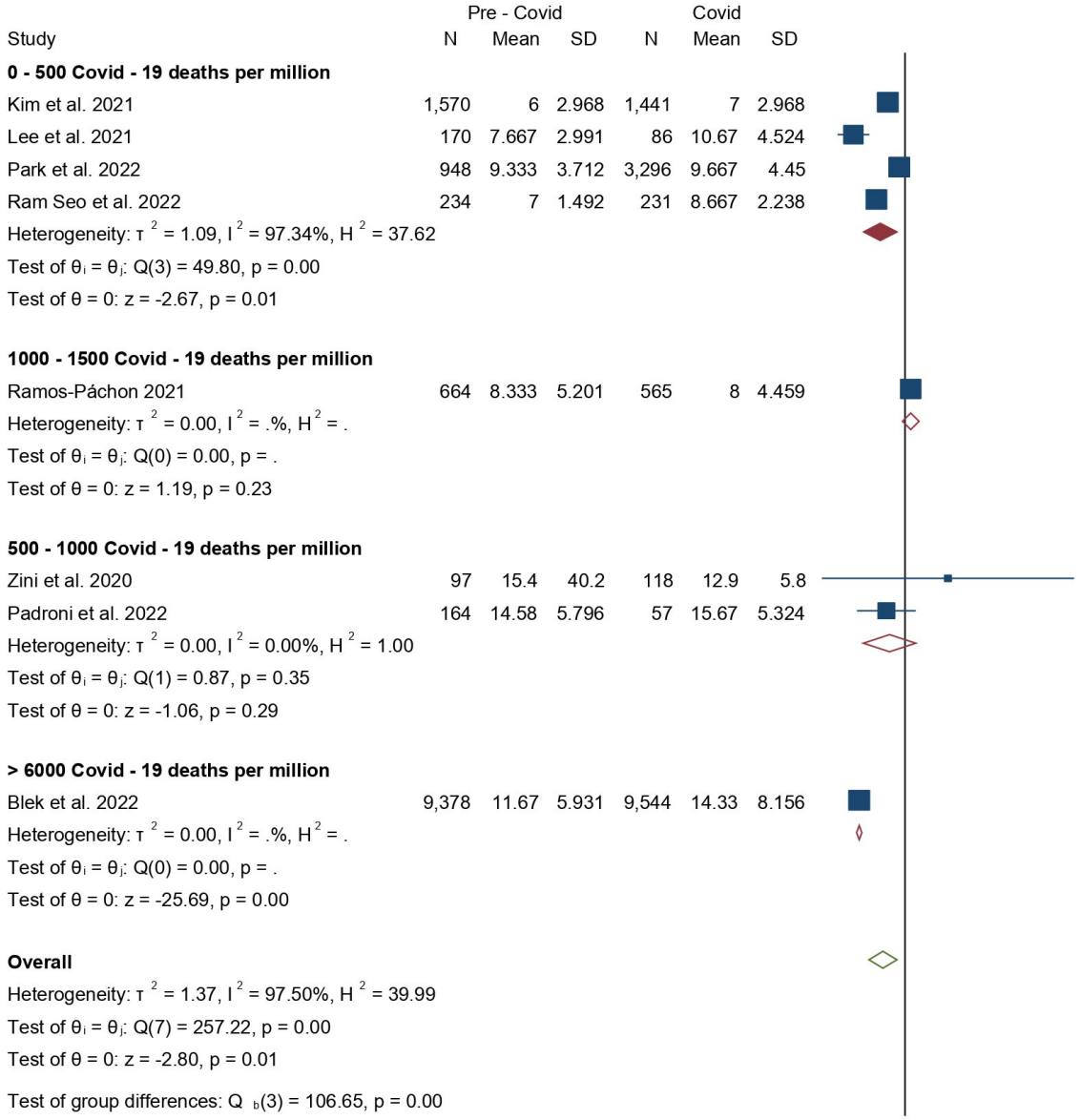
Appendix figure 3.9 (a) - Subgroup analysis of response time interval by location

(b)



Appendix figure 3.9 (b) - Subgroup analysis of response time interval by COVID-19 cases per million

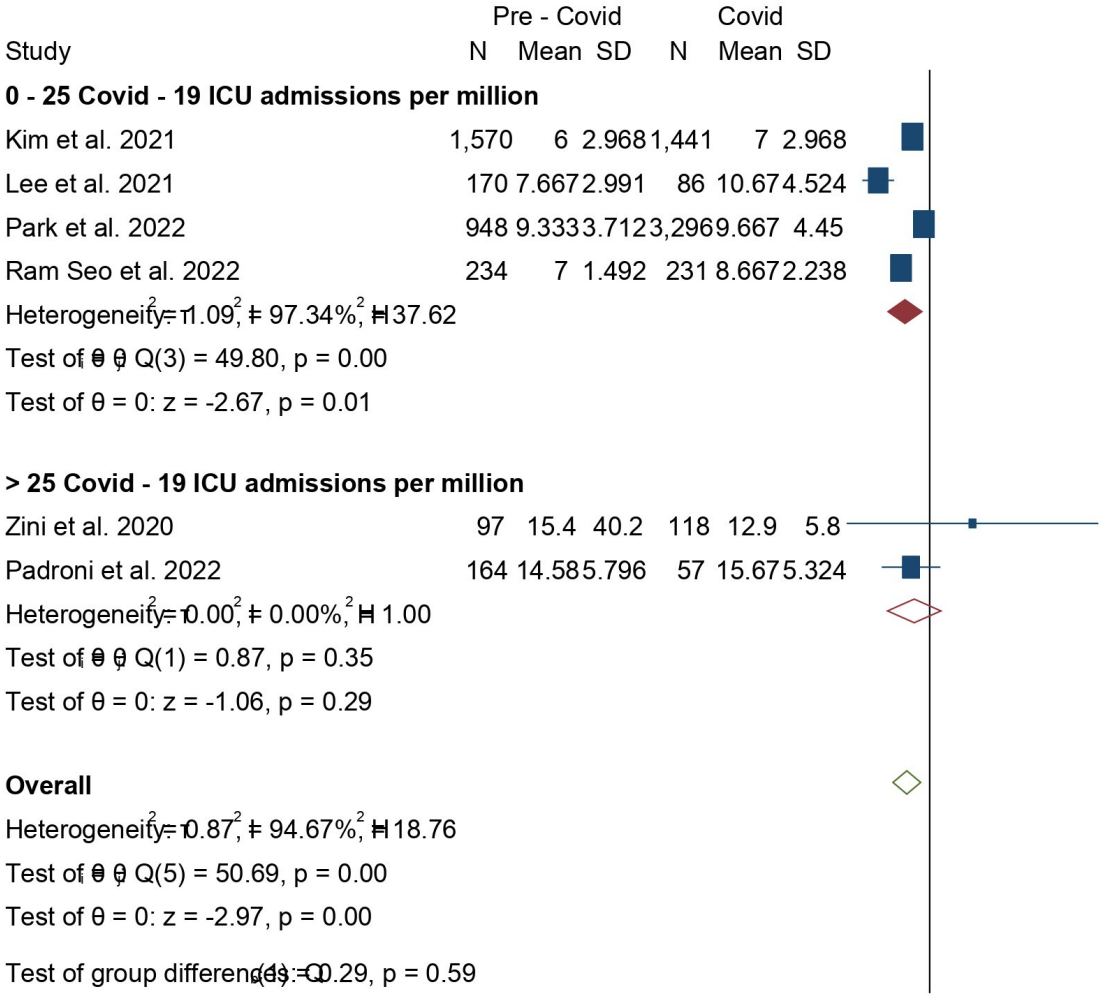
(c)



Appendix figure 3.9 (c) - Subgroup analyses of response time interval by COVID-19 deaths per

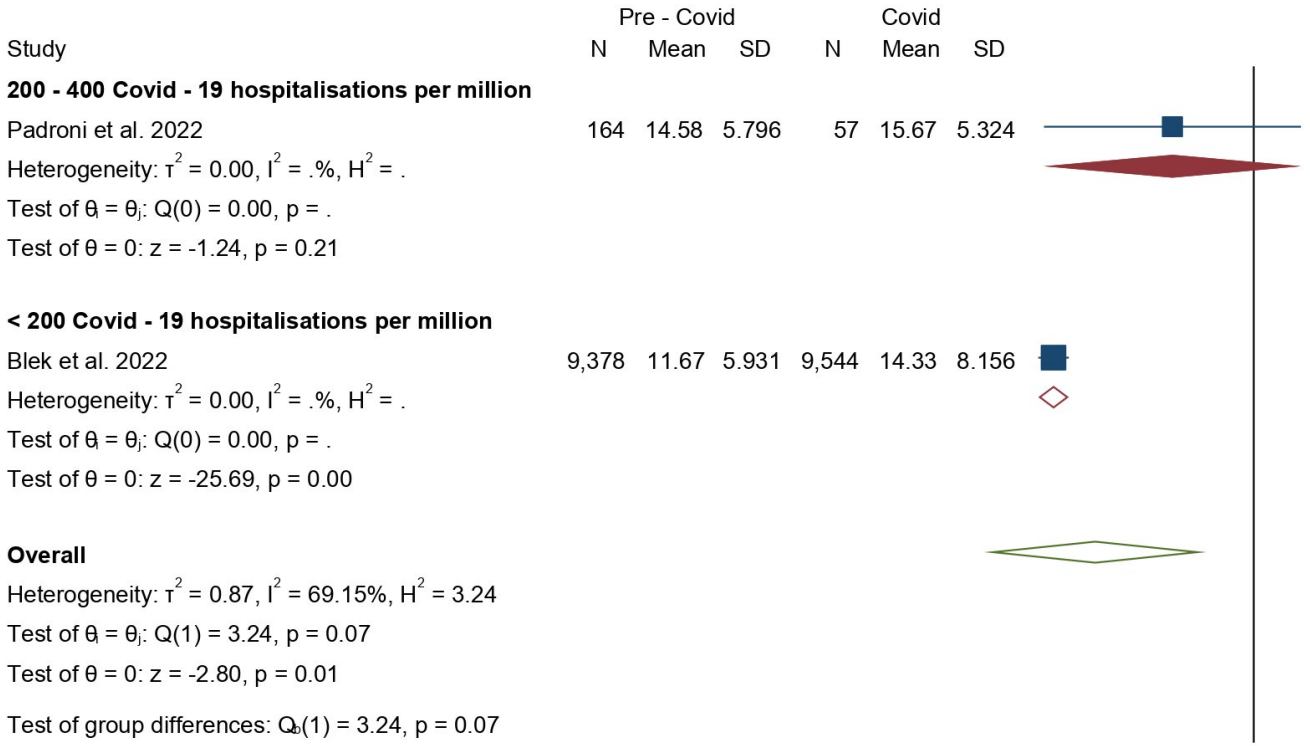
....

(d)



Appendix figure 3.9 (d) - Subgroup analysis of response time interval by COVID-19 ICU admissions per million

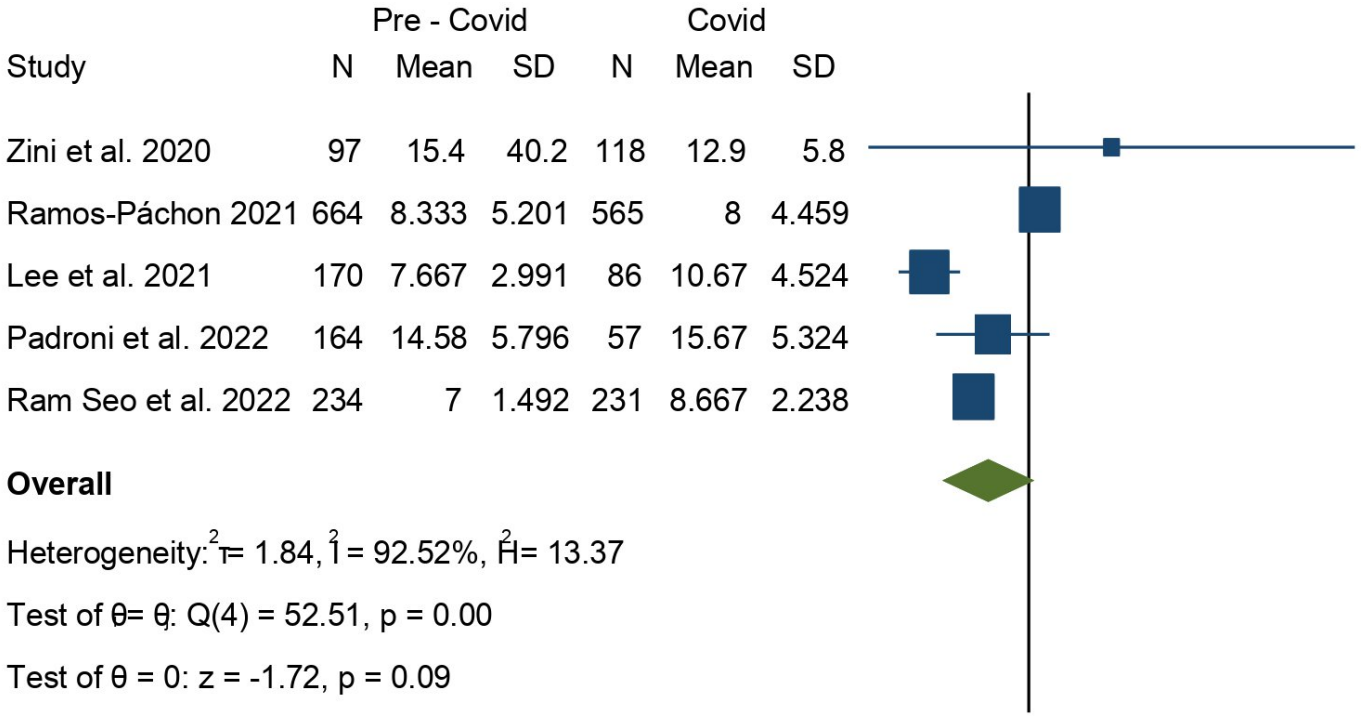
(e)



Appendix figure 3.9 (e) - Subgroup analysis of response time interval by COVID-19 hospitalisations per million

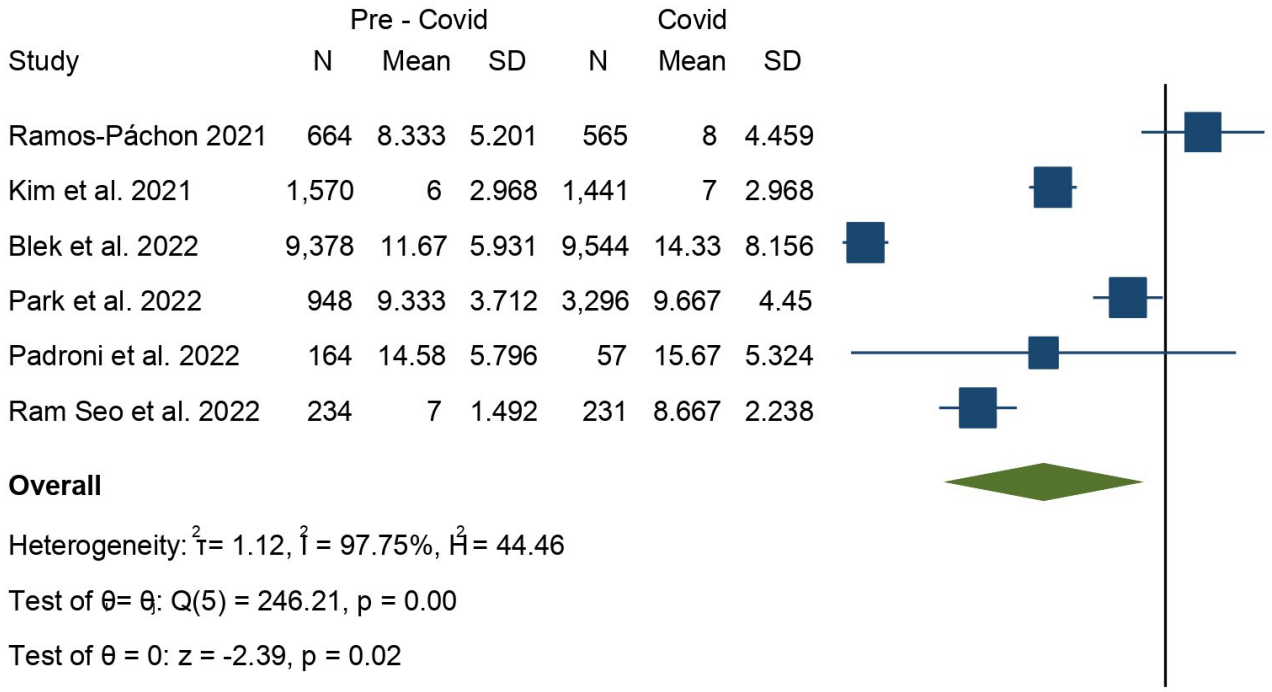
Appendix 3.10 - Forest plots of sensitivity analysis for response time interval

(a)



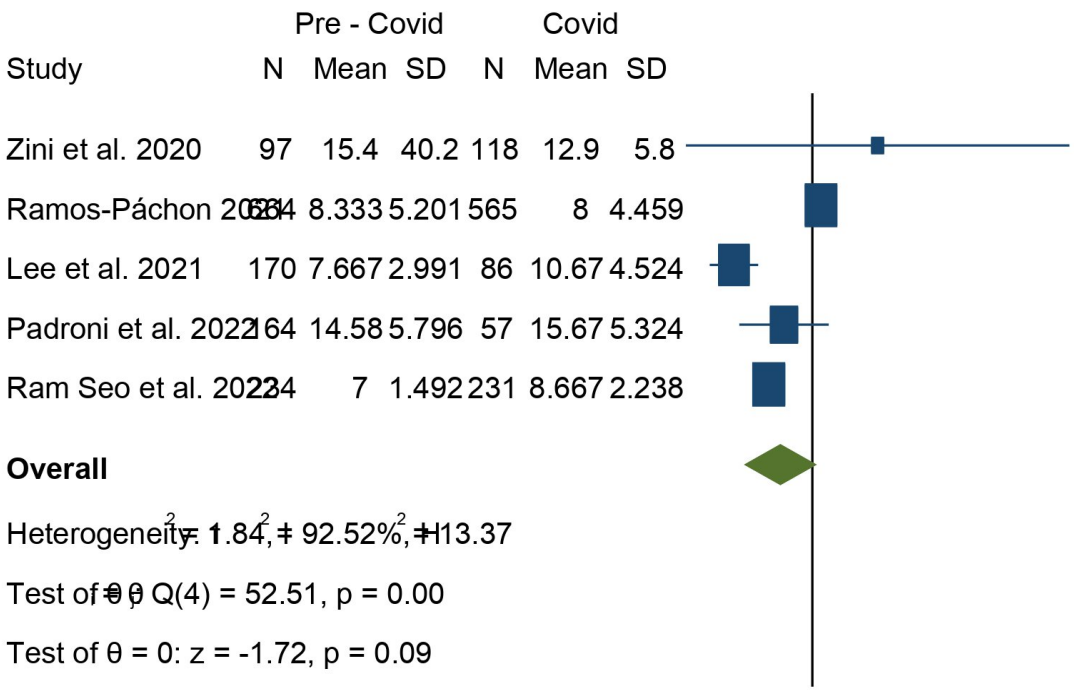
Appendix figure 3.10 (a) - Sensitivity analysis of response time interval by location of stroke diagnosis

(b)



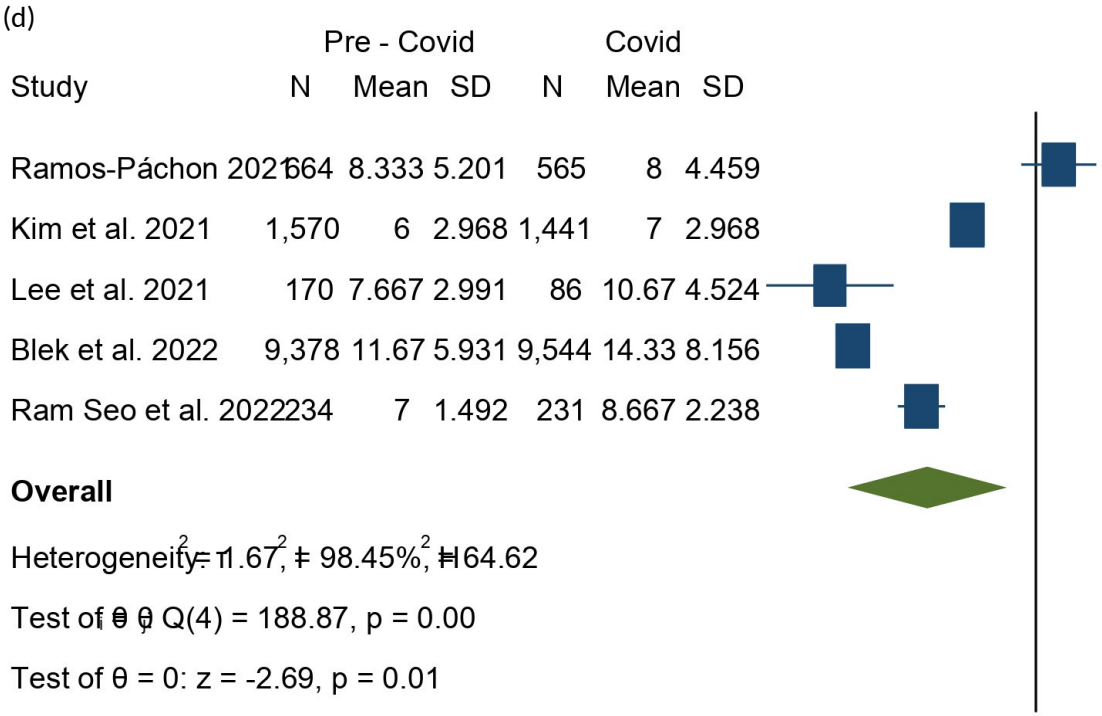
Appendix figure 3.10 (b) - Sensitivity analysis of response time interval by definition of call volume

(c)



Appendix figure 3.10 (c) - Sensitivity analysis of response time interval by the number of weeks since the WHO declared COVID-19 a pandemic on 11th March 2020

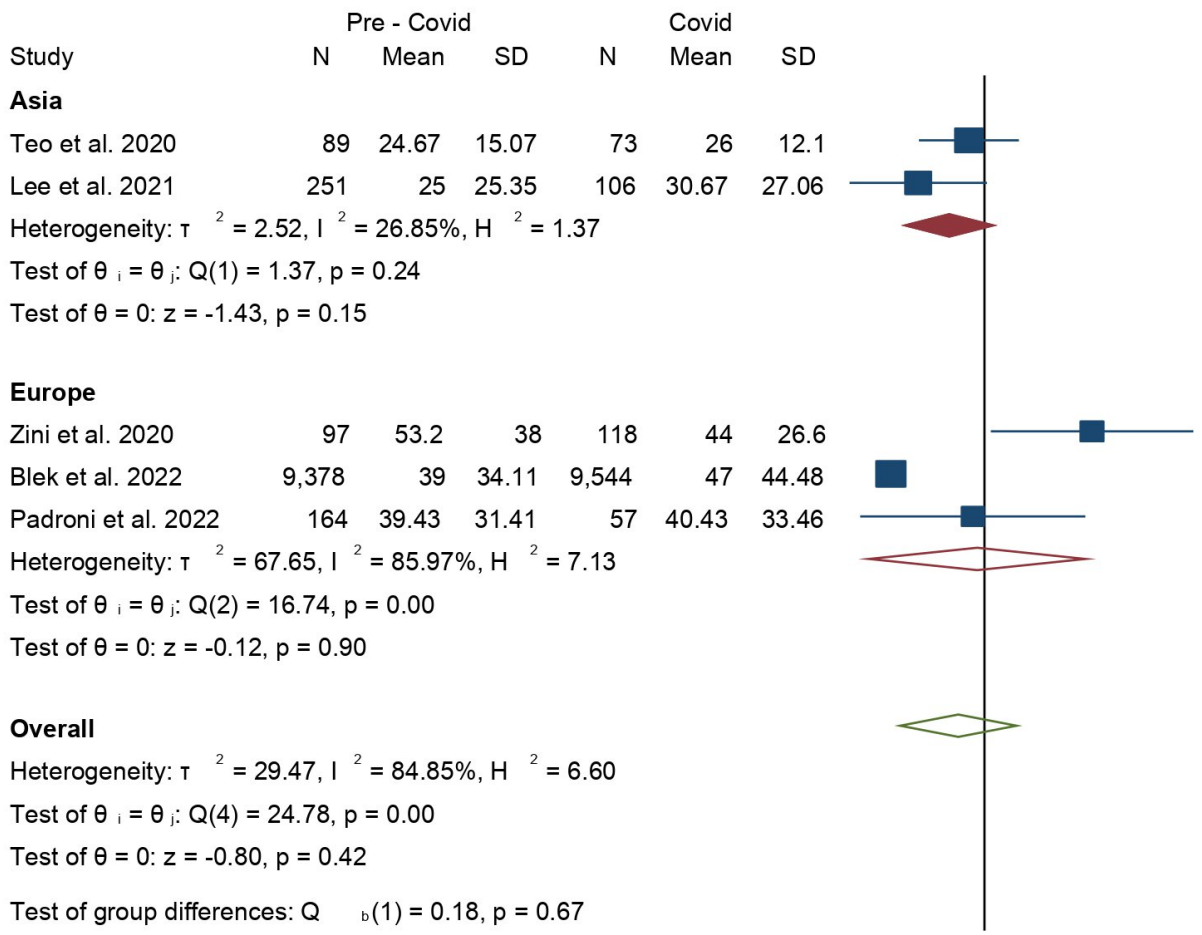
(d)



Appendix figure 3.10 (d) - Sensitivity analysis of response time interval by its definition

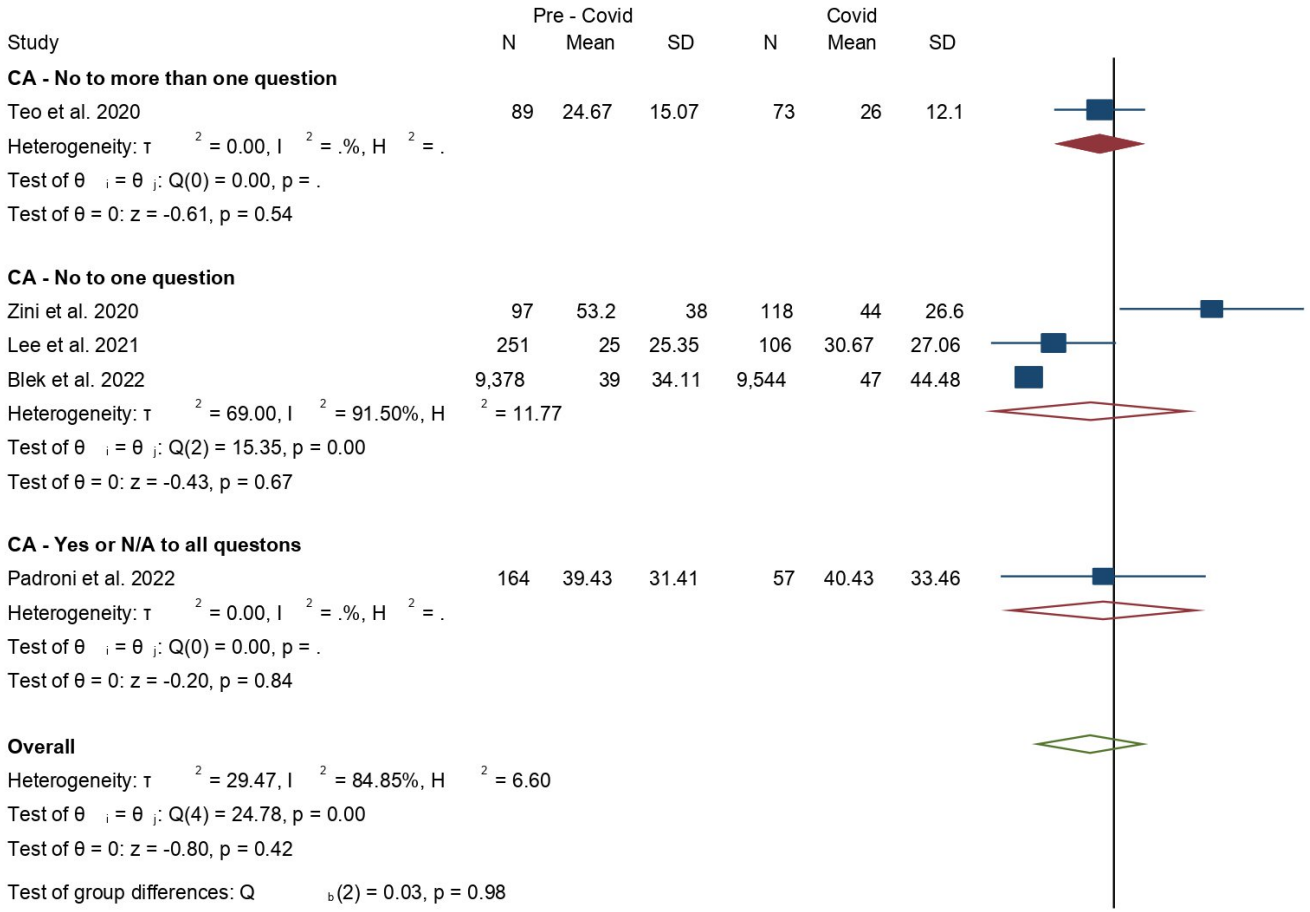
Appendix 3.11 - Forest plots of subgroup analyses for patient care time interval

(a)



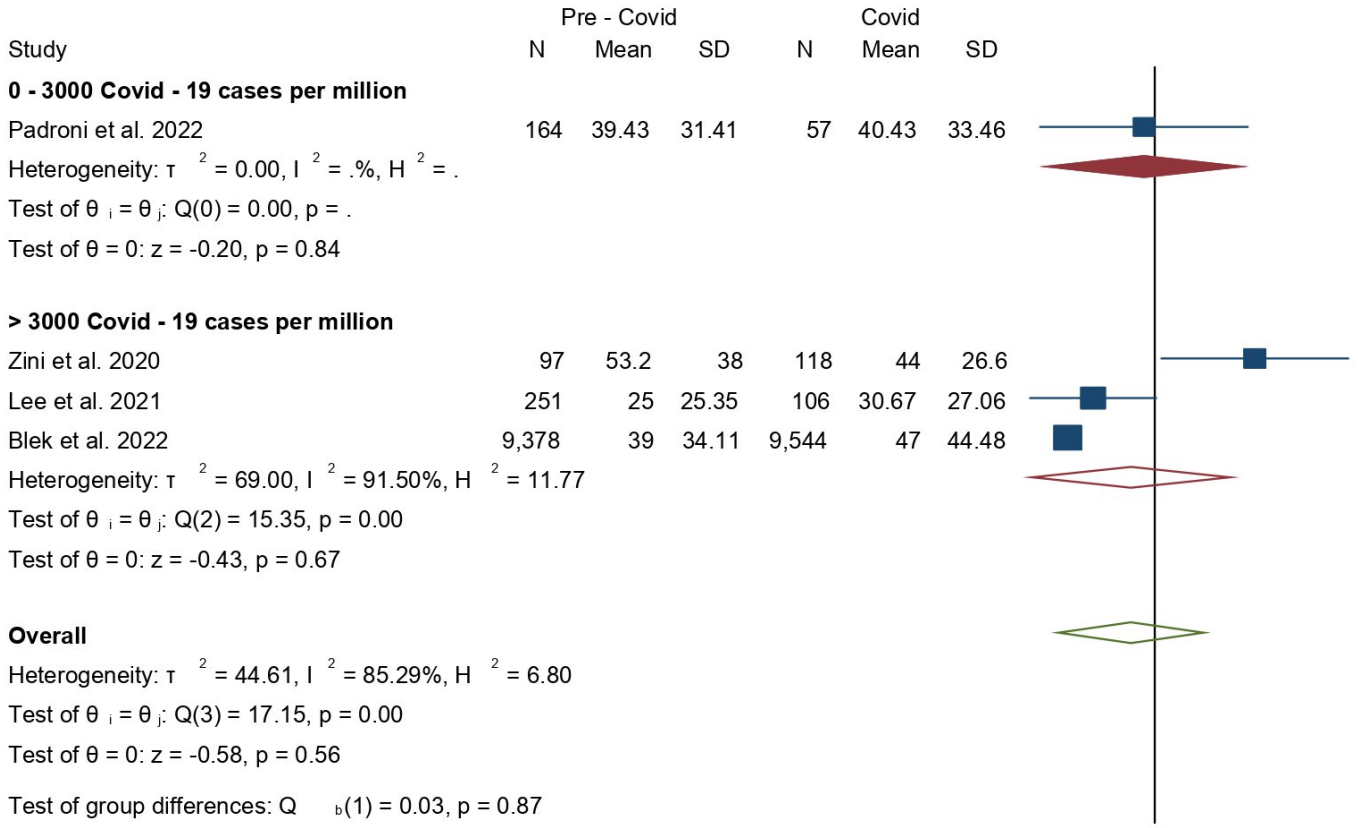
Appendix figure 3.11 (a) - Subgroup analyses of patient care time interval by location

(b)



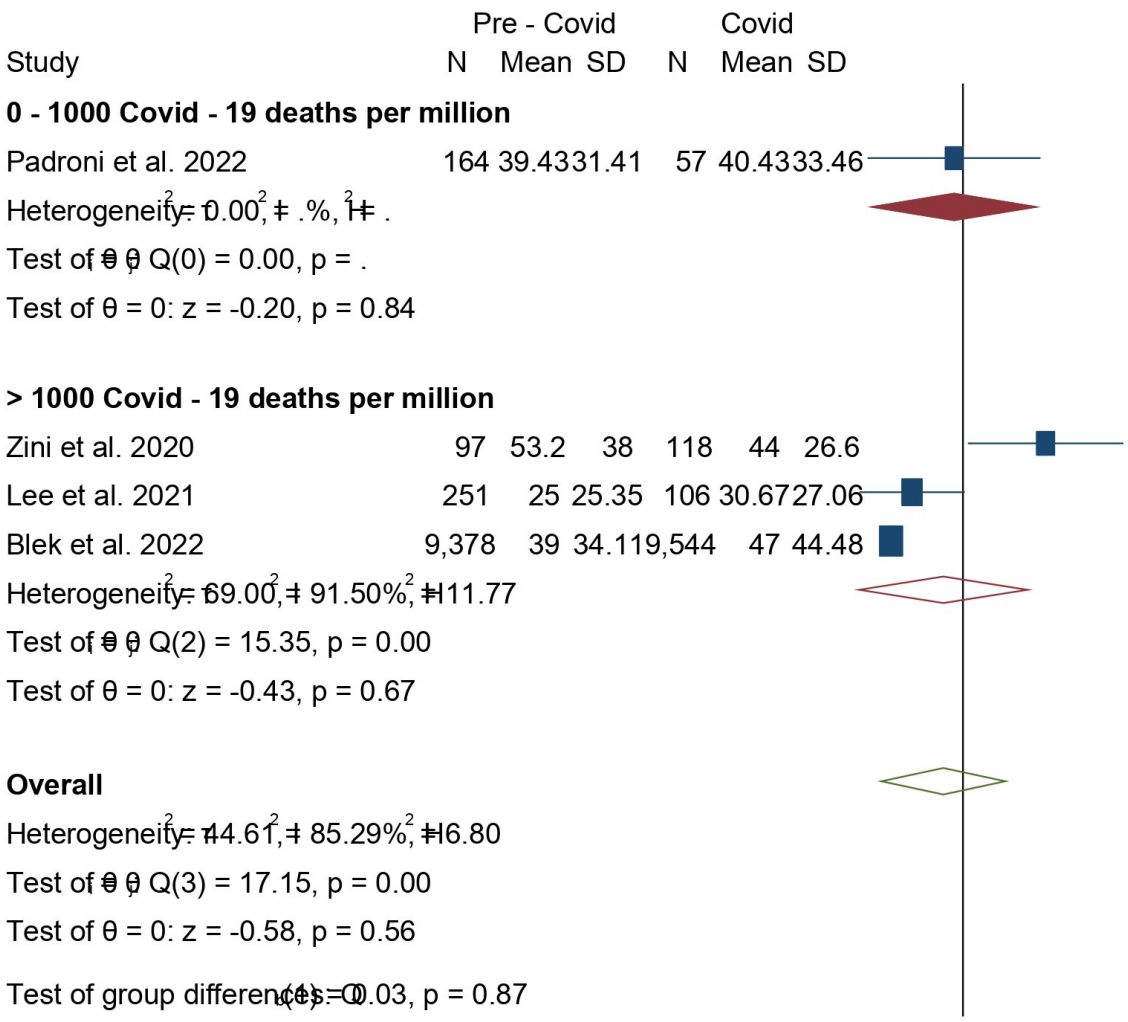
Appendix figure 3.11 (b) - Subgroup analysis of patient care time interval by study quality

(c)



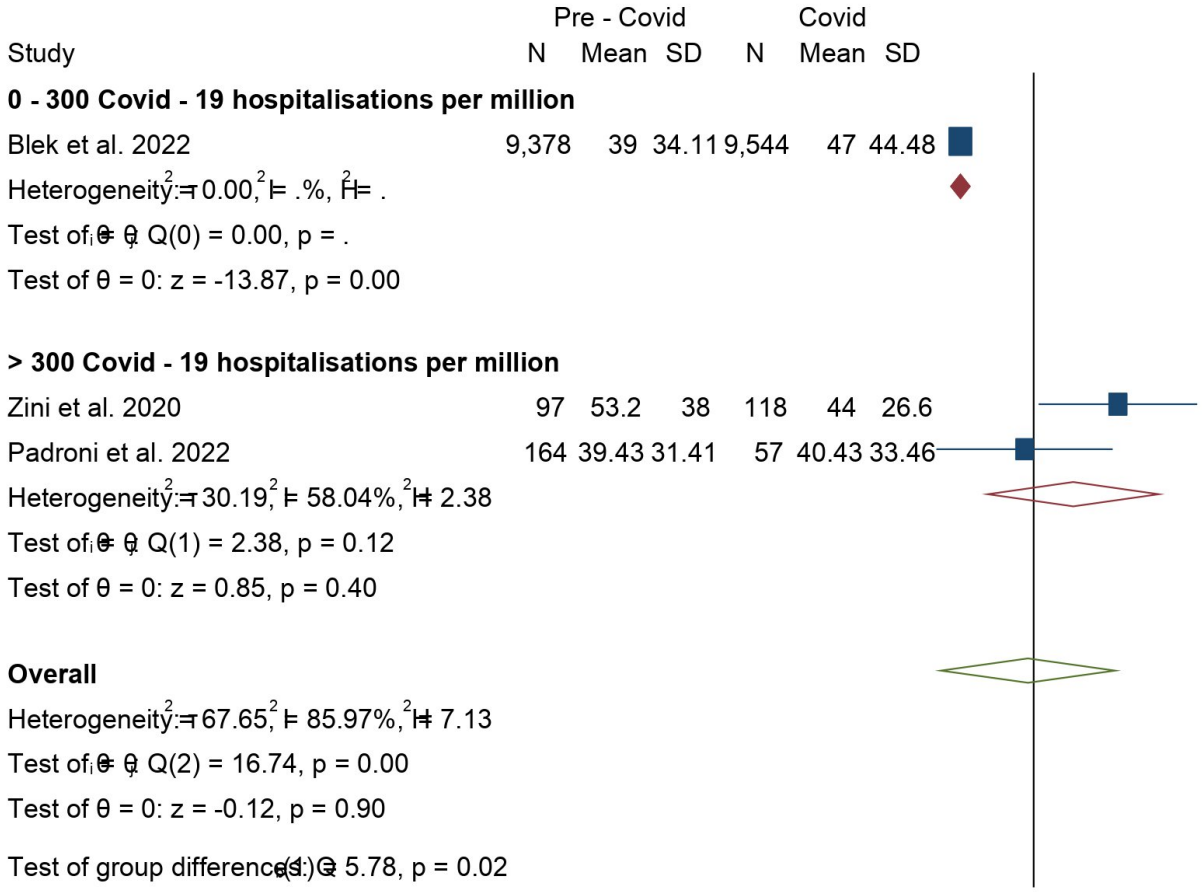
Appendix figure 3.11 (c) - Subgroup analysis of patient care time interval by COVID-19 cases per million

(d)



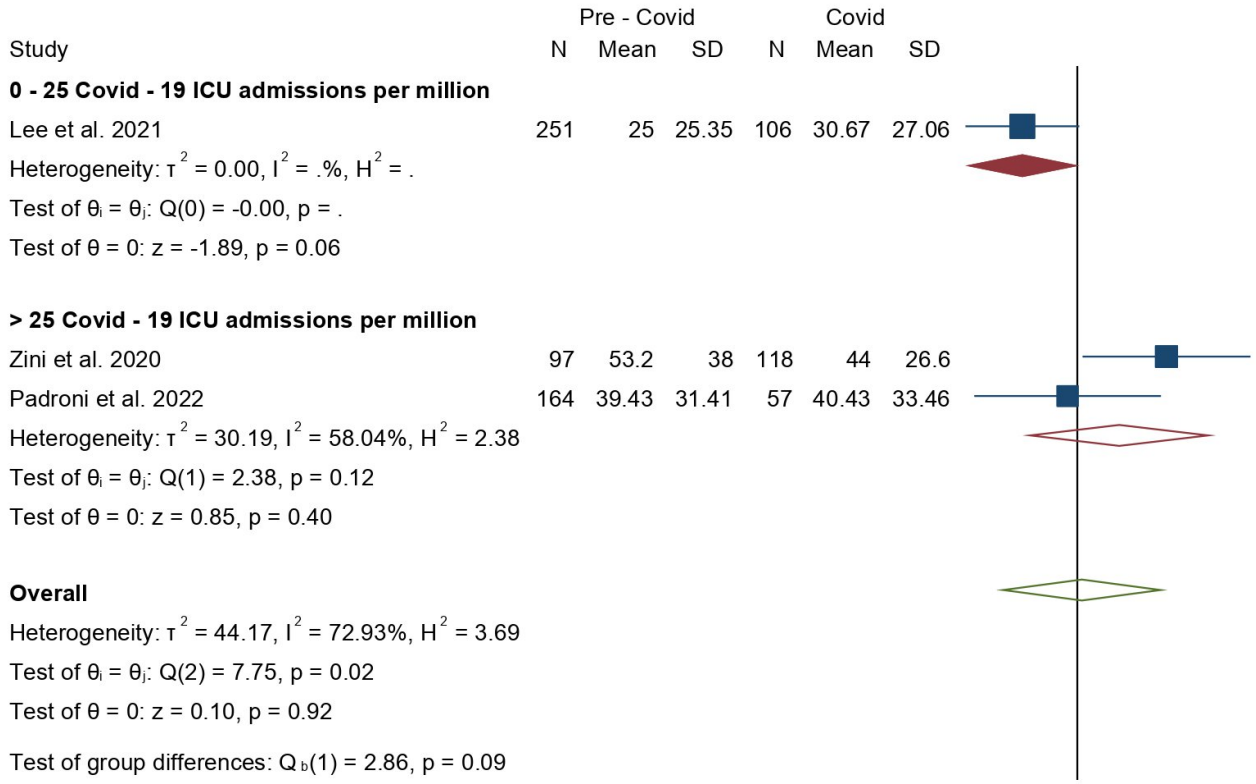
Appendix figure 3.11 (d) - Subgroup analysis of patient care time interval by COVID-19 deaths per million

(e)



Appendix figure 3.11 (e) - Subgroup analysis of patient care time interval by COVID-19 hospitalisations per million

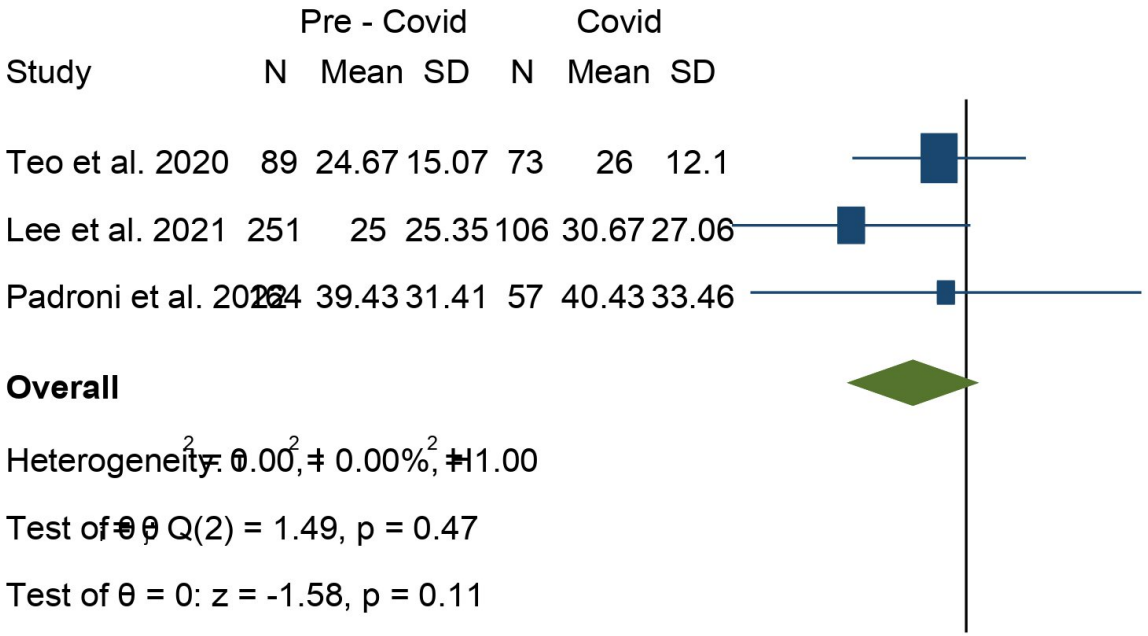
(f)



Appendix figure 3.11 (f) - Subgroup analysis of patient care time interval by COVID-19 intensive care unit admissions per million

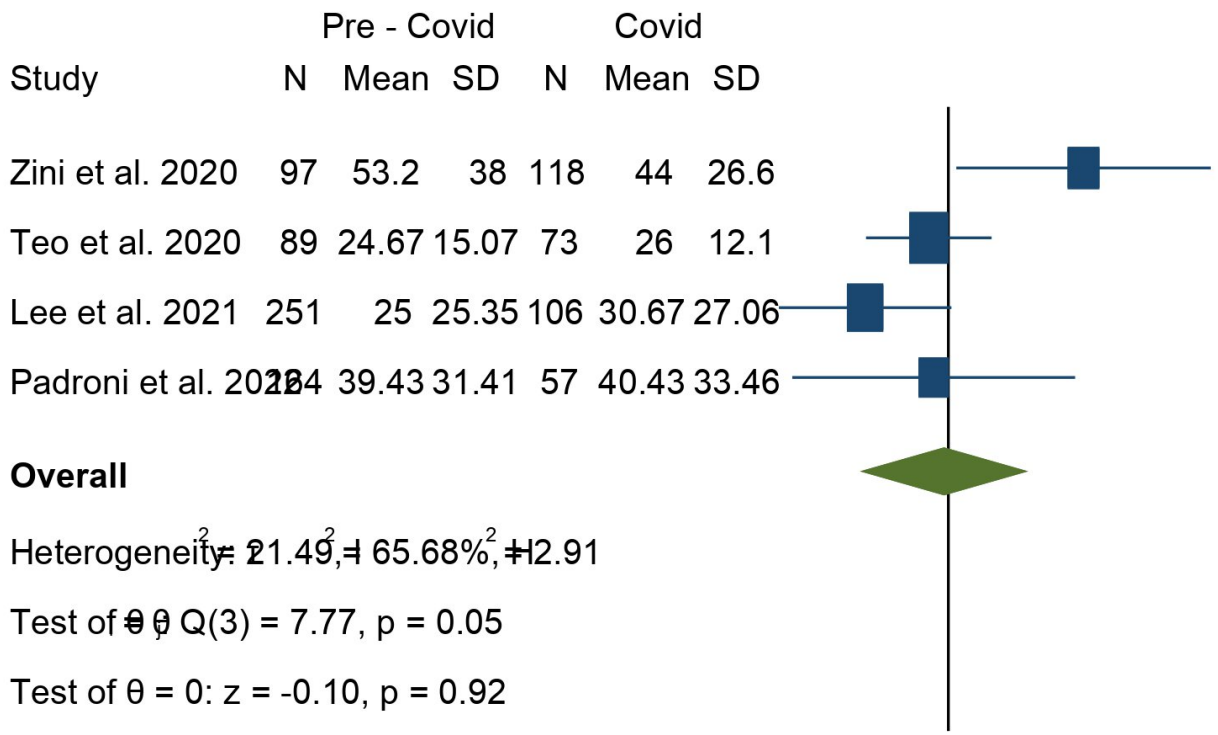
Appendix 3.12 - Forest plots of sensitivity analyses for patient care time interval

(a)



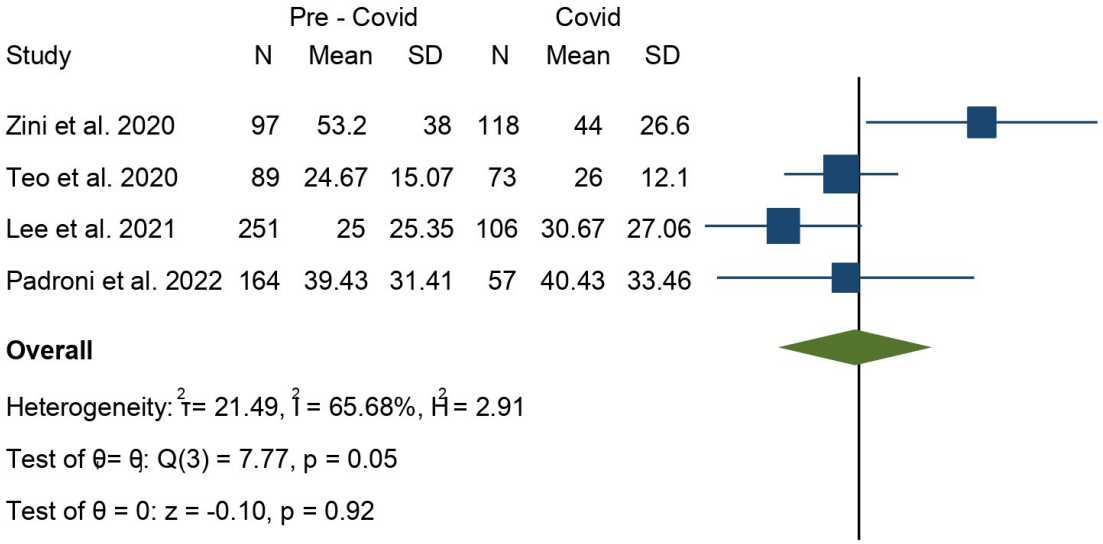
Appendix figure 3.12 (a) - Sensitivity analysis of patient care time interval by definition of call volume

(b)



Appendix figure 3.12 (b) - Sensitivity analyses of patient care time interval by location of stroke diagnosis

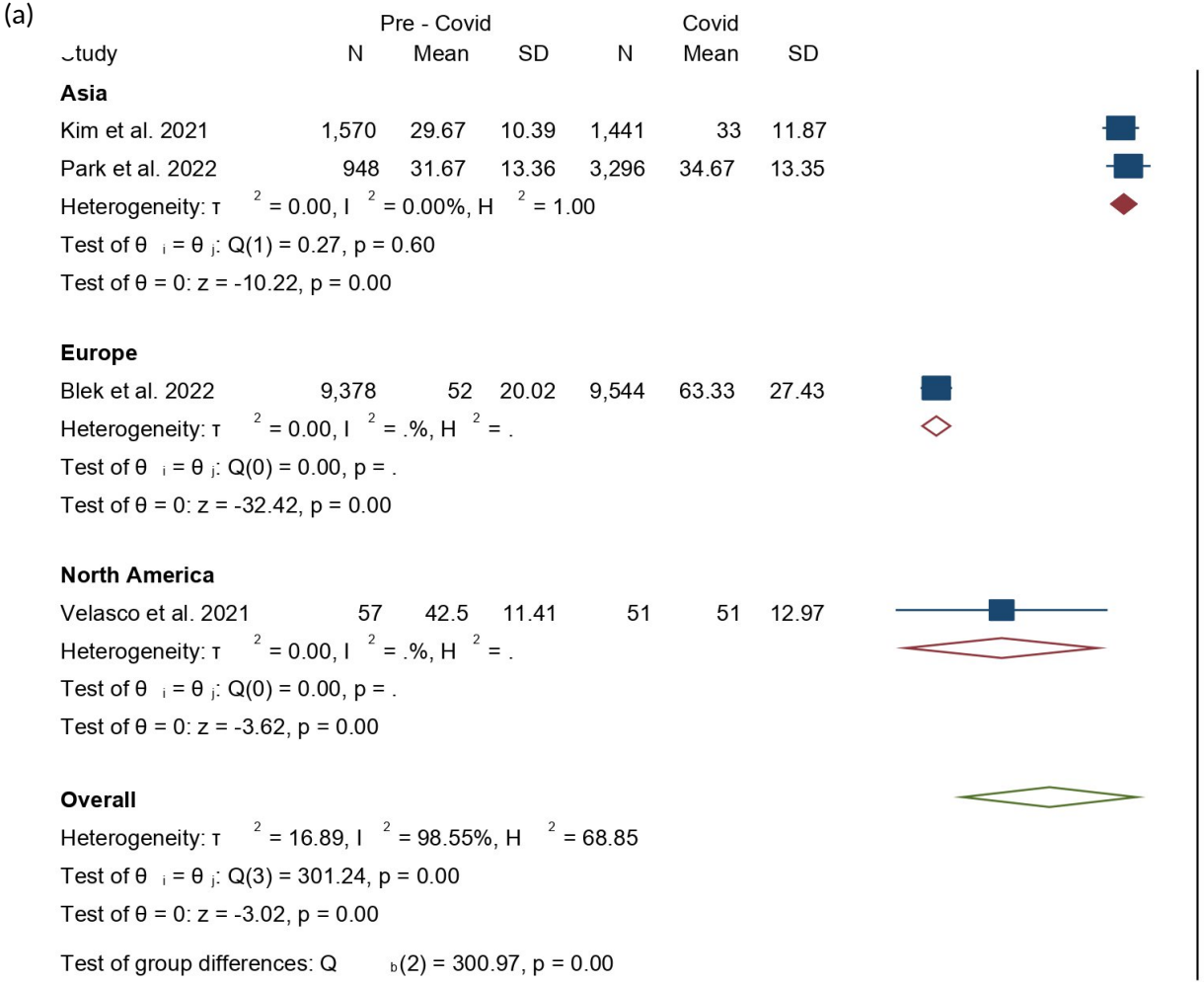
(c)



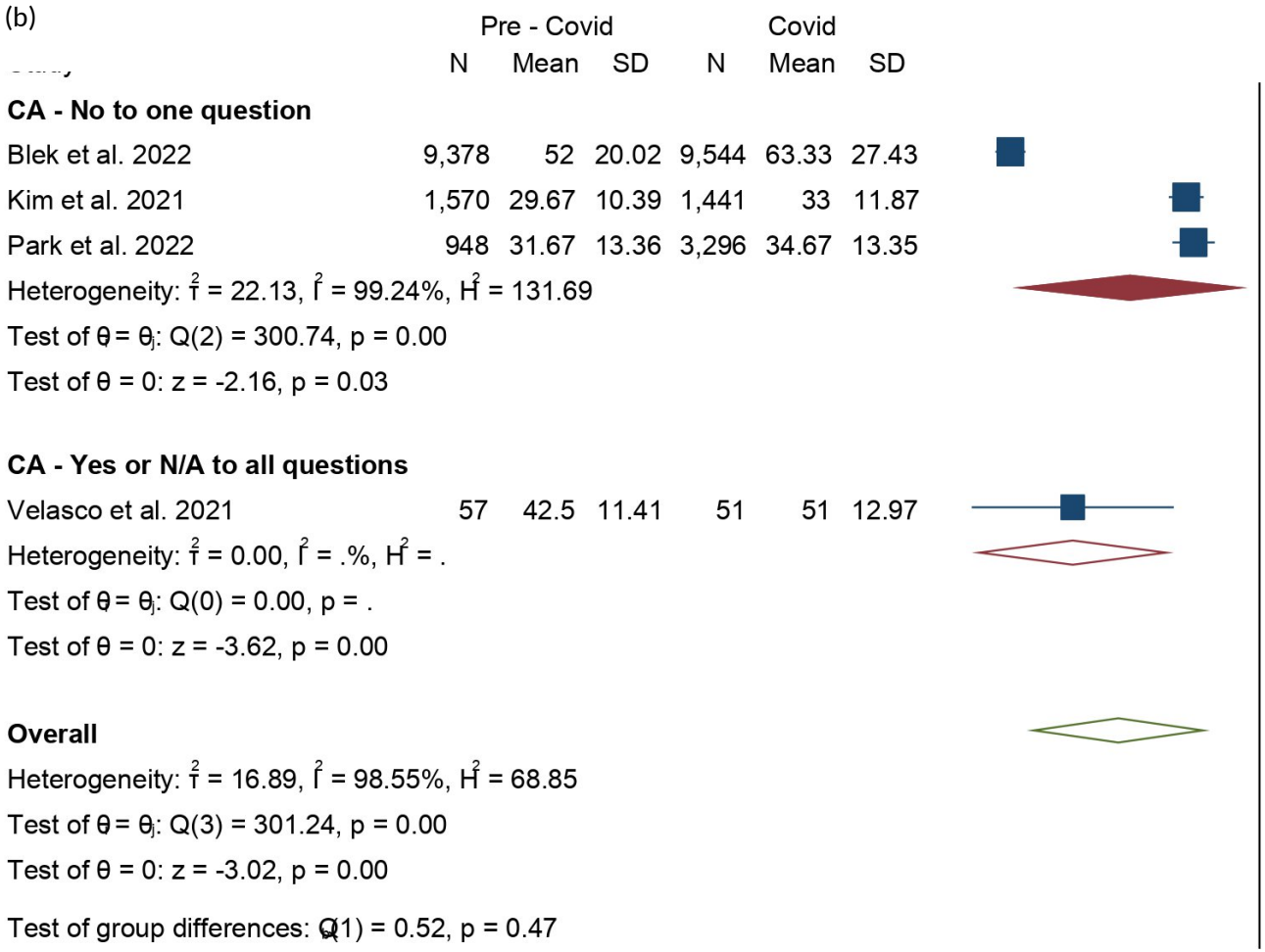
Appendix figure 3.12 (c) - Sensitivity analyses of patient care time interval by the number of weeks since WHO declared a pandemic on 11th March 2020

Appendix 3.13 - Forest plots of subgroup analyses for total prehospital time interval

(a)

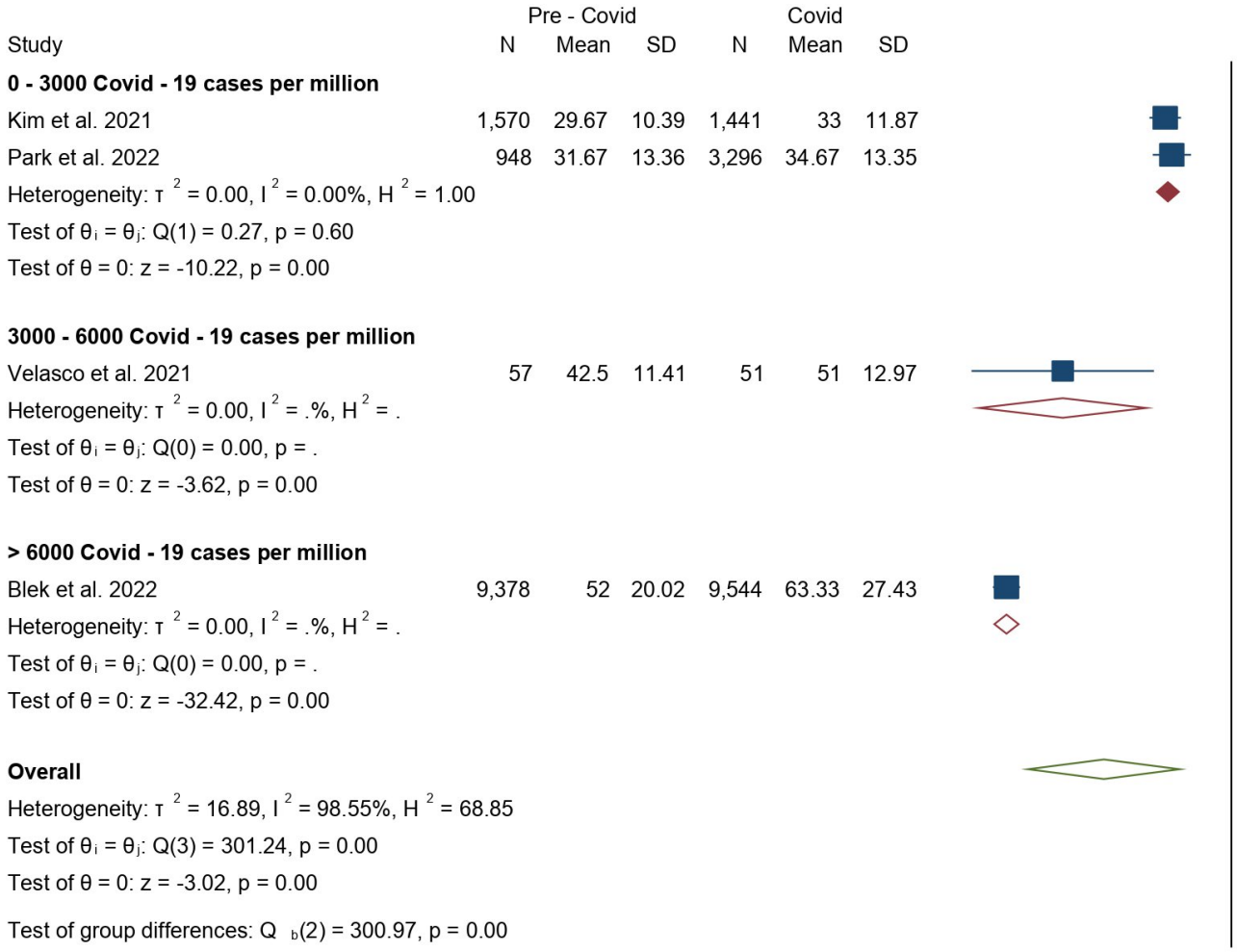


Appendix figure 3.13 (a) - Subgroup analysis of total prehospital time interval by location



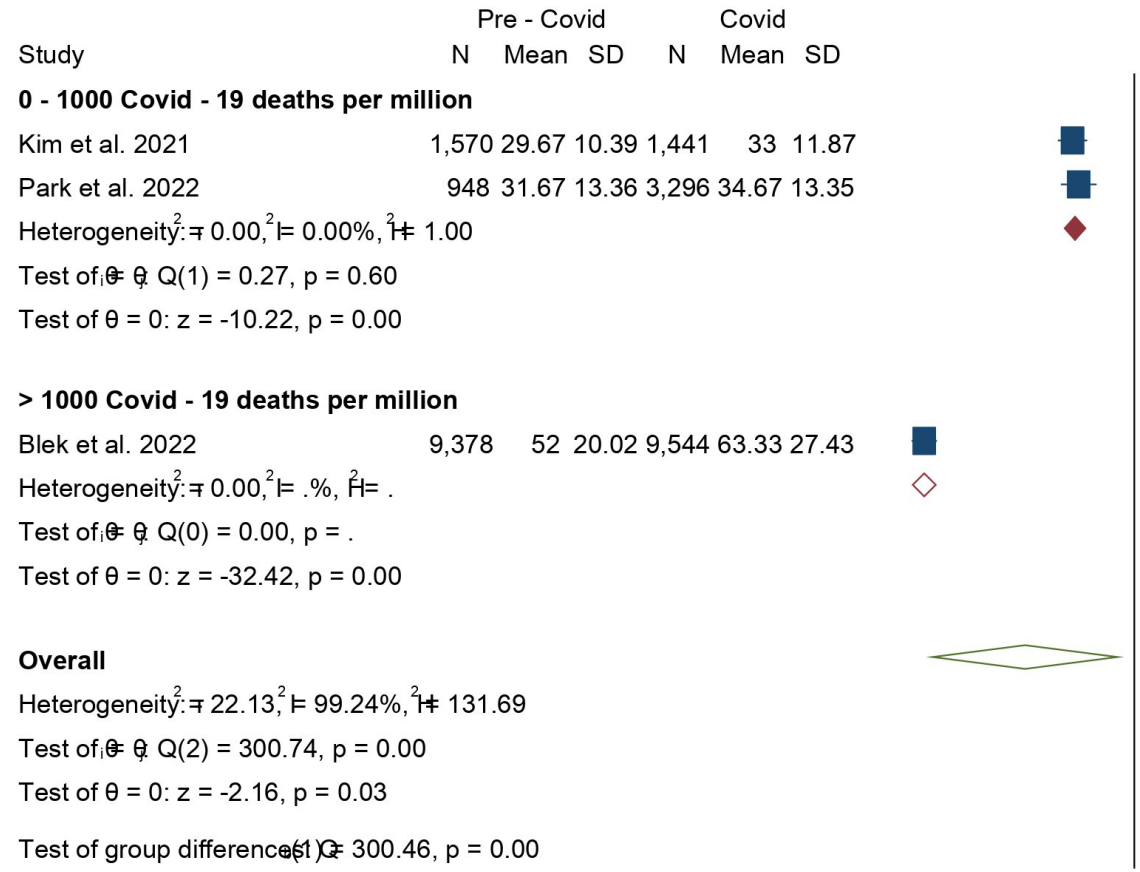
Appendix figure 3.13 (b) - Subgroup analysis of total prehospital time interval by study quality

(c)



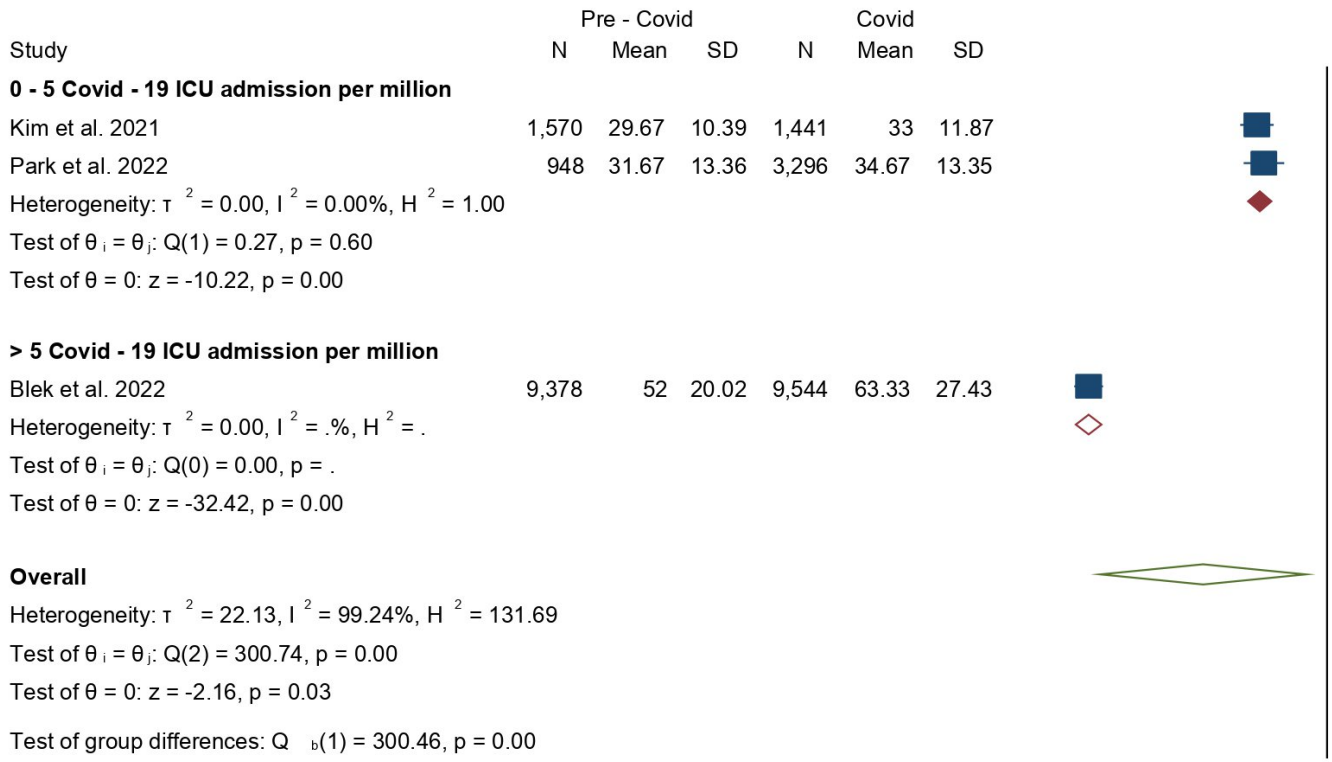
Appendix figure 3.13 (c) - Subgroup analysis of total prehospital time interval by COVID-19 cases per million

(d)



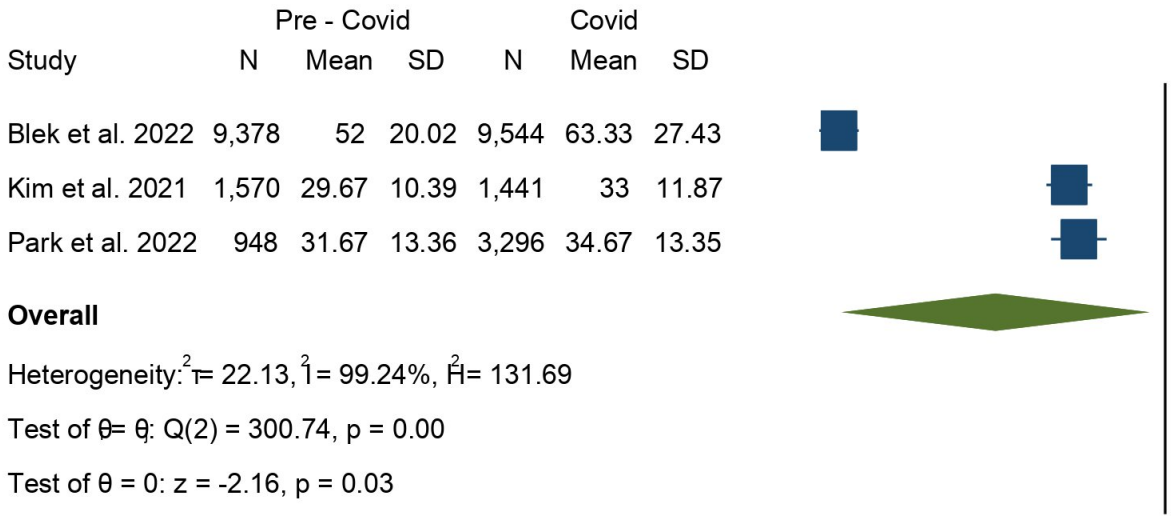
Appendix figure 3.13 (d) - Subgroup analysis of total prehospital time interval by COVID-19 deaths per million

(e)



Appendix figure 3.13 (e) - Subgroup analysis of prehospital time interval by intensive care unit COVID-19 admissions per million

Appendix 3.14 - Forest plots of sensitivity analysis for total prehospital time interval



Appendix figure 3.14 (a) - Sensitivity analysis of total prehospital time by definition of call volume

Appendix 3.15 - Patient care time intervals figure pre-COVID-19 and during COVID-19 when definition is divided into “scene time” and “transport time”

Pre-COVID-19					COVID-19				
Study	**Median**	**LQ**	**UQ**	**Sample size**	**Study**	**Median**	**LQ**	**UQ**	**Sample size**
Scene time interval									
Velasco et al. 2021[119]	17	11.5	21.25	57	Velasco et al. 2021	14	13	17.5	51
Kim et al. 2021[95]	7	5	10	1570	Kim et al. 2021	9	6	13	1441
Seo et al. 2022[98]	5.5	4	8	234	Ram Seo et al. 2022	7	5	10	231
Park et al. 2022[97]	8	6	11	948	Park et al. 2022	9	6	13	3296
Transport time interval									
Kim et al. 2021[95]	13	8	19	1570	Kim et al. 2021	12	8	19	1441
Seo et al. 2022[98]	8	5	11	234	Ram Seo et al. 2022	8	5	12	231
Park et al. 2022[97]	12	7	19	948	Park et al. 2022	13	8	20	3296

Key = LQ: Lower quartile, UQ: Upper quartile

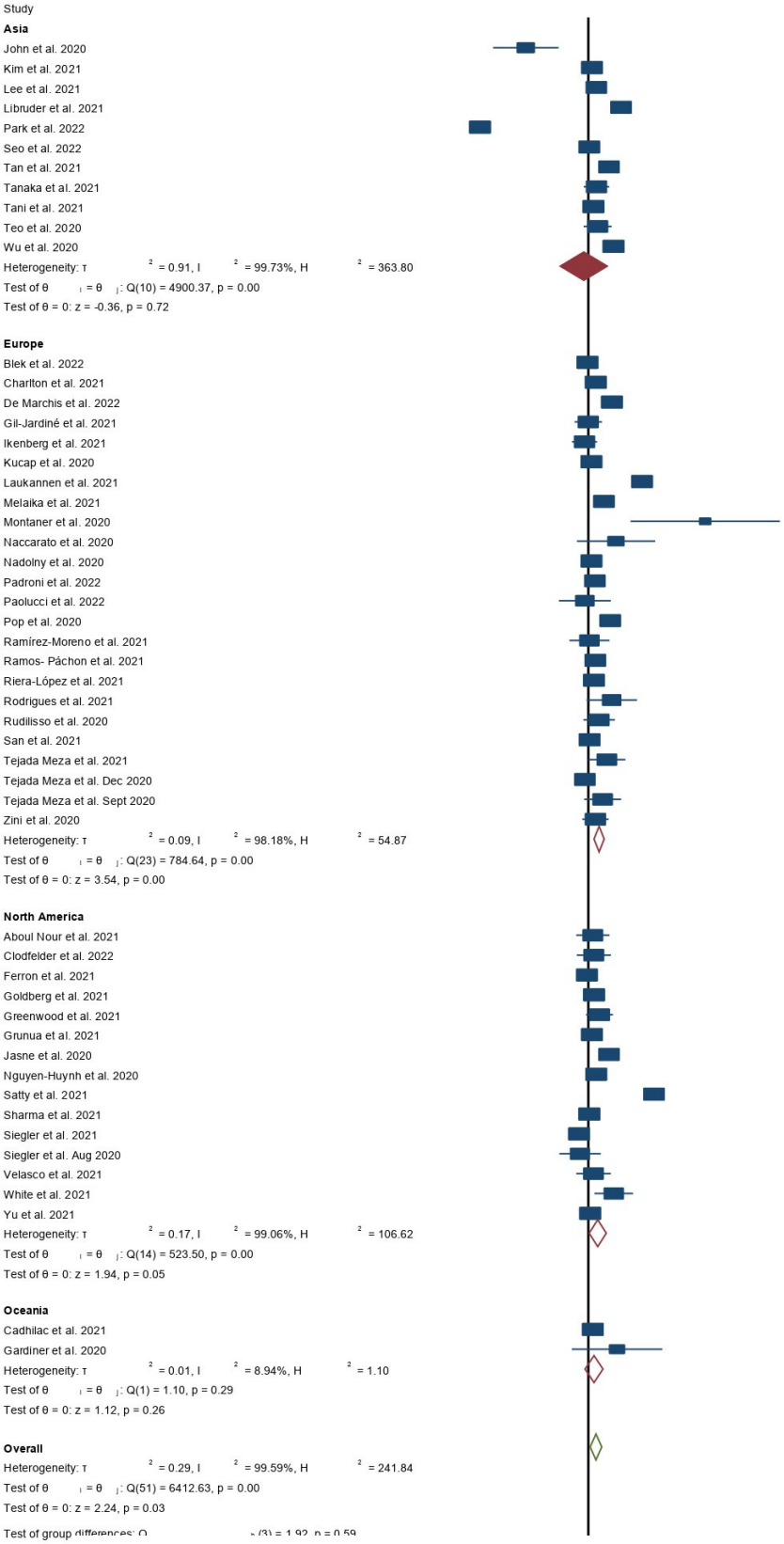
Appendix 3.15 – Definitions of call volume used in articles included in this systematic review and meta-analysis

Study	Definition of emergency call volume
Cadilhac et al.[73]	Arrival mode EMS
Gardiner et al.[74]	Aeromedical retrievals
Ferron et al.[75]	Call volume
Grunua et al.[76]	(Emergency Health Services) EHS encounters
Yu et al.[54]	Arrival mode EMS
Tan et al.[77]	Arrival mode EMS
Wu et al.[78]	Method reaching hospital ambulance
Charlton et al.[79]	Incidence of emergency calls
Laukkanen et al.[80]	Ambulance missions/calls
Gil-Jardiné et al.[81]	EMS calls
Pop et al.[82]	Stroke alerts by EMS
Ikenberg et al[83]	EMS stroke code
Teo et al.[56]	EMS mode of arrival
Libruder et al.[84]	Arrival by ambulance
Naccarato et al.[85]	Prehospital code stroke
Padroni et al.[86]	Arrival mode EMS
Paolucci et al.[87]	Referral mode – ambulance call
Zini et al.[88]	Stroke code activation - ambulance
Tanaka et al.[89]	Route of arrival – direct ambulance transport
Tani et al.[90]	Brought to hospital by ambulance
Melaika et al.[91]	Stroke alerts by EMS
Blek et al.[55]	EMS patient encounters
Kucap et al.[92]	EMS interventions
Nadolny et al.[93]	Ambulance call
Rodrigues et al.[94]	Prehospital code stroke activations
Kim et al.[95]	Patient encounters by EMS

Lee et al.[96]	Arrival mode EMS
Park et al.[97]	EMS responses
Seo et al.[98]	EMS activation
Montaner et al.[99]	Stroke code activations by 911
Ramírez- Moreno et al.[100]	Stroke code activations by EMS
Ramos-Pachón et al.[101]	EMS code stroke activations
Riera-López et al.[53]	EMS stroke code activations
Rudilisso et al.[102]	EMS stroke codes
Tejada Meza et al.[103]	Code stroke activated prehospital
Tejada Meza et al.[104]	Brought in by ambulance
Tejada Meza et al.[105]	Pre-hospital stroke code activation
De Marchis et al.[106]	Referral mode emergency service
San et al.[107]	EMS call
John et al.[108]	Mode of arrival EMS
Aboul Nour et al.[109]	EMS from home/scene
Clodfelder et al.[110]	EMS stroke alert
Goldberg et al[111]	EMS runs/calls
Greenwood et al.[112]	Arrival mode EMS
Jasne et al.[113]	Arrival mode EMS
Nguyen-Huynh et al.[114]	Arrival mode EMS
Satty et al.[115]	EMS encounters
Sharma et al.[116]	EMS call
Siegler et al[117]	Arrival mode EMS
Siegler et al.[118]	Arrival mode EMS
Velasco et al.[119]	Hospital EMS transports
White et al.[120]	Mode of arrival EMS

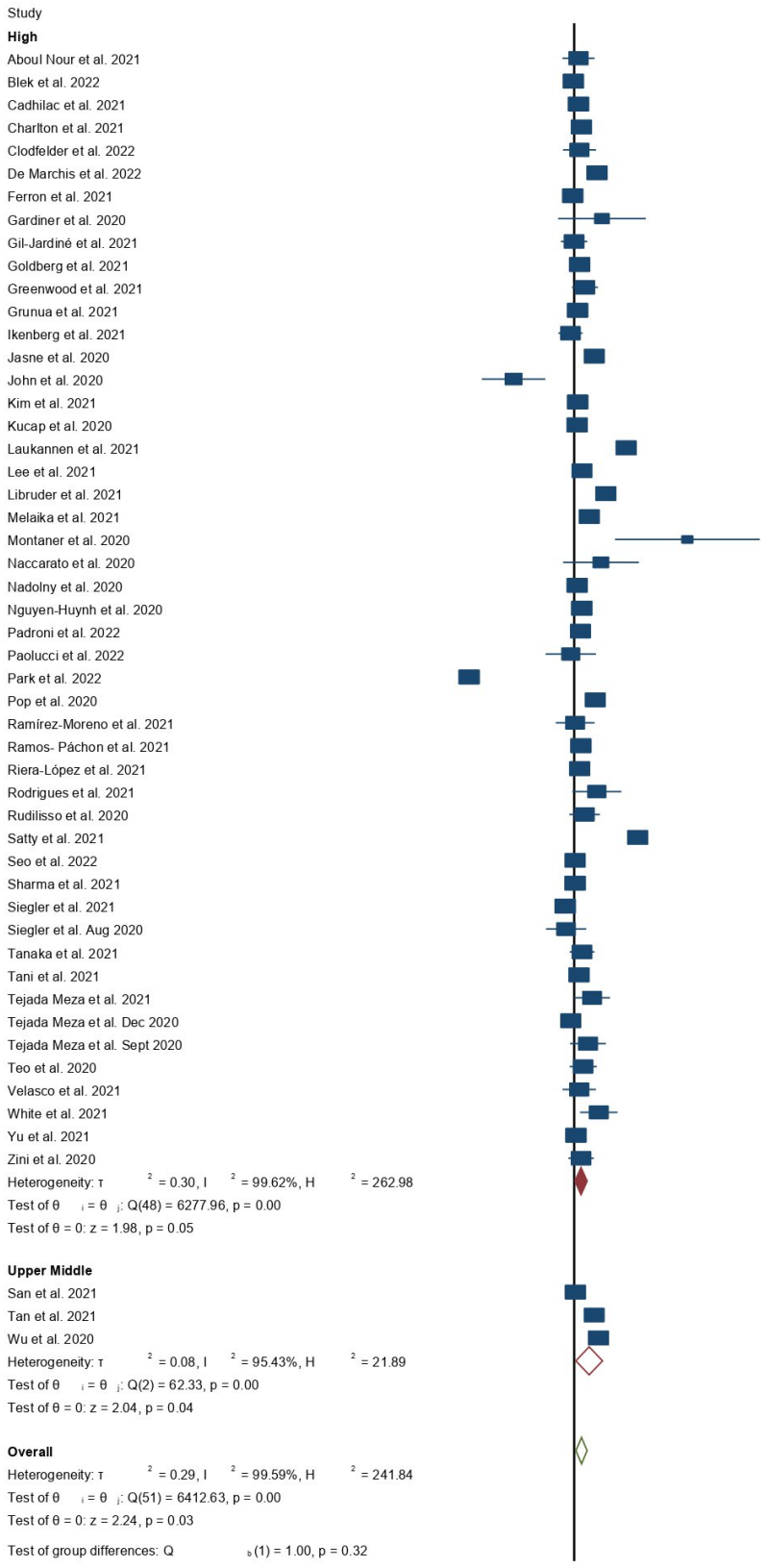
Appendix 3.17 - Forest plots of subgroup analyses of call volume

(a)



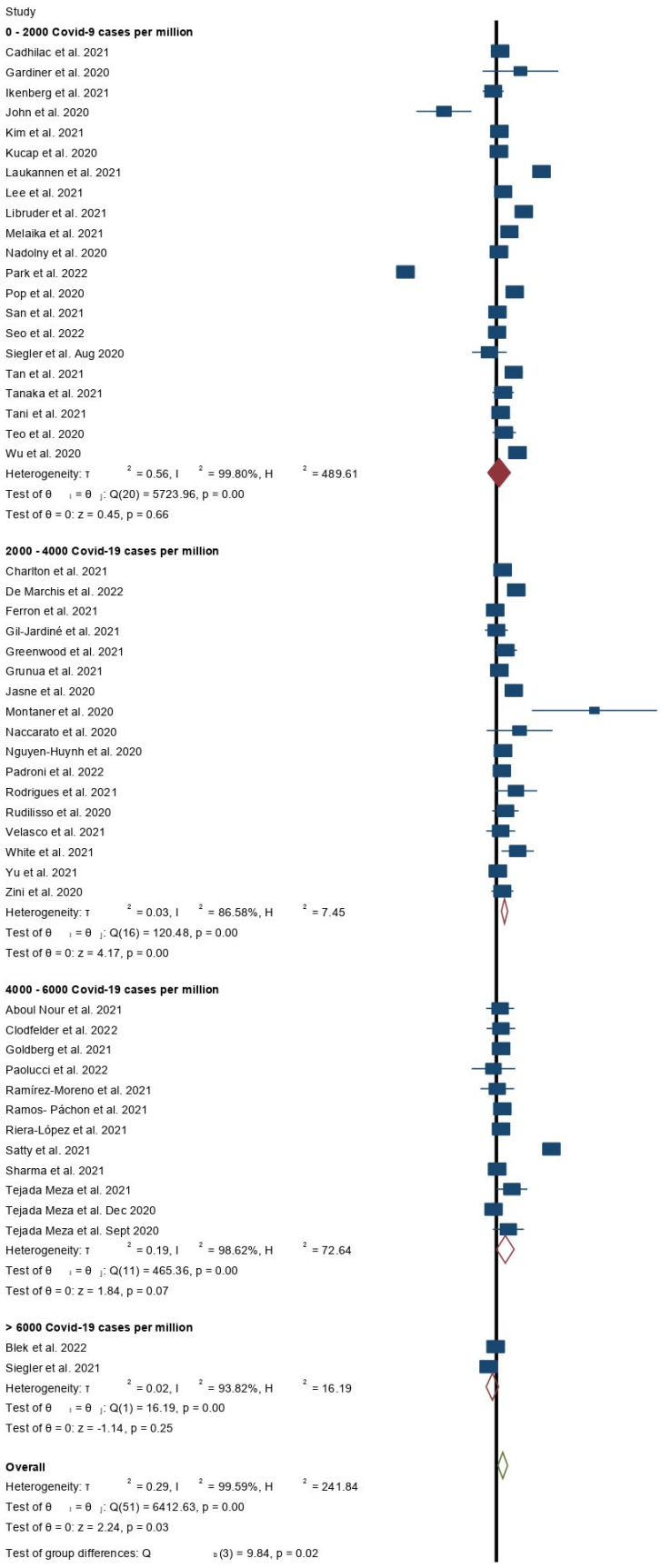
Appendix figure 3.17 (a) - Subgroup analysis of call volume by location

(b)



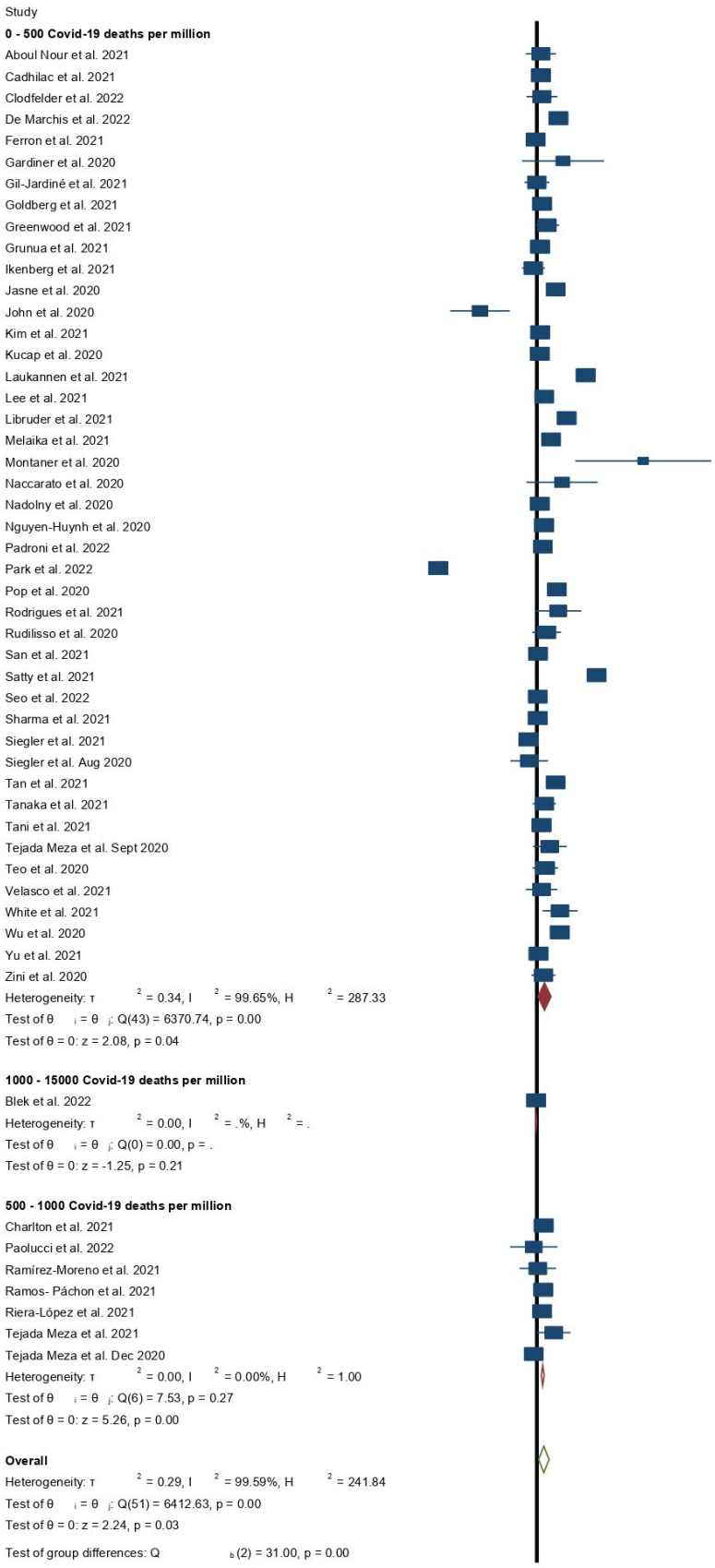
Appendix figure 3.17 (b) - Subgroup analyses of call volume by income level

(c)



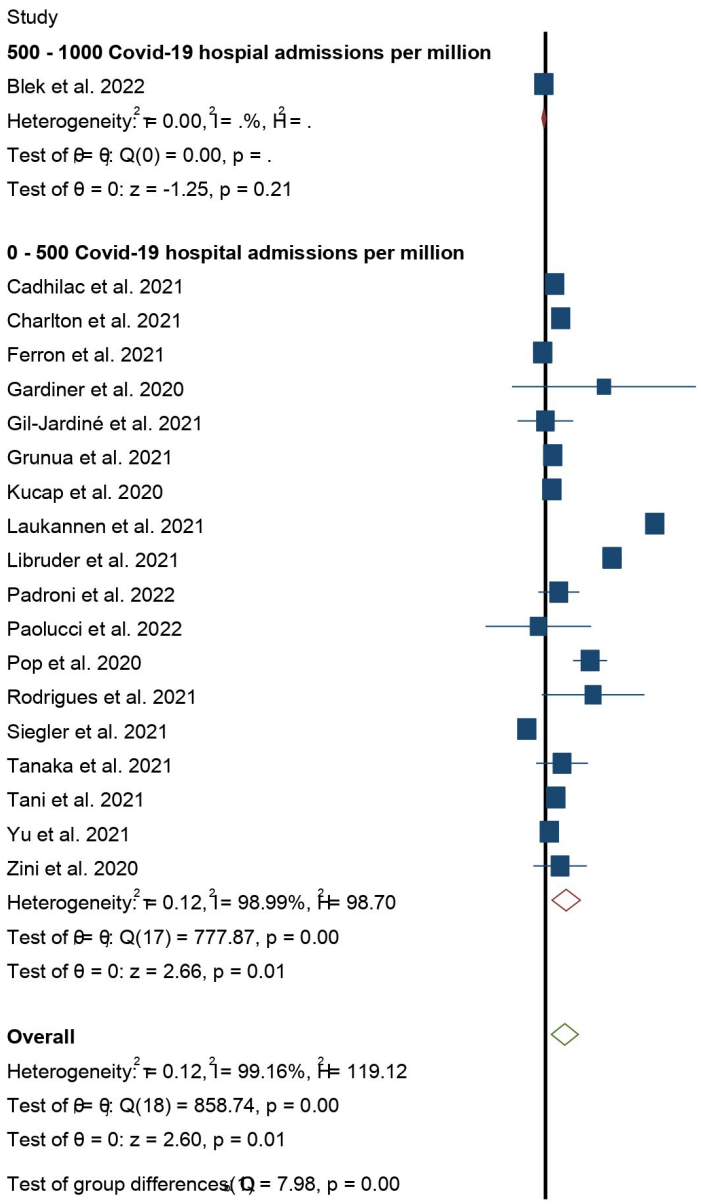
Appendix figure 3.17 (c) - Subgroup analysis of call volume by COVID-19 cases per million

(d)



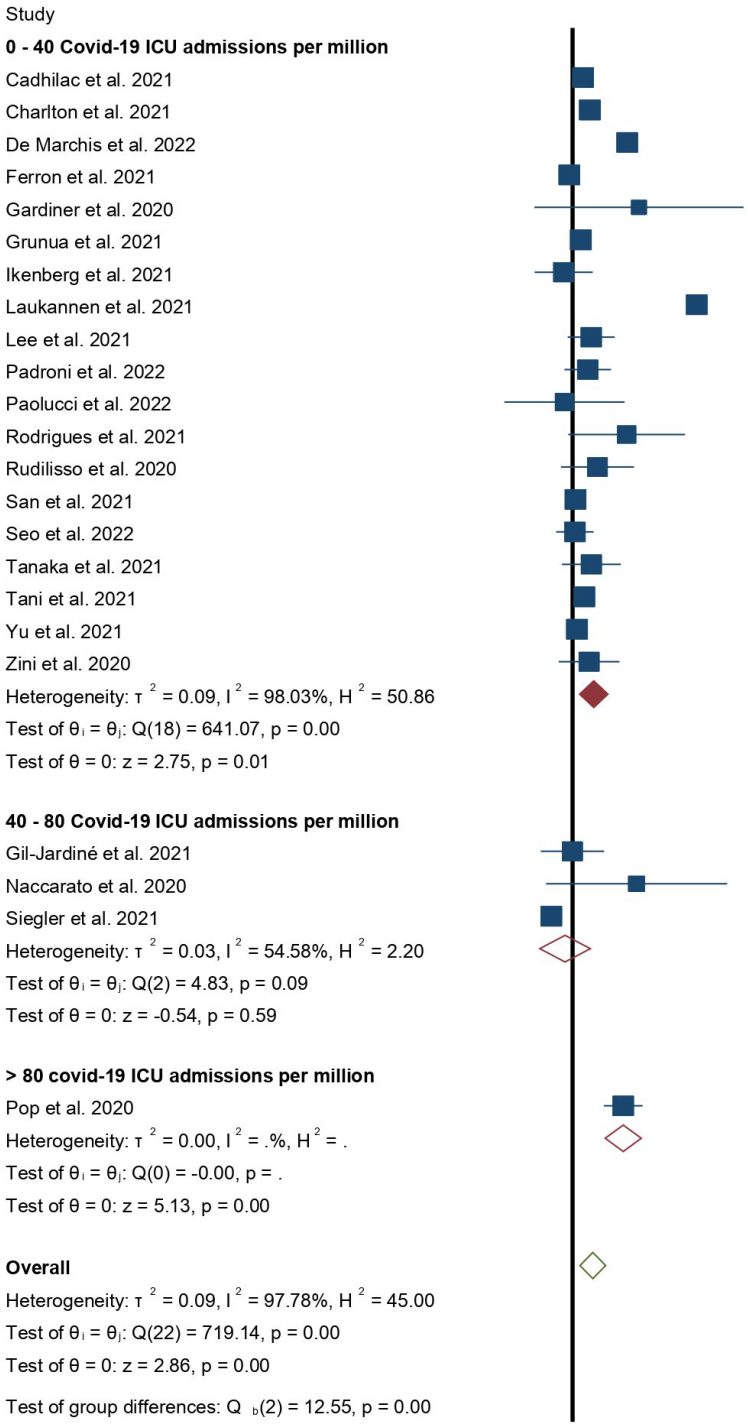
Appendix figure 3.17 (d) - Subgroup analysis of call volume by COVID-19 deaths per m

(e)



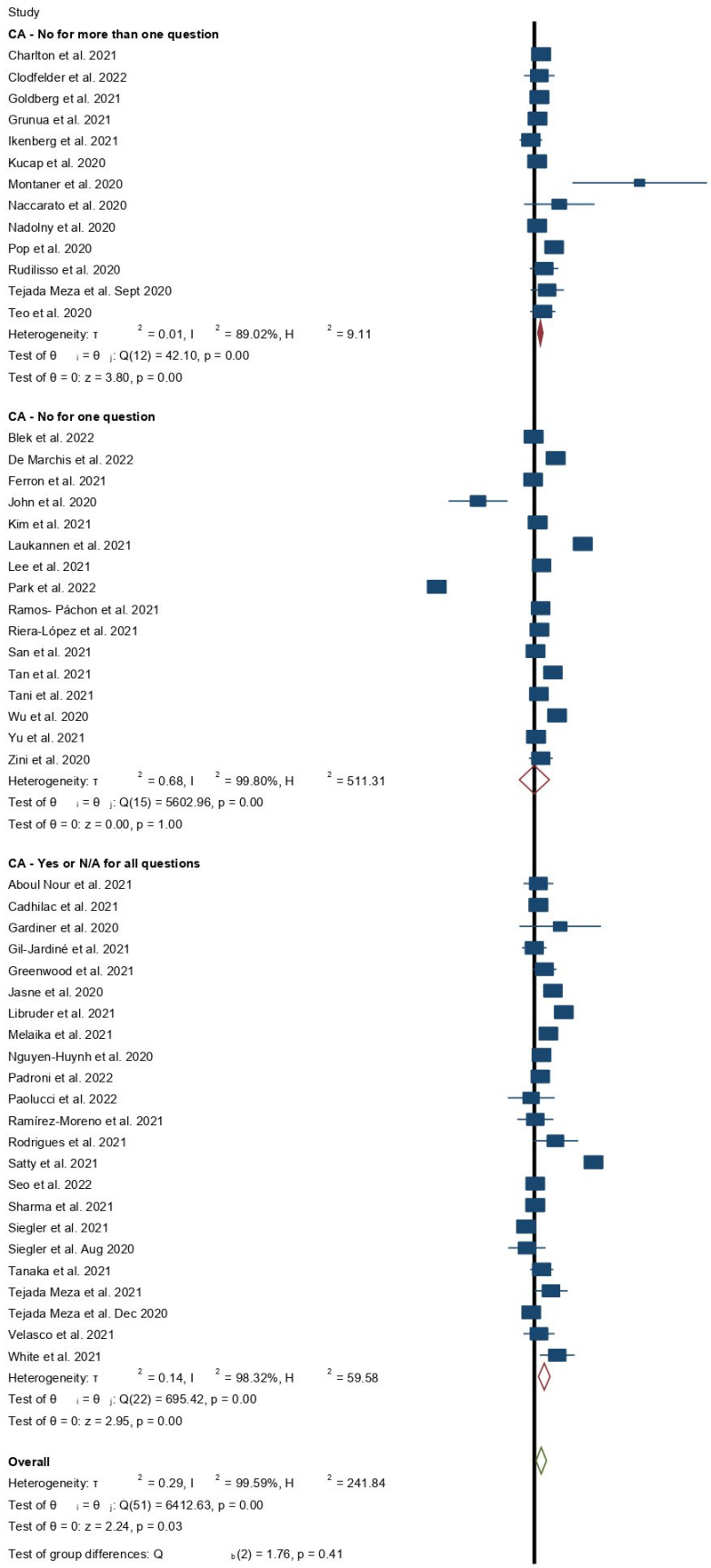
Appendix figure 3.17 (e) - Subgroup analysis of call volume by COVID-19 hospitalisations

(f)



Appendix figure 3.17 (f) - Subgroup analysis of call volume by COVID-19 ICU admissions per million

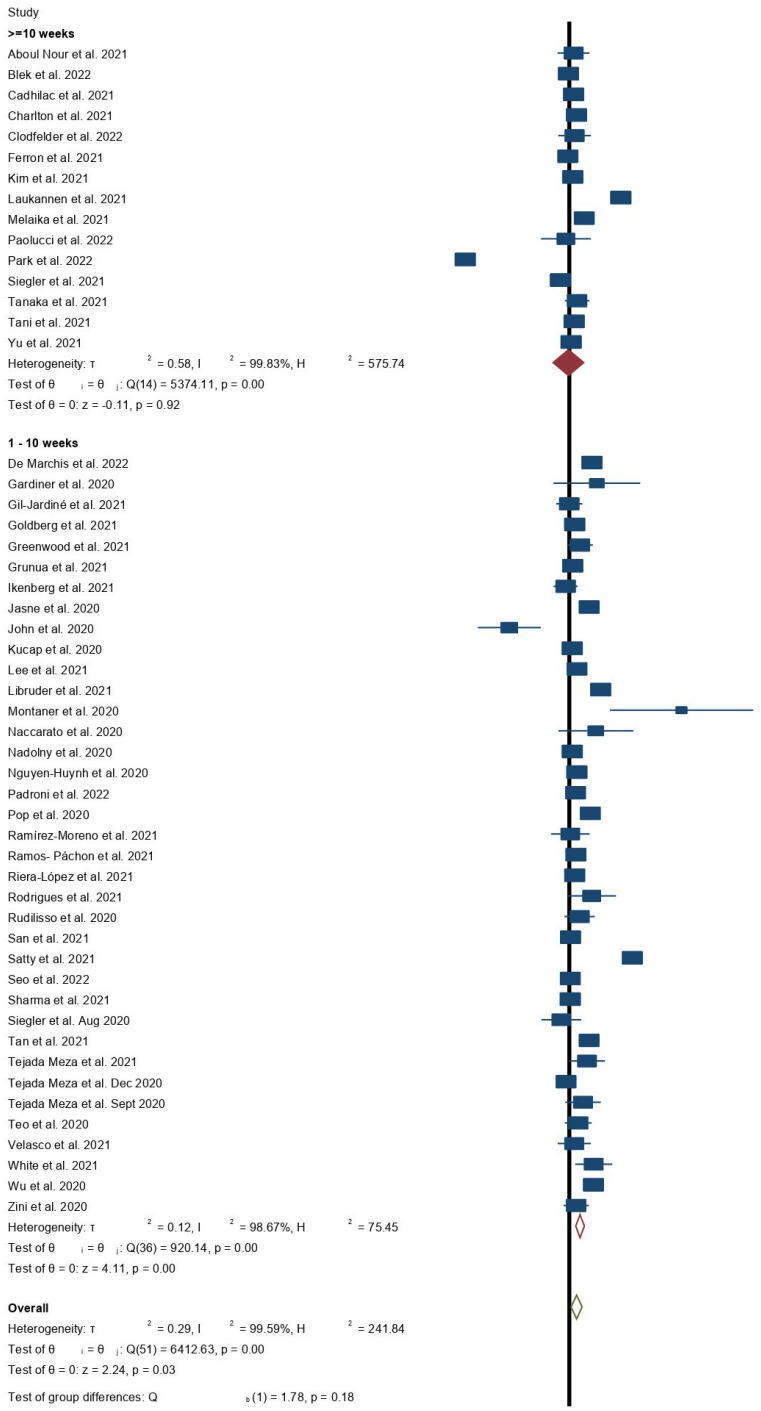
(g)



Appendix figure 3.17 (g) - Subgroup analysis of call volume by study quality

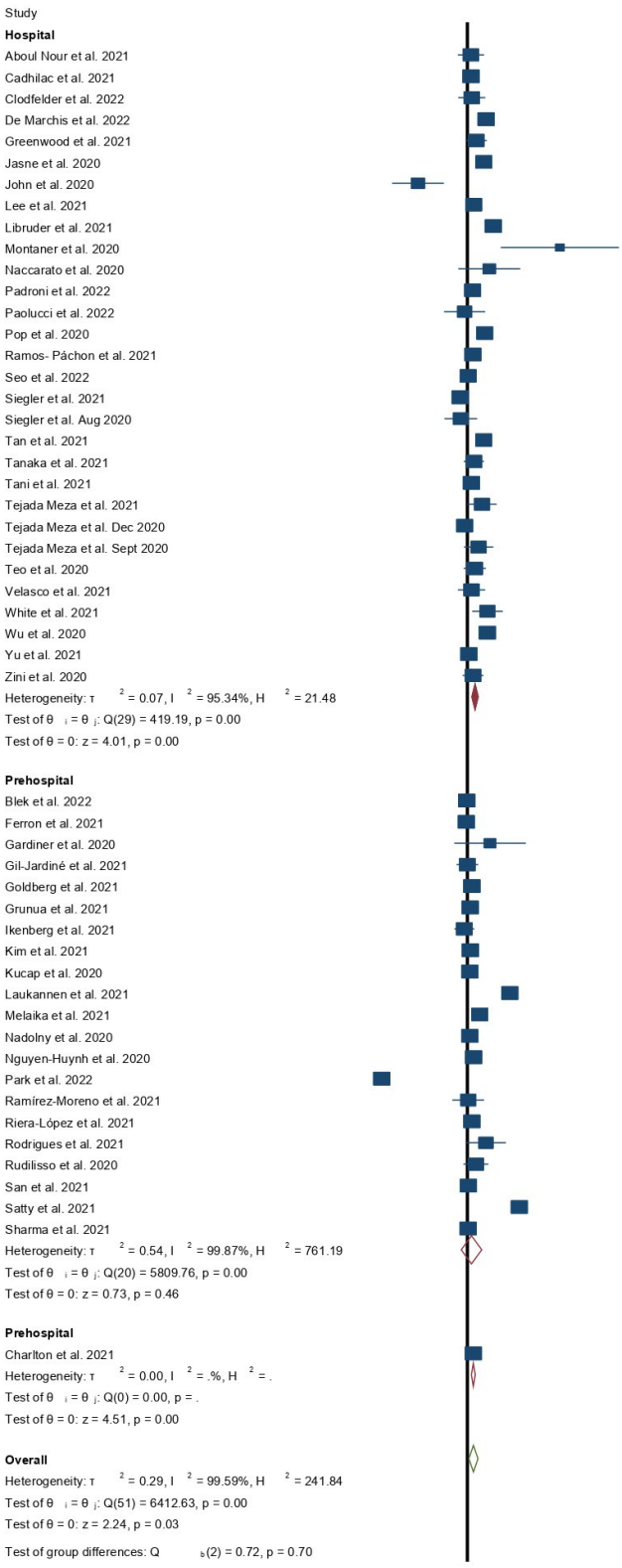
Appendix 3.18 - Forest plots of sensitivity analyses for call volume

(a)



Appendix figure 3.18 (a) - Sensitivity analysis of call volume for post number of weeks post W declaration of a pandemic on 11th March 2020

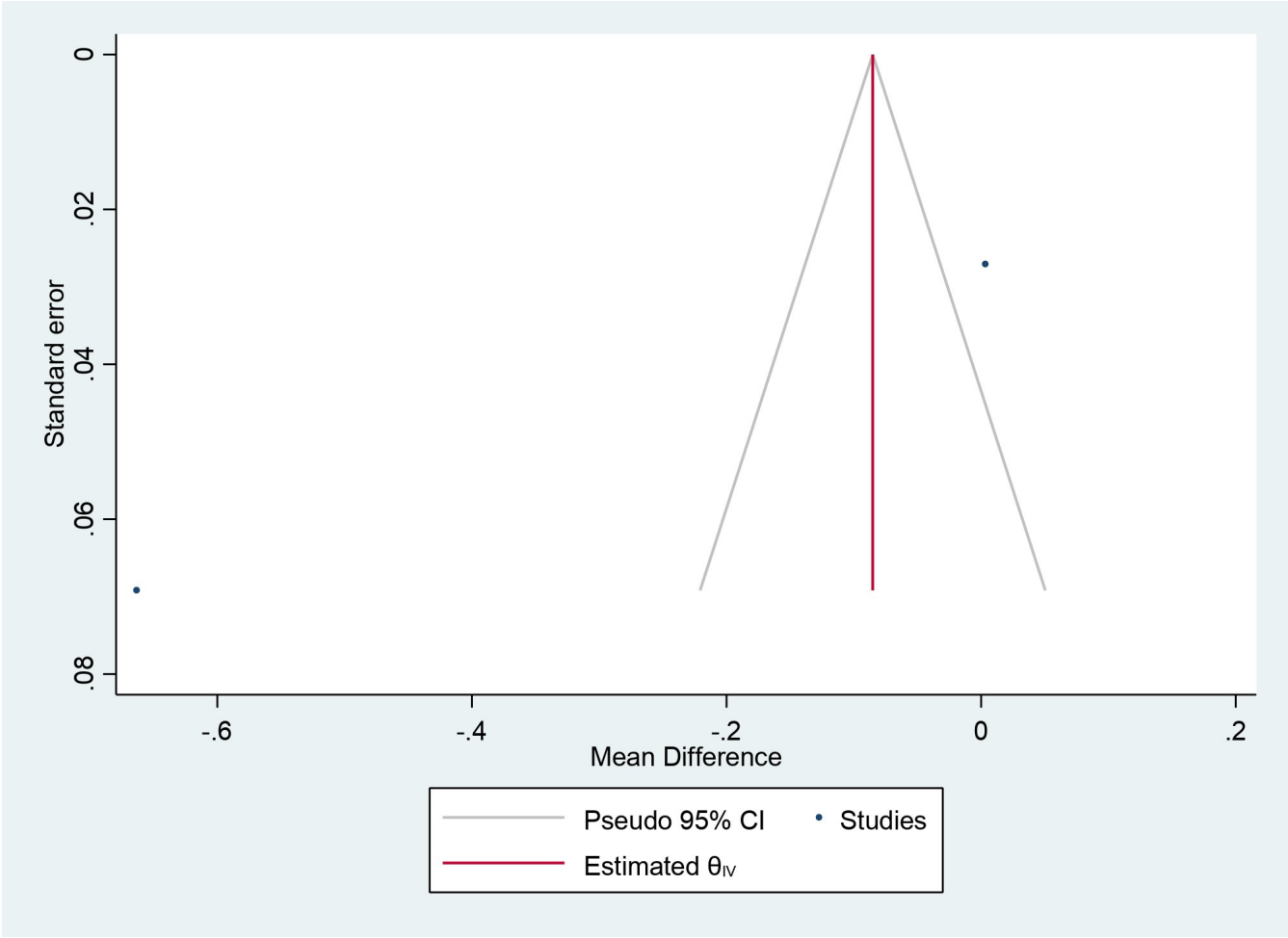
(b)



Appendix figure 3.18 (b) - Sensitivity analysis of call volume for location of stroke/TIA diagnosis

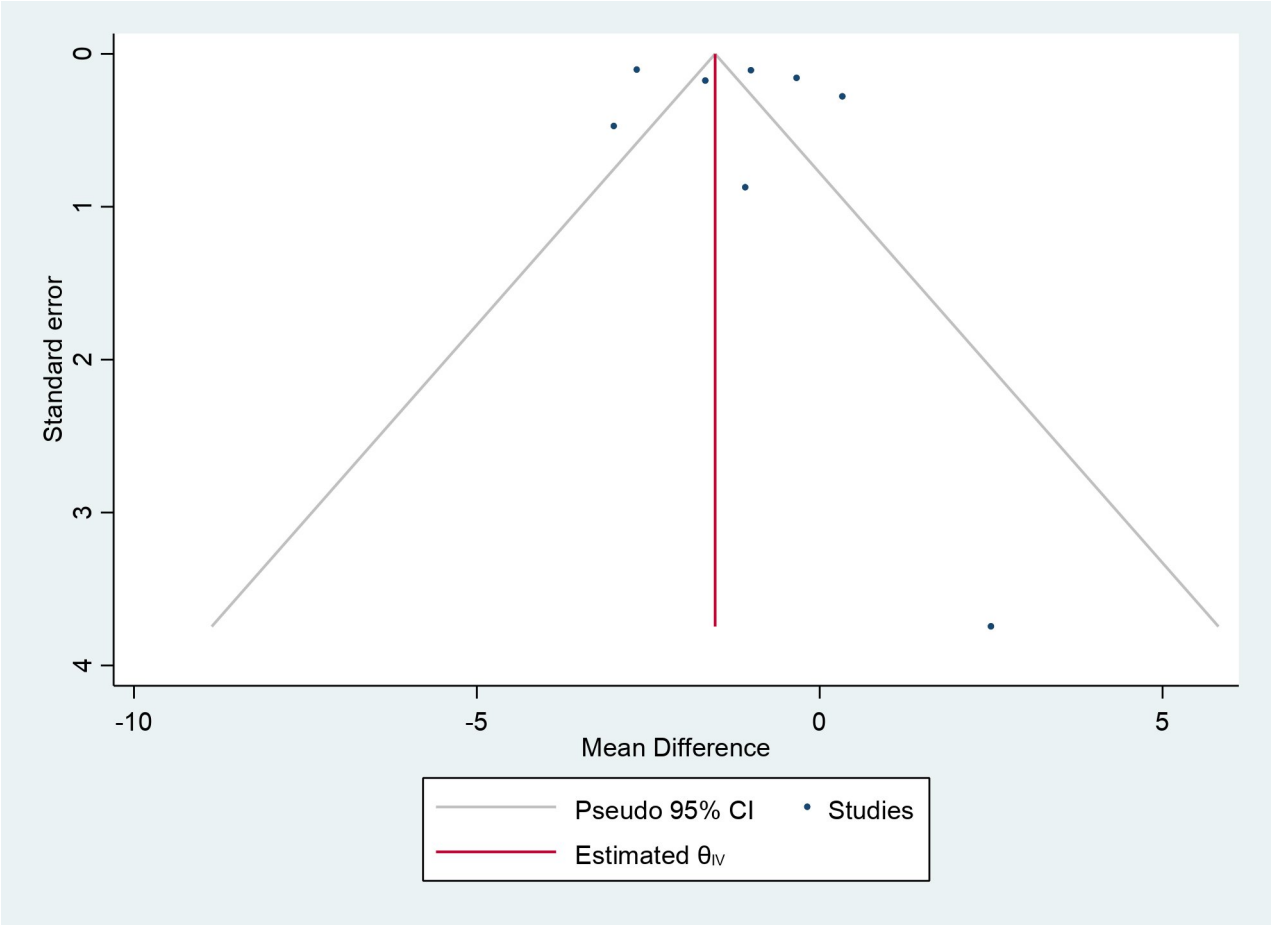
(a)

Appendix 3.19 - Funnel plots for activation, response, patient care and total prehospital time



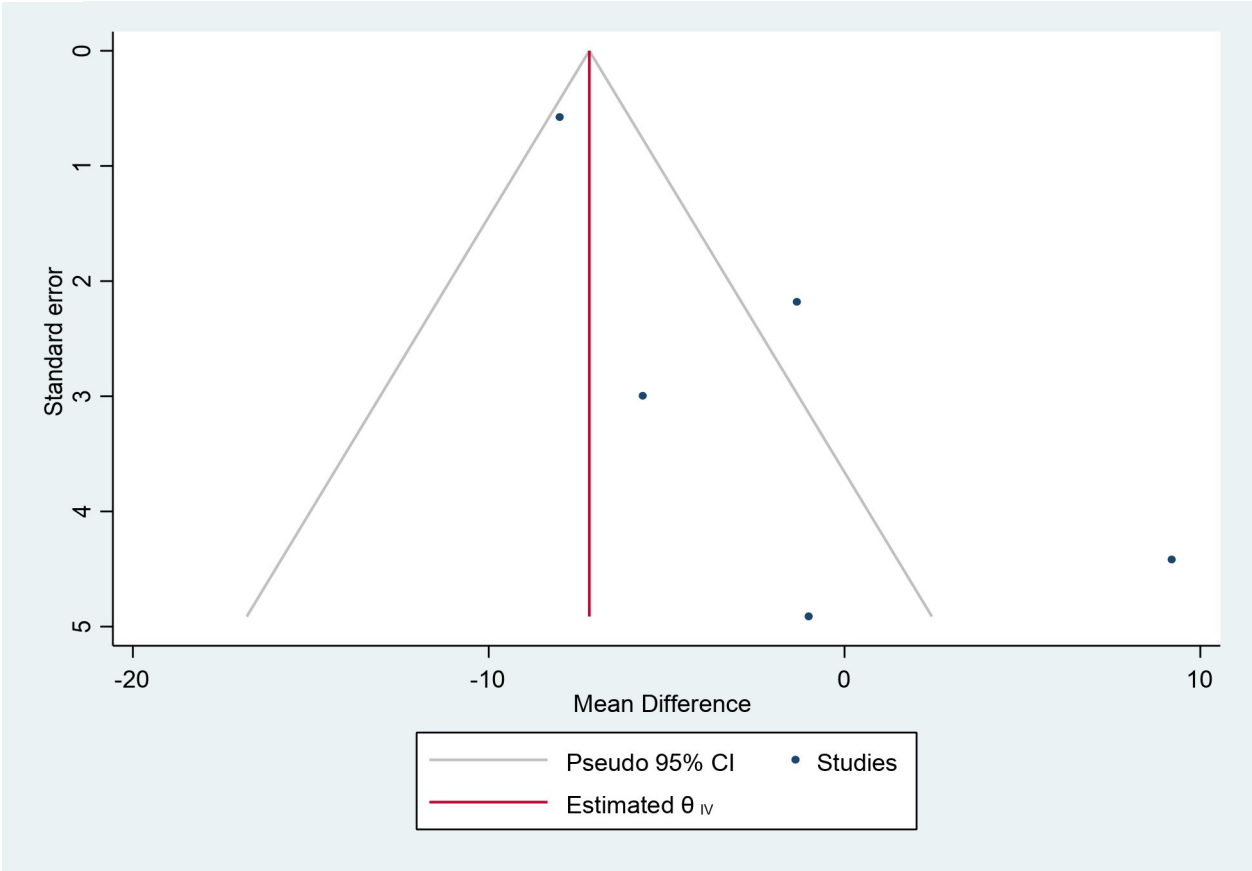
Appendix figure 3.19 (a) Funnel plot of study included in meta-analysis of activation time interval

(b)



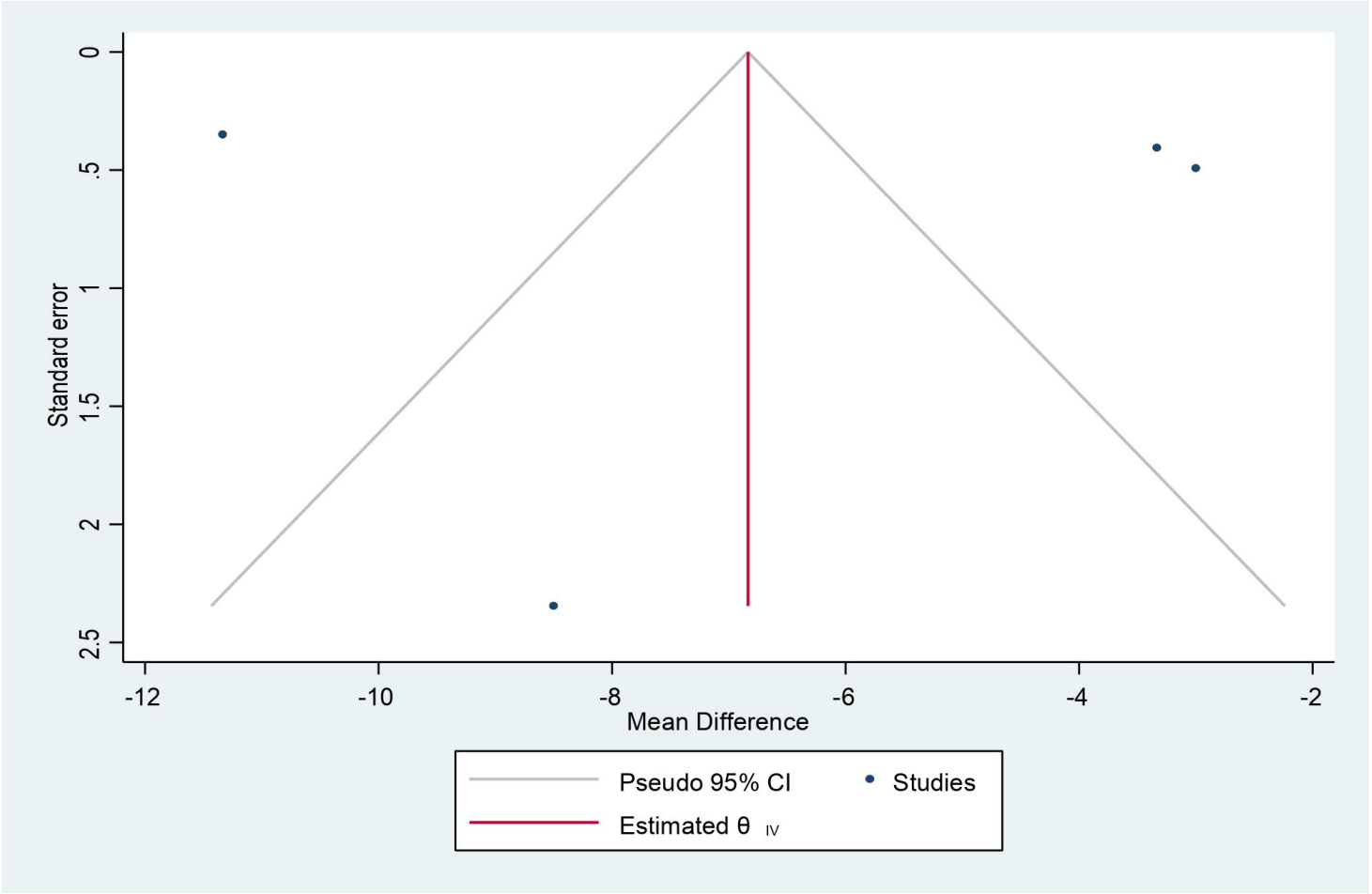
Appendix figure 3.19 (b) - Funnel plot of studies included in the meta-analysis of response time interval

(c)



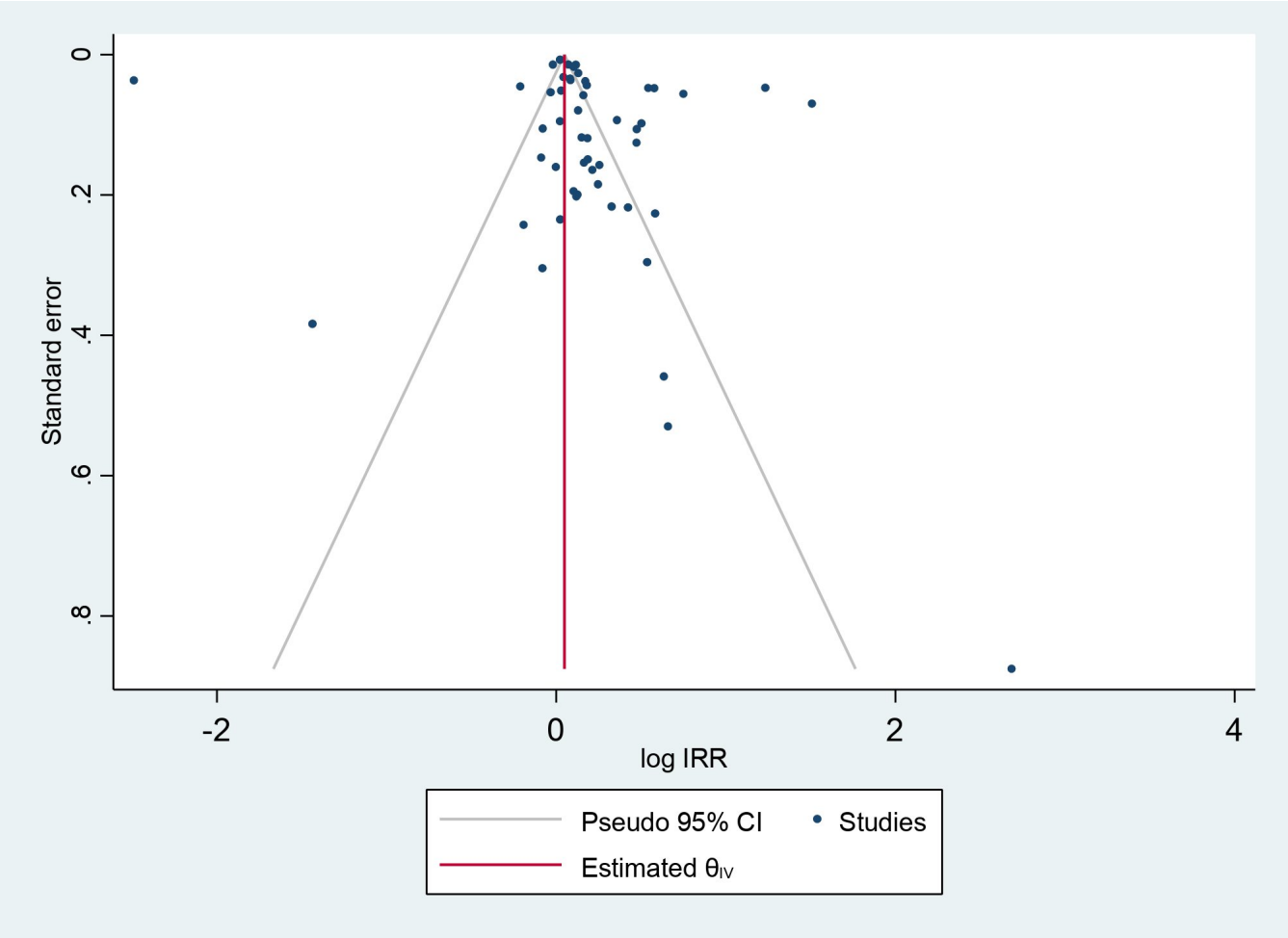
Appendix figure 3.19 (c) Funnel plot of studies included in the meta-analysis of patient care time interval

(d)



Appendix figure 3.19 (d) - Funnel plot of studies included in the meta-analysis of total prehospital time interval

Appendix 3.20 - Funnel plot of the meta-analysis of call volume



Appendix figure 3.20 - Funnel plot of studies included in the meta-analysis of call volume for suspected stroke/TIA

Appendix 3.21 - Results of critical appraisal using JBI checklists

Cohort studies

Study	1.Were the two groups similar and recruited from the same population?	2.Were the exposures measured similarly to assign people to both exposed and unexposed groups?	3.Was the exposure measured in a valid and reliable way?	4.Were confounding factors identified?	5.Were strategies to deal with confounding factors stated?	6.Were the groups/participants free of the outcome at the start of the study (or at the moment of exposure)?	7.Were the outcomes measured in a valid and reliable way	8.Was the follow up time reported and sufficient to be long enough for outcomes to occur?	9.Was follow up complete, and if not, were the reasons to loss to follow up described and explored?	10.Were strategies to address incomplete follow up utilized?	11.Was appropriate statistical analysis used?
Jasne et al. 2020[113]	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	N/A	N/A	Yes
Nguyen-Huynh 2020[114]	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	N/A	N/A	Yes
Riera-López 2021[53]	Yes	Yes	Yes	Yes	No	N/A	Yes	Yes	N/A	N/A	Yes
Siegler et al 2020[117]	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	N/A	N/A	Yes
Yu et al. 2021[54]	Yes	Yes	Yes	Yes	No	N/A	Yes	Yes	N/A	N/A	Yes
Blek et al. 2022[55]	Yes	Yes	Yes	Yes	No	N/A	Yes	Yes	N/A	N/A	Yes
Study	1.Were the two	2.Were the	3.Was the	4.Were	5.Were	6.Were the	7.Were	8.Was	9.Was	10.Were	11.Was

	groups similar and recruited from the same population?	exposures measured similarly to assign people to both exposed and unexposed groups?	exposure measured in a valid and reliable way?	confounding factors identified?	strategies to deal with confounding factors stated?	groups/participants free of the outcome at the start of the study (or at the moment of exposure)?	the outcomes measured in a valid and reliable way	the follow up time reported and sufficient to be long enough for outcomes to occur?	follow up complete, and if not, were the reasons to loss to follow up described and explored?	strategies to address incomplete follow up utilized?	appropriate statistical analysis used?
Clodfelder et al. 2022[110]	Yes	Yes	Yes	No	No	N/A	Yes	Yes	N/A	N/A	Yes
Goldberg et al. 2021[111]	Yes	Yes	Yes	No	No	N/A	Yes	Yes	N/A	N/A	Yes
Greenwood et al. 2021[112]	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	N/A	N/A	Yes
Grunua et al. 2021[76]	Yes	Yes	Yes	No	N/A	N/A	Yes	Yes	Unclear	N/A	Yes
Ikenberg et al. 2020[83]	Yes	Yes	Yes	No	No	N/A	Yes	Yes	N/A	N/A	Yes
Kucap et al. 2020[92]	Yes	Yes	Yes	Yes	Unclear	N/A	Yes	Yes	N/A	N/A	Unclear
Lee et al. 2021[96]	Yes	Yes	Yes	Yes	No	N/A	Yes	Yes	N/A	N/A	Yes
Melaika et al. 2021[91]	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	Yes	N/A	Yes
Study	**1.Were the two groups similar and recruited from the**	**2.Were the exposures measured**	**3.Was the exposure measured in**	**4.Were confounding factors**	**5.Were strategies to deal with**	**6.Were the groups/participants free of the**	**7.Were the outcomes**	**8.Was the follow up**	**9.Was follow up complete,**	**10.Were strategies to address**	**11.Was appropriate statistical**

	same population?	similarly to assign people to both exposed and unexposed groups?	a valid and reliable way?	identified?	confounding factors stated?	outcome at the start of the study (or at the moment of exposure)?	measured in a valid and reliable way	time reported and sufficient to be long enough for outcomes to occur?	and if not, were the reasons to loss to follow up described and explored?	incomplete follow up utilized?	analysis used?
Montaner et al. 2020[99]	Yes	Yes	Yes	No	No	N/A	Yes	No	N/A	N/A	Yes
Pop et al. 2020[82]	Yes	Yes	Yes	Yes	No	N/A	Yes	No	N/A	N/A	Yes
Ramírez – Moreno 2021[100]	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	N/A	N/A	Yes
Aboul Nour et al. 2021[109]	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	N/A	N/A	Yes
Rodrigues et al. 2021[94]	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	N/A	N/A	Yes
Rudlisso et al. 2020[102]	Yes	Yes	Yes	Yes	No	N/A	Yes	Unclear	No	N/A	Yes
San et al. 2020[107]	Yes	Yes	Yes	Yes	No	N/A	Yes	Yes	N/A	N/A	Yes
Sharma et al. 2021[116]	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	N/A	N/A	Yes
Study	**1.Were the two groups similar and**	**2.Were the exposures**	**3.Was the exposure**	**4.Were confounding**	**5.Were strategies to**	**6.Were the groups/participants**	**7.Were the**	**8.Was the**	**9.Was follow up**	**10.Were strategies**	**11.Was appropriate**

	recruited from the same population?	measured similarly to assign people to both exposed and unexposed groups?	measured in a valid and reliable way?	factors identified?	deal with confounding factors stated?	free of the outcome at the start of the study (or at the moment of exposure)?	outcomes measured in a valid and reliable way	follow up time reported and sufficient to be long enough for outcomes to occur?	complete, and if not, were the reasons to loss to follow up described and explored?	to address incomplete follow up utilized?	statistical analysis used?
Siegler et al. 2021[118]	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	N/A	N/A	Yes
Wu et al. 2020[78]	Yes	Yes	Yes	Yes	No	N/A	Yes	Yes	N/A	N/A	Yes
Tan et al. 2021[77]	Yes	Yes	Yes	Yes	No	N/A	Yes	Yes	N/A	N/A	Yes
Libruder et al. 2021[84]	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	N/A	N/A	Yes
White et al. 2021[120]	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	N/A	N/A	Yes
Laukkanen et al. 2021[80]	Yes	Yes	Yes	Yes	No	N/A	Yes	Yes	N/A	N/A	Yes
Tanaka et al. 2021[89]	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	N/A	N/A	Yes
Satty et al. 2021[115]	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	N/A	N/A	Yes
John et al. 2020[108]	Yes	Yes	Yes	Yes	No	N/A	Yes	Yes	N/A	N/A	Yes
Naccarato et al.[85]	Yes	Yes	Yes	Yes	No	N/A	Yes	No	N/A	N/A	Yes
Study	**1.Were the two groups similar and recruited from the**	**2.Were the exposures measured**	**3.Was the exposure measured in**	**4.Were confounding factors**	**5.Were strategies to deal with**	**6.Were the groups/participants free of the**	**7.Were the outcomes**	**8.Was the follow up**	**9.Was follow up complete,**	**10.Were strategies to address**	**11.Was appropriate statistical**

	same population?	similarly to assign people to both exposed and unexposed groups?	a valid and reliable way?	identified?	confounding factors stated?	outcome at the start of the study (or at the moment of exposure)?	measured in a valid and reliable way	time reported and sufficient to be long enough for outcomes to occur?	and if not, were the reasons to loss to follow up described and explored?	incomplete follow up utilized?	analysis used?
De Marchis et al.[106]	Yes	Yes	Yes	Yes	Yes	N/A	Yes	No	N/A	N/A	Yes
Gardiner et al 2020[74]	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	N/A	N/A	Yes
Ramos-Pachón et al. 2021[101]	Yes	Yes	Yes	Yes	No	N/A	Yes	Yes	N/A	N/A	Yes
Velasco et al. 2021[119]	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	N/A	N/A	Yes
Padroni et al. 2022[86]	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	N/A	N/A	Yes
Teo et al. 2020[56]	Yes	Yes	Yes	No	No	N/A	Yes	Yes	N/A	N/A	Yes
Tejada Meza et al. Dec 2020[103]	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	N/A	N/A	Yes
Tejada Meza et al. Sept 2020[104]	Yes	Yes	Yes	Yes	No	N/A	Yes	Unclear	N/A	N/A	Yes
Study	**1.Were the two groups similar and recruited from the same population?**	**2.Were the exposures measured similarly to**	**3.Was the exposure measured in a valid and**	**4.Were confounding factors identified?**	**5.Were strategies to deal with confounding**	**6.Were the groups/participants free of the outcome at the**	**7.Were the outcomes measured**	**8.Was the follow up time**	**9.Was follow up complete, and if**	**10.Were strategies to address incomplete**	**11.Was appropriate statistical analysis**

		assign people to both exposed and unexposed groups?	reliable way?		factors stated?	start of the study (or at the moment of exposure)?	in a valid and reliable way	reported and sufficient to be long enough for outcomes to occur?	not, were the reasons to loss to follow up described and explored?	follow up utilized?	used?
Tejada Meza et al. 2021[105]	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	N/A	N/A	Yes
Nadolny et al. 2020[93]	Yes	Yes	Yes	No	No	N/A	Yes	Yes	N/A	N/A	Yes
Kim et al. 2021[95]	Yes	Yes	Yes	Yes	No	N/A	Yes	Yes	N/A	N/A	Yes
Paolucci et al. 2022[87]	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	N/A	N/A	Yes

Cross-sectional Studies

Study	1.Were the criteria for inclusion in the sample clearly defined?	2.Were the study subjects and the setting described in detail?	3.Was the exposure measured in a valid and reliable way?	4.Were objective, standard criteria used for measurement of the condition?	5.Were confounding factors identified?	6.Were strategies to deal with confounding factors stated?	7.Were the outcomes measured in a valid and reliable way?	8.Was appropriate statistical analysis used?
Charlton et al. 2021[79]	Yes	No	Yes	Yes	No	No	Yes	Yes
Ferron et al. 2021[75]	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Seo et al. 2022[98]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Quasi-experimental studies

Study	1.Is it clear in the study what is the 'cause' and what is the 'effect' (i.e., there is no confusion about which variable comes first)?	2.Were the participants included in any comparisons similar?	3.Were the participants included in any comparisons receiving similar treatment/care, other than the exposure or intervention of interest?	4.Was there a control group?	5.Were there multiple measurements of the outcome both pre and post the intervention/exposure?	6.Was follow up complete and if not, were differences between groups in terms of their follow up adequately described and analyzed?	7.Were the outcomes of participants included in any comparisons measured in the same way?	8.Were outcomes measured in a reliable way?	9.Was appropriate statistical analysis used?
Tani et al. 2021[90]	Yes	Yes	Yes	Yes	No	N/A	Yes	Yes	Yes
Park et al. 2022[97]	Yes	Yes	Yes	Yes	No	N/A	Yes	Yes	Yes
Gil-Jardiné 2021[81]	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	Yes
Zini et al. 2020[88]	Yes	Yes	Yes	Yes	No	N/A	Yes	Yes	Yes
Cadilhac et al. 2021[73]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Appendix 3.22 - GRADE Summary of findings table

Certainty assessment							Nº of patients		Effect		Certainty	Importance
Nº of studies	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	COVID/19	pre-COVID-19	Relative (95% CI)	Absolute (95% CI)		
Response time												
8	observational studies	not serious	very serious[a]	not serious	not serious	publication bias strongly suspected all plausible residual confounding would reduce the demonstrated effect[b]	15338	13225	-	mean **1.29 mins higher during COVID-19** (2.19 lower to 0.38 lower)	⨁◯◯◯ Very low	CRITICAL
Total prehospital time												
4	observational studies	not serious	serious[c]	not serious	not serious	publication bias strongly suspected strong association all plausible residual confounding would reduce the demonstrated effect[d]	14332	11953	-	mean **6.42 minutes higher during COVID-19** (10.6 lower to 2.25 lower)	⨁⨁◯◯ Low	CRITICAL
Emergency call volume												
52	observational studies	serious[e]	serious[f]	not serious	not serious	publication bias strongly suspected strong association all plausible residual confounding would reduce the demonstrated effect[g]	101695	113330	-	Incidence Rate Ratio **1.19 times higher in pre-COVID-19 period** (1.02 higher to 1.39 higher)	⨁◯◯◯ Very low	CRITICAL

CI: confidence interval

Explanations

a. Heterogeneity is high at 98.76%. Subgroup and sensitivity analyses were needed to explore possible causes of this hetergeneity.

b. Effects of neither study falls near the overall effect line and within the confidence intervals.

c. Heterogeneity is 98.55%. Subgroup and sensitivity analyses were needed to investigate possible causes of this heterogeneity.

d. No severe asymmetry detected. However, only one study out of four is close to the overall effect line and within the confidence intervals.

e. The key reason why studies had reduced critical appraisal scores was due to the lack of controlling for confounding variables.

f. Heterogeneity is high at 99.59%. Subgroup and sensitivity analyses were used to investigate this heterogeneity.

g. Although the majority of studies are close to the overall effect line and within the confidence intervals, some are outside these parameters and asymmetry is visible to the right.

Appendix 3.23 - Outputs from chapter 3

Publications

Title	Date of Publication	Authors	Link
Effects of the COVID-19 pandemic on prehospital emergency care for adults with stroke and transient ischaemic attack: A systematic review and meta-analysis (paper)	June 2023	Burton E Aladkhen J O'Donnell C Masterson S Merwick Á McCarthy VJC Kearney PM Buckley CM	https://doi.org/10.1080/10903127.2023.2219729
Effects of the COVID-19 pandemic on prehospital emergency care for adults with stroke and	June 2023	Burton E Aladkhen J O'Donnell C Masterson S Merwick Á McCarthy VJC Kearney PM Buckley CM	https://www.cambridge.org/core/journals/prehospital-and-disastermedicine/issue/A6A000328D2C39C1D96C106038F1996B

transient ischaemic attack: A systematic review and meta-analysis (abstract)			
Effects of the COVID-19 pandemic on prehospital emergency care for stroke and transient ischaemic attack: A protocol for a systematic review and meta-analysis (abstract)	September 2022	Burton McCarthy VJC Merwick Á Kearney PM Buckley CM	EFFECTS OF THE COVID-19 PANDEMIC ON PRE - HOSPITAL CARE FOR STROKE AND TRANSIENT ISCHAEMIC ATTACK: A PROTOCOL FOR A SYSTEMATIC REVIEW AND META-ANALYSIS | European Stroke Journal; 7(1 SUPPL):522, 2022. | EMBASE (bvsalud.org)

Conferences

Title	Conference	Date	Type	Authors
Effects of the COVID-19 pandemic on prehospital emergency care for adults with stroke and transient ischaemic attack: A systematic review and meta-analysis	World Association of Disaster and Emergency Medicine	May 2023	Oral presentation	Burton E Aladkhen J O'Donnell C Masterson S Merwick Á McCarthy VJC Kearney PM Buckley CM
Effects of the COVID-19 pandemic on prehospital emergency care for adults with stroke and transient ischaemic attack: A systematic review and meta-analysis	Royal College of Physicians Ireland Faculty of Public Health Medicine Winter Scientific Meeting	December 2022	Poster presentation	Burton E Aladkhen J O'Donnell C Masterson S Merwick Á McCarthy VJC Kearney PM Buckley CM
Effects of the COVID-19 pandemic on prehospital emergency care for adults with stroke and transient ischaemic attack: A systematic review and meta-analysis	Irish Paramedicine Education and Research Network Research Forum	December 2022	Oral presentation	Burton E Aladkhen J O'Donnell C Masterson S Merwick Á McCarthy VJC Kearney PM Buckley CM

Effects of the COVID-19 pandemic on prehospital emergency care for adults with stroke and transient ischaemic attack: A systematic review and meta-analysis	Irish Association of Emergency Medicine Conference	October 2022	Oral presentation	Burton E Aladkhen J O'Donnell C Masterson S Merwick Á McCarthy VJC Kearney PM Buckley CM
Effects of the COVID-19 pandemic on prehospital emergency care for stroke and transient ischaemic attack: A protocol for a systematic review and meta-analysis	EEuropean Stroke Organisation	May 2022	Poster presentation	Burton E McCarthy VJC Merwick Á Kearney PM Buckley CM

Lay Summary

Title	Date of publication	Authors	Link
Ambulance times and calls for suspected stroke and TIA (mini-stroke) during the COVID-19 pandemic: What's in the papers?	October 2023	Burton E Broderick A Desmond A Kelleher L Kaye M Smithers M	Ambulance times and calls for suspected stroke and TIA (mini-stroke) during the COVID-19 pandemic: What's in the papers? - Cork Stroke Support

Policy Brief

Title	Date of publication	Authors	Link
Effects of the COVID-19 pandemic on prehospital care for stroke and transient ischaemic attack: A systematic review and meta-analysis Policy Brief	July 2023	Burton E Aladkhen J O'Donnell C Masterson S Merwick Á McCarthy VJC Kearney PM Buckley CM	Policy Briefs | The SPHeRE Programme | Structured Population and Health-services Research Education

Chapter 4 Appendices

Appendix 4.1 - Ethical approval confirmation for the study reported in chapter 4

COISTE EITICE UM THAIGHDE CLINICIÚIL
Clinical Research Ethics Committee of the Cork Teaching Hospitals

Tel: +353-21-4901901
Email: crec@ucc.ie

University College Cork
Lancaster Hall
6 Little Hanover Street
Cork
Ireland

CREC Review Reference Number: ECM 4 (h) 05/04/2022
& ECM 3 (v) 28/03/2023

1st March 2023

Dr Claire Buckley
School of Public Health
University College Cork.
4th Floor
Western Gateway Building
Western Road
Cork

Study Title: Temporal trends of ambulance activation, response and patient care times for suspected stroke/ transient ischaemic attack (TIA) before and during the COVID-19 pandemic in Ireland.

Dear Dr Buckley

The following amendment has been approved:

- Cover Letter dated 22nd February 2023
- Amendment Form signed 2nd February 2023
- Data Collection Sheet Version 3.

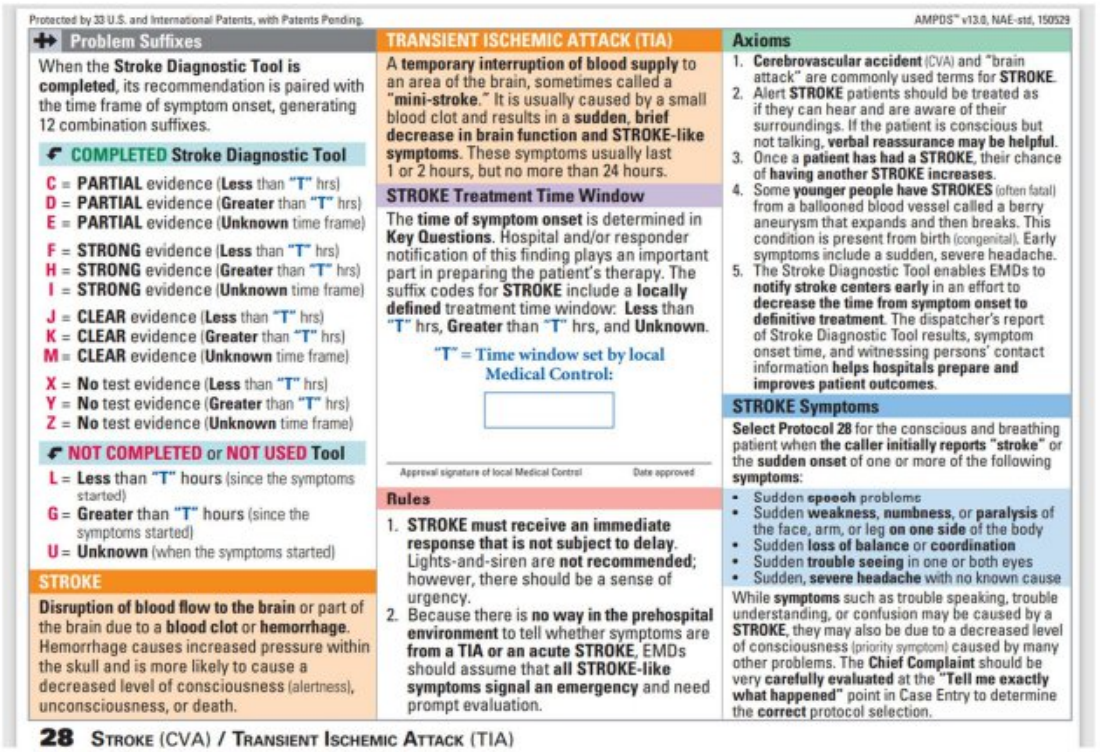
Approval is granted to implement this amendment.

Yours sincerely

Professor David Kerins
Chairman
Clinical Research Ethics Committee
of the Cork Teaching Hospitals

The Clinical Research Ethics Committee of the Cork Teaching Hospitals, UCC, is a recognised Ethics Committee under Regulation 7 of the European Communities (Clinical Trials on Medicinal Products for Human Use) Regulations 2004, and is authorised by the Department of Health and Children to carry out the ethical review of clinical trials of investigational medicinal products. The Committee is fully compliant with the Regulations as they relate to Ethics Committees and the conditions and principles of Good Clinical Practice.

Appendix 4.2 - AMPDS code stroke protocol



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Problem Suffixes

When the **Stroke Diagnostic Tool is completed**, its recommendation is paired with the time frame of symptom onset, generating 12 combination suffixes.

COMPLETED Stroke Diagnostic Tool

- **C** = **PARTIAL** evidence (**Less** than **"T"** hrs)
- **D** = **PARTIAL** evidence (**Greater** than **"T"** hrs)
- **E** = **PARTIAL** evidence (**Unknown** time frame)
- **F** = **STRONG** evidence (**Less** than **"T"** hrs)
- **H** = **STRONG** evidence (**Greater** than **"T"** hrs)
- **I** = **STRONG** evidence (**Unknown** time frame)
- **J** = **CLEAR** evidence (**Less** than **"T"** hrs)
- **K** = **CLEAR** evidence (**Greater** than **"T"** hrs)
- **M** = **CLEAR** evidence (**Unknown** time frame)
- **X** = **No** test evidence (**Less** than **"T"** hrs)
- **Y** = **No** test evidence (**Greater** than **"T"** hrs)
- **Z** = **No** test evidence (**Unknown** time frame)

NOT COMPLETED or NOT USED Tool

- **L** = **Less** than **"T"** hours (since the symptoms started)
- **G** = **Greater** than **"T"** hours (since the symptoms started)
- **U** = **Unknown** (when the symptoms started)

STROKE

Disruption of blood flow to the brain or part of the brain due to a **blood clot** or **hemorrhage**. Hemorrhage causes increased pressure within the skull and is more likely to cause a decreased level of consciousness (alertness), unconsciousness, or death.

TRANSIENT ISCHEMIC ATTACK (TIA)

A **temporary interruption of blood supply** to an area of the brain, sometimes called a **"mini-stroke."** It is usually caused by a small blood clot and results in a **sudden, brief decrease in brain function and STROKE-like symptoms**. These symptoms usually last 1 or 2 hours, but no more than 24 hours.

STROKE Treatment Time Window

The **time of symptom onset** is determined in **Key Questions**. Hospital and/or responder notification of this finding plays an important part in preparing the patient's therapy. The suffix codes for **STROKE** include a **locally defined** treatment time window: **Less** than **"T"** hrs, **Greater** than **"T"** hrs, and **Unknown**.

"T" = Time window set by local Medical Control:

Approval signature of local Medical Control — Date approved

Rules

1. **STROKE must receive an immediate response that is not subject to delay.** Lights-and-siren are **not recommended**; however, there should be a sense of urgency.
2. Because there is **no way in the prehospital environment** to tell whether symptoms are **from a TIA or an acute STROKE**, EMDs should assume that **all STROKE-like symptoms signal an emergency** and need prompt evaluation.

Axioms

1. **Cerebrovascular accident** (CVA) and "brain attack" are commonly used terms for **STROKE**.
2. Alert **STROKE** patients should be treated as if they can hear and are aware of their surroundings. If the patient is conscious but not talking, **verbal reassurance may be helpful**.
3. Once a **patient has had a STROKE**, their chance of **having another STROKE increases**.
4. Some **younger people have STROKES** (often fatal) from a ballooned blood vessel called a berry aneurysm that expands and then breaks. This condition is present from birth (congenital). Early symptoms include a sudden, severe headache.
5. The Stroke Diagnostic Tool enables EMDs to **notify stroke centers early** in an effort to **decrease the time from symptom onset to definitive treatment**. The dispatcher's report of Stroke Diagnostic Tool results, symptom onset time, and witnessing persons' contact information **helps hospitals prepare and improves patient outcomes**.

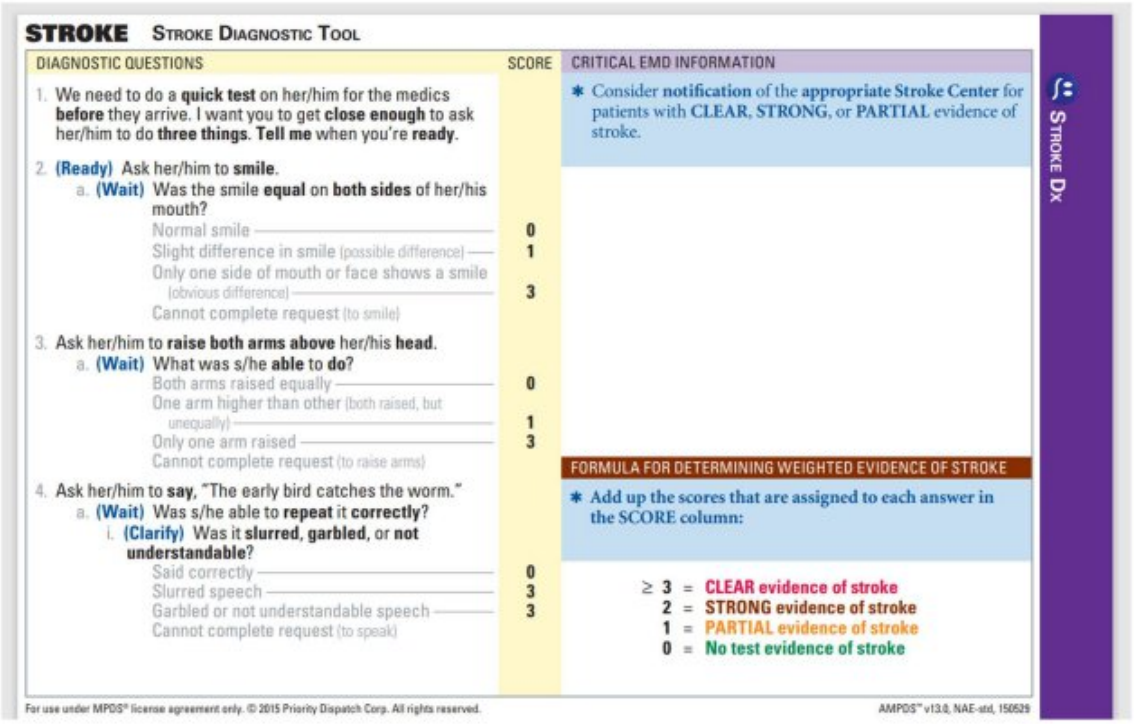
STROKE Symptoms

Select Protocol 28 for the conscious and breathing patient when **the caller initially reports "stroke"** or the **sudden onset** of one or more of the following **symptoms**:

- Sudden **speech** problems
- Sudden **weakness, numbness**, or **paralysis** of the face, arm, or leg **on one side** of the body
- Sudden **loss of balance** or **coordination**
- Sudden **trouble seeing** in one or both eyes
- Sudden, **severe headache** with no known cause

While **symptoms** such as trouble speaking, trouble understanding, or confusion may be caused by a **STROKE**, they may also be due to a decreased level of consciousness (priority symptom) caused by many other problems. The **Chief Complaint** should be very **carefully evaluated** at the **"Tell me exactly what happened"** point in Case Entry to determine the **correct** protocol selection.

28 STROKE (CVA) / TRANSIENT ISCHEMIC ATTACK (TIA)



STROKE STROKE DIAGNOSTIC TOOL

DIAGNOSTIC QUESTIONS	SCORE
1. We need to do a **quick test** on her/him for the medics **before** they arrive. I want you to get **close enough** to ask her/him to do **three things**. **Tell me** when you're **ready**.	
2. **(Ready)** Ask her/him to **smile**.	
a. **(Wait)** Was the smile **equal** on **both sides** of her/his mouth?	
Normal smile	0
Slight difference in smile (possible difference)	1
Only one side of mouth or face shows a smile (obvious difference)	3
Cannot complete request (to smile)	
3. Ask her/him to **raise both arms above** her/his **head**.	
a. **(Wait)** What was s/he **able** to **do**?	
Both arms raised equally	0
One arm higher than other (both raised, but unequally)	1
Only one arm raised	3
Cannot complete request (to raise arms)	
4. Ask her/him to **say**, "The early bird catches the worm."	
a. **(Wait)** Was s/he able to **repeat** it **correctly**?	
i. **(Clarify)** Was it **slurred, garbled**, or **not understandable**?	
Said correctly	0
Slurred speech	3
Garbled or not understandable speech	3
Cannot complete request (to speak)	

CRITICAL EMD INFORMATION

* Consider **notification** of the **appropriate Stroke Center** for patients with **CLEAR, STRONG**, or **PARTIAL** evidence of stroke.

FORMULA FOR DETERMINING WEIGHTED EVIDENCE OF STROKE

* Add up the scores that are assigned to each answer in the SCORE column:

- ≥ 3 = **CLEAR evidence of stroke**
- 2 = **STRONG evidence of stroke**
- 1 = **PARTIAL evidence of stroke**
- 0 = **No test evidence of stroke**

STROKE DX

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STROKE Symptoms

Select Protocol 28 for the conscious and breathing patient when **the caller initially reports "stroke"** or the **sudden onset** of one or more of the following **symptoms**:

- Sudden **speech** problems
- Sudden **weakness**, **numbness**, or **paralysis** of the face, arm, or leg **on one side** of the body
- Sudden **loss of balance** or **coordination**
- Sudden **trouble seeing** in one or both eyes
- Sudden, **severe headache** with no known cause

While **symptoms** such as trouble speaking, trouble understanding, or confusion may be caused by a **STROKE**, they may also be due to a decreased level of consciousness (priority symptom) caused by many other problems. The **Chief Complaint** should be very **carefully evaluated** at the **"Tell me exactly what happened"** point in Case Entry to determine the **correct** protocol selection.

Rules

1. The Stroke Diagnostic Tool is considered **COMPLETED** if **any of the three requests are accomplished**. It is considered **NOT COMPLETED** when **none of the requests are accomplished**. All Diagnostic Questions **should be asked**, regardless of whether any previous request was completed.
2. The EMD should **return to Protocol 28** after asking **all of the Diagnostic Questions**.
3. If the caller reports a **pre-existing speech or motor deficit** during a test, **clarify** if it is now **worse than before**.

Expressive Aphasia

The **inability** of certain stroke patients **to speak clearly** the things they want to say. In essence, they know what they want to say, but have trouble actually saying it. This is **not slurred speech** per se (which is another symptom of stroke), but the **blocking of certain words and more complex phrases**. Sometimes the patient can answer questions using simple, common words such as "yes" and "no," but stumble when asked for longer phrases or when asked to say more robust words like "rhinoceros."

Receptive Aphasia

The **inability to understand** auditory information input, which manifests itself as **jumbled**, **nonsensical speech or inappropriate speech**. In essence, the speech formulation mechanism is okay, but the brain doesn't understand what is heard that would otherwise generate appropriate speech downloading to the mouth and vocal cords. This is sometimes referred to by the term "word salad."

Limitations Warning

This **Stroke Diagnostic Tool** is used to strengthen the EMD's identification of stroke patients on Protocol 28 and for other clinical situations defined by local Medical Control (e.g., ground-level falls, sudden onset of immobility, fainting, sudden weakness, and other non-obvious presentations of stroke).

The tool is based on commonly used methods (the Cincinnati Stroke Scale and F.A.S.T. test) that have spread among the lay public to help them identify stroke victims. The tool subjectively evaluates various combinations of symptoms that are known to equate to stroke. Using an internal logic weighting formula, the tool then assigns the case to one of four categories: **CLEAR**, **STRONG**, **PARTIAL**, or **No test evidence** of the case being an actual stroke. The tool does not currently attempt to identify Receptive Aphasia, which is sometimes difficult to recognize by non-medical professionals (see definition in the Additional Information).

The Stroke Diagnostic Tool will likely be the basis of **future studies in dispatch stroke identification outcome**, and its logic weighting formula will be further refined as a result.

The EMD's use of this tool is significantly simpler in ProQA® than in manual cards, which require the EMD to do some simple math to work out the formula and look up the results.

STROKE STROKE DIAGNOSTIC TOOL

Further information on the process of assigning a code 28 using the AMPDS system

- ***Initial call taking event:***

  AMPDS employs a structured caller interrogation protocol to prioritise calls and assign EMS resources to incidents through the associated ProQA paramount software system (Priority Dispatch Corp.,). The data endpoint is represented by a 'number-letter-number-letter' sequence (AMPDS code), indicating the chief complaint, Determinant (response) level (corresponding to the speed and configuration of EMS response required, Ω (Omega) to E (Echo)), determinant descriptor (starting at 1 and listed in order of decreasing priority), and (where indicated) a problem suffix letter (delineates the type of incident or safety concerns eg: V = Violent; W = weapon).

- ***Amending the triage code:***

  The Emergency Call Taker (ECT) will continuously evaluate the condition of the patient throughout the pre-resource arrival phase of the emergency call and update answers provided to key questions during the triage process accordingly. The ProQA paramount software will automatically update the dispatch code to the most appropriate based on the updated answers.

  The changing of the dispatch code is not manual – the emergency call taker can only change the answers to the “Key Questions” on the protocol being used. If those new answers point to another appropriate dispatch code the software will

highlight that a ‘reconfigured’ dispatch code is available. The ECT will then press ‘Reconfigure: [new dispatch code]’ and this will be applied on the call.

- **Relationship between the prioritisation code**

The prioritisation code (purple, red, amber, yellow, green, blue) is applied to each of the dispatch codes on the CAD system. Historically purple calls were Echo, Red calls were Delta, Amber were Charlie, Yellow were Bravo, Green were Alpha, and Blue were Omega.

The organisation is free to establish whatever colour they deem necessary against individual dispatch codes. For instance, currently the dispatch code 28C00C is set to red (Partial evidence less than 4 hours), while 28C00D is set to amber (partial evidence greater than 4 hours).

- **Dispatch determinants**

Stroke Charlie Override: The system does allow for the manual upgrading of a call should there be an agency policy in place that allows such practice. ECTs and Emergency Dispatchers do have the ability to upgrade calls which are called “overrides”. They essentially override the dispatch code in place to an approved override code (these have the format for stroke calls: 28(letter)00, where 00 makes it clear that an override has been carried out. A good example of where this happens all the time is for seizure calls which could receive the dispatch code

12A01 up to 12A05. NAS do not permit as per policy to keep seizure calls at an alpha determinant level, so ECTs must override the call immediately to 12B00.

- **Stroke/TIA history (do all patients with a stroke history get a stroke activation even for an unrelated problem?):**

No. The history will be documented but if no symptoms of stroke are present and other issues are present, the call taker will triage the call for the current presenting issue. The ECT does have the freedom to launch the stroke diagnostic tool on any call to either rule it in or out based on the results of this test.

Appendix 4.3 - Minor methodological issues not fully addressed in methods and including data cleaning processes

Appendix Table 4.3 (a) - Categorization of the 13-stroke code protocol determinant descriptors into 5 categories

Not alert	28-C-1	Not alert
Unknown status/other codes not applicable	28-C-12	Other
Stroke charlie override	28-C-00	
Breathing normally <35	28-A-1	Breathing
Breathing normally greater than or equal to 35	28-C-11	
Abnormal breathing	28-C-2	
Sudden speech problems	28-C-3	Sudden onset of stroke/TIA symptoms
Sudden weakness or numbness	28-C-4	
Sudden paralysis or facial drop	28-C-5	
Sudden loss of balance or co-ordination	28-C-6	
Sudden vision problems	28-C-7	
Sudden onset of severe headache	28-C-8	
Stroke history	28-C-9	History of cerebrovascular disease
TIA history	28-C-10	

Appendix Table 4.3 (b) - Ambulance time intervals analysis for suspected stroke/TIA

Extreme values
Exploratory analysis of the dataset identified heteroscedasticity with extreme values predominantly in wave 4 and 5 of the pandemic, mainly present for allocation and mobilisation performance. A random sample of 100 cases were selected and checked. These data points were found to be true values. Thus, we used the log of the dependent variable in each regression to account for these extreme values. During the COVID-19 period we observed an increase in ambulance time intervals for suspected stroke/TIA calls. However, when we carried out regression analysis comparing this effect across waves, it appears only some waves are contributing to this difference for certain intervals. Extreme values are observed in waves 4 and 5, which could have contributed to the observed increase. In some cases, the extreme values result from a change of protocol from another principal complaint, such as COVID-19, to stroke/TIA or vice versa. The International Academies of Emergency Dispatch introduced the COVID-19 protocol in March 2020. Thus, whether the increases were because of change in protocol or true reflections of the time elapsed, both indicate that circumstances changed during the pandemic.

Zero-time intervals values

Furthermore, we found a number of time intervals of 0 seconds in the dataset. These were predominantly present for allocation time interval. After exploring a subset of these, we concluded that these could also represent true values. If the resource was on scene when the stroke/TIA occurred, or the vehicle was already mobile to scene. Prior to calculating the log value, time intervals with a value of 0 seconds were removed from the dependent variable.

If the resource was at the scene or mobile when allocated by the ECT, the ECT may over-ride the system and enter the same time variable in the required time value fields. This would return a 00:00:00 time value as a measure when calculating between the required time variables that are used to generate a time value.

The above situation is describing two possible scenarios:

1. A situation where prehospital providers were mobile (enroute to scene) – ECT assigns allocation performance of 0 as the crew is already mobile, thus allocation step can be skipped from the prehospital care provider perspective.

2. When the prehospital providers were already at the scene – ECT assigns allocation performance and mobilisation performance of 0 as the crew is already on scene.

As calls can only be assigned one AMPDS code (chief complaint), as they are dealt with in isolation. Thus, when analysing this data, we must use the assigned time variable, which as described above, may be zero.

An example of situation 1 may be that the crew are already on the road after another call and continue to this next call - thus allocation time is 0. For situation 2, the crew may be at a healthcare facility already and then receive a stroke call for a resident/patient in that facility. Thus, allocation and mobilisation performance are 0.

Appendix 4.4 - Patient and Public Involvement in this study reported using The GRIPP2 checklist

1. Aim - Report the aim of PPI in this study

The aim of PPI in this study was to ensure those with lived experience of stroke/TIA helped to shape the review, from research question development to dissemination.

2. Methods - Provide a clear description of the methods used for PPI in the study

We worked with a PPI panel of 13 stroke/TIA survivors and family members (8 men, 5 women) throughout this study. The group included: 7 stroke survivors, 2 TIA survivors and 4 family members of stroke/TIA survivors. EB met with the majority of the group on an online conference platform and interacted with other members over the phone and by email. EB met with the group on six occasions to discuss this study. EB also forwarded materials for review to the panel on numerous occasions throughout the duration of this work.

Firstly, the group were involved in refining the research question from an early stage. EB asked the panel to discuss their priorities for prehospital stroke/TIA care, which contributed to the refinement of the research question and the selection of outcomes for this study. Furthermore, the panel were given the opportunity to input on the population to be studied, and what they would like to know about those included.

As the study progressed, EB presented preliminary findings to the group and asked for direction and input on interpretation. When the final results of the study were available EB met with the panel to discuss the findings and their possible impact. As a result, the group co-designed a lay summary of the findings.

On the topic of stakeholder involvement, the PPI panel also highlighted various stroke survivor and patient organisations where the summary could be sent. They also advised on practice and policy stakeholders to involve throughout the project, and organisations where the policy brief on findings could be distributed.

3. Study results - Outcome - Report the results of PPI in the study, including both positive and negative outcomes

In terms of priorities, the group highlighted the importance of time in the context of stroke/TIA care. Members reflected on their stroke/TIA journeys in the immediate phase after symptom recognition, and how prehospital emergency services can be an integral part of that journey. They also discussed the importance of education, for both stroke/TIA survivors and bystanders, in understanding potential stroke/TIA symptoms and when to raise the alarm.

The PPI contributors advised that they prefer the term “stroke/TIA survivor” over “stroke/TIA patient” or “stroke/TIA victim. “As a result, we use these terms wherever possible in communication and dissemination of findings.

The panel understood how prehospital delays could have occurred during a healthcare crisis, such as COVID-19. They surmised that cleaning protocols, PPE donning and doffing practices, increased pressures on healthcare services and reduction in staffing due to COVID-19 infection or isolation could have caused delays at different stages in the patient journey. However, simultaneously, the group were divided in terms of the meantime differences between COVID-19 and pre-COVID-19 ambulance times. Some believed any time difference was significant due to the short periods of time which are at play in the prehospital phase. Whereas others believed, in the context of the situation, these delays were minor. As a whole, the group agreed that factual and clear information needed to be presented to public audiences. However, that the tone and other finer nuances needed to be taken into consideration when delivering the message to a general audience. In short, they believe the core message of this work, is regardless of the situation always call an ambulance if you believe you or someone else could be having a stroke/TIA.

In terms of dissemination, it was suggested that healthcare professionals, including the ambulance service, and policy makers should be aware of study findings. The PPI panel also stressed that stroke/TIA survivors and their families/caregivers needed to be informed of study results. As a result, EB co-presented this work with a PPI contributor at a national healthcare conference.

4. Discussions and conclusions – Outcomes - Comment on the extent to which PPI influenced the study overall. Describe positive and negative effects.

The PPI panel had a strong influence on the conceptualisation and overall development of this study, throughout all phases. We wished to include the panel in as many stages of the process as possible to enrich the study and optimise its value through the addition of lived experience. However, on reflection we would like to have included greater PPI input in the analysis phase, constantly asking the group what they would like to know and presenting information to them on a regular basis. However, as this study is part of a doctoral project, time and budget constraints meant that only preliminary and final results could be presented once to the panel.

5. Reflections/critical perspective - Comment critically on the study, reflecting on the things that went well and those that did not, so others can learn from this experience

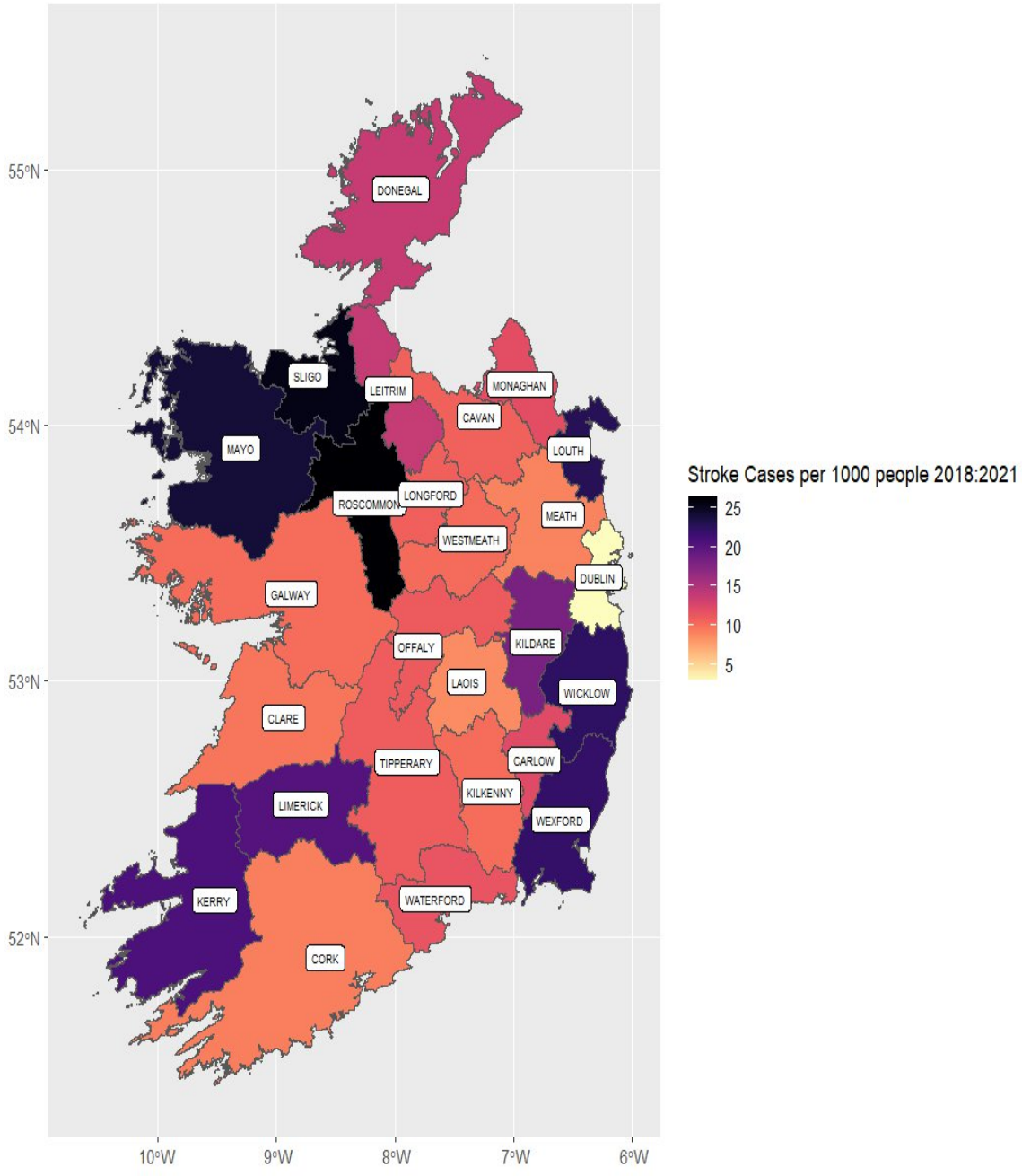
Overall, the inclusion of PPI throughout this review was a positive experience. We believe the purpose, impact and implications of this study were enriched by the inclusion of the lived experience of stroke/TIA. However effective PPI requires time and other resources. Thus, within the confines of a PhD it can be challenging to include optimal levels of PPI.

Appendix 4.5 - Breakdown of suspected stroke/TIA cases by year and sex

Year	Male	Female	Unknown Sex*	Total
2018	3998 (43.8%)	4131 (45.3%)	997 (10.9%)	**9126**
2019	4435 (48.4%)	4703 (51.3%)	29 (0.3%)	**9167**
2020	4838 (49.2%)	4965 (50.5%)	31 (0.3%)	**9834**
2021	5735 (48.3%)	6117 (51.5%)	25 (0.2%)	**11877**
Total	19006 (47.5%)	19916 (49.8%)	1082 (2.7%)	**40004**

*Unknown – (patient sex was not entered into the electronic healthcare record by the prehospital practitioner and there was an indexing error in the database, resulting in some records in the dataset not returning a value for sex November 2018.

Appendix 4.6 - Frequency of Suspected Stroke/TIA Calls per 1000 people by County - 2018-2021



County	Population (2016)	Stroke/TIA Calls (2018-2021)	Stroke/TIA Calls per 1000 people
Cork	542,868	5020	9.25
Dublin*	1,347,359	4021	3
Galway	258,058	2600	10.1
Donegal	159,192	2195	13.7
Kildare	110,546	1996	18.1
Limerick	97,559	1985	20.3
Meath	195,044	1763	9
Tipperary	159,553	1748	11
Wexford	76,000	1678	22.1
Wicklow	72,269	1620	22.4
Mayo	65,460	1572	24
Kerry	74,652	1550	20.8
Louth	63,633	1454	22.8
Waterford	116,176	1331	11.5
Clare	118,817	1158	9.7
Kilkenny	99,232	1000	10.1
Westmeath	88,770	909	10.2
Offaly	77,961	867	11.1
Roscommon	32,377	854	26.4
Sligo	32,365	824	25.5
Cavan	76,176	814	10.7
Monaghan	61,386	738	12
Laois	84,697	725	8.6
Carlow	56,932	695	12.2
Longford	40,873	443	10.8
Leitrim	32,044	441	13.8
Cross Border	Not applicable	3	Not applicable

Appendix 4.7 - Number of suspected stroke/TIA cases per county per day during the pre-COVID-19 and COVID-19 periods

County	Total Stroke Call Volume during COVID-19 (volume per day – 671 days)	Stroke Call Volume pre-COVID-19 (volume per day - 790 days)
Carlow	347 (0.5)	348 (0.4)
Cavan	426 (0.6)	388 (0.5)
Clare	591 (0.9)	567 (0.7)
Cork	2545 (3.8)	2475 (3.1)
Donegal	1106 (1.6)	1089 (1.4)
Dublin	1959 (2.9) *	2062 (2.6) *
Galway	1320 (2)	1280 (1.6)
Kerry	743 (1.1)	807 (1)
Kildare	1040 (1.5)	956 (1.2)
Kilkenny	504 (0.8)	496 (0.6)
Laois	383 (0.6)	342 (0.4)
Leitrim	224 (0.3)	217 (0.3)
Limerick	1035 (1.5)	950 (1.2)
Longford	233 (0.3)	210 (0.3)
Louth	724 (1.1)	730 (0.9)
Mayo	772 (1.2)	800 (1)
Meath	909 (1.4)	854 (1.1)
Monaghan	360 (0.5)	378 (0.5)
Offaly	450 (0.7)	417 (0.5)
Roscommon	445 (0.7)	409 (0.5)
Sligo	404 (0.6)	420 (0.5)
Tipperary	856 (1.3)	892 (1.1)
Waterford	681 (1)	650 (0.8)
Westmeath	475 (0.7)	434 (0.5)
Wexford	813 (1.2)	865 (1.1)
Wicklow	832 (1.2)	788 (1)
Cross Border	1 (na)	2 (na)

This table shows the number of total stroke/TIA cases per County in the dataset during COVID-19 and pre-COVID-19. Number in brackets is the average number of stroke cases per day in that county during COVID-19 and pre-COVID-19 (rounded to 1 decimal place).

*Dublin data does not contain figures from Dublin Fire Brigade

Appendix 4.8 - Number of 999/112 and non 999/112 calls during pre-COVID-19 and COVID-19 period

Time period	112 or 999	Non 112 or 999	Missing
COVID-19	15253	4916	9
Pre-COVID-19	14674	5122	30

Appendix 4.9 - Types of resource allocated during the pre-COVID-19 and COVID-19 period

	Pre-COVID-19	COVID-19	Total
Total Number of Suspected Stroke/TIA Cases	19826	20178	40004
Total Number of Resources Allocated	**27424**	**27846**	**55270**
Aircorp112	22	23	45
Ambulance Officer Response	157	123	280
A Garda Siochana*	1	0	1
CFR Responder Group*	1608	28	1636
Coast Guard	22	27	49
Community Engagement Officer	0	14	14
Community Paramedic	20	119	139
Cork City Fire Brigade	2	2	4
COVID 19 Resource	18	71	89
Defence Forces	13	36	49
Doctor Responder	14	18	32
Dublin Fire Brigade	5	5	10
Emergency Ambulance	23868	25629	49497
HELIMED 92*	16	29	45
Intermediate Care Vehicle	271	239	510
Lifeboat	5	5	10
NAS Motorcycle	138	136	274
NAS Off Duty Responder	10	8	18
Northern Ireland Ambulance Service	5	0	5
Rapid Response Vehicle	1229	1334	2563

A Garda Síochána" *– police force in the Republic of Ireland;* ***"CFR"*** *– community first responder;* ***"HELIMED 92"*** *– helicopter used for aeromedical missions by the national Ambulance Service of the Republic of Ireland*

Appendix 4.10 - Table of Number of Resources (categorised) vs Time Status (time since last known well) for pre-COVID-19 vs COVID-19 period

(a)

Number of Resources (category)	**>4 hours**		**<4 hours**		**Unknown**		**Overall Total**
Time Period	Pre-COVID-19	COVID-19	Pre-COVID-19	COVID-19	Pre-COVID-19	COVID-19	
One	3838	4476	9607	9675	583	581	28760
Two or More	1621	1706	3917	3502	260	238	11244
Total (pre-COVID-19 vs COVID-19)	5459	6182	13524	13177	843	819	
Overall Total	11641		26701		1662		40004

(b)

Number of Resources (number)	**Greater than 4 hours**		**Less than 4 hours**		**Unknown**		**Overall Total**
Time Period	Pre-COVID-19	COVID-19	Pre-COVID-19	COVID-19	Pre-COVID-19	COVID-19	
1	3838	4476	9607	9675	583	581	28760
2	1196	1156	3038	2546	194	166	8296
3	344	362	656	719	52	51	2184
4	54	117	176	172	8	15	542
5	14	52	35	45	4	4	154
6	11	15	10	14	1	2	53
7	2	2	2	5	1	0	12
8	0	1	0	1	0	0	2
10	0	1	0	0	0	0	1
Total (pre-COVID-19 vs COVID-19)	5459	6182	13524	13177	843	819	
Overall Total	11641		26701		1662		40004

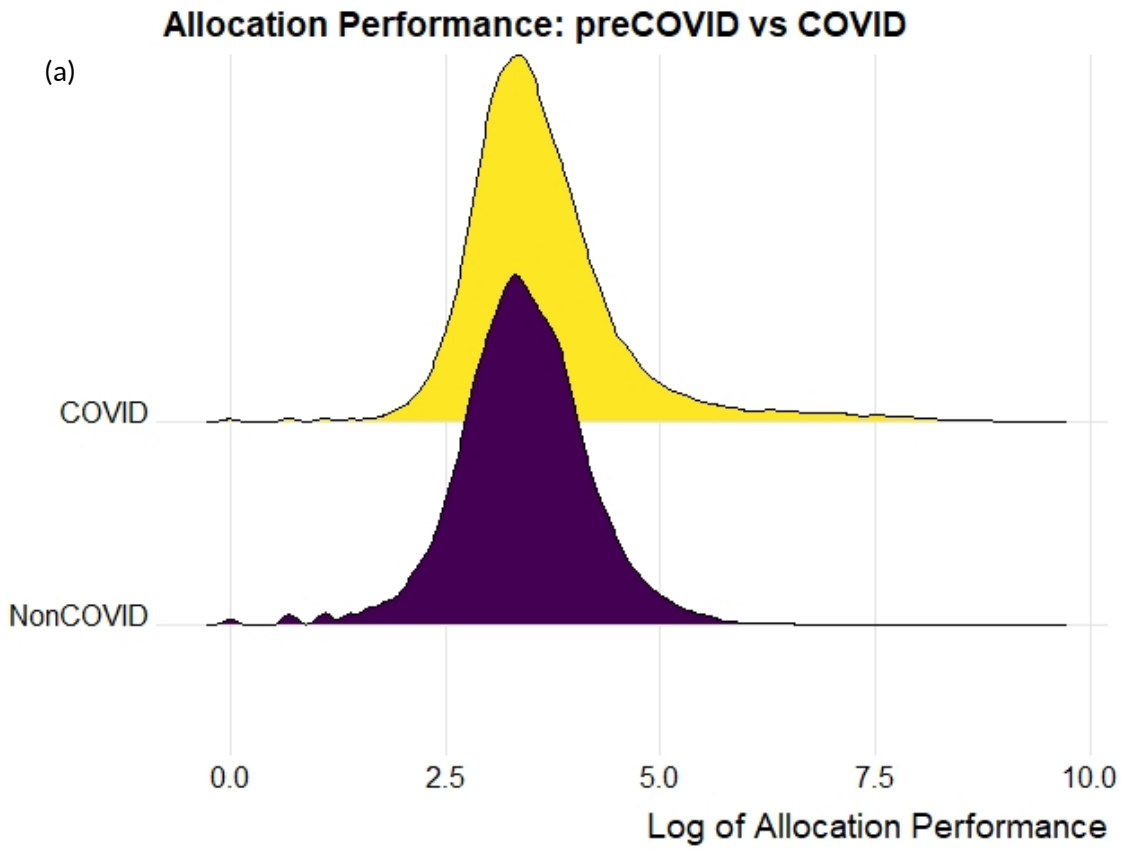
Appendix 4.11 - Table of the range, median and mean of the five-time intervals included in this study

Variable	Range	Mean	Median
Allocation Performance	00:00:00 to 03:30:27	1min 3 secs	28 secs
Mobilisation Performance	00:00:00 to 03:30:34	2 min 20 secs	1 min 32 secs
Response Time	00:00:00 to 23:59:56	18 mins 13 secs	14 mins 54 secs
Time Spent on Scene	00:00:00 to 2:23:45	24 mins 36 secs	22 mins 45 secs
Conveyance Time	00:00:00 to 07:05:00	26 mins 59 secs	24 mins 11 secs

Appendix 4.12 - Mean ambulance time intervals during pre-COVID-19 and the five COVID-19 waves

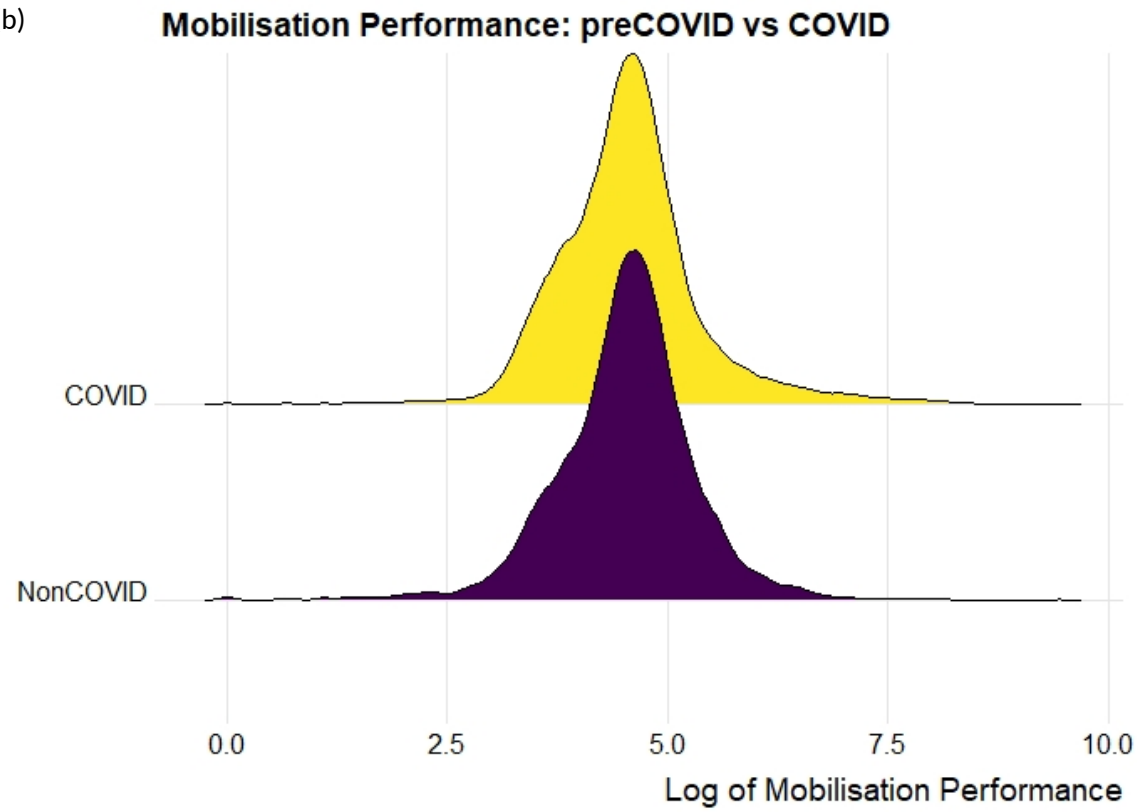
Time	Allocation Performance	Mobilisation Performance	Response Time	On Scene	Conveyance Time
Pre-COVID-19	39 secs	2 mins	20 mins 19 secs	23 mins 01 secs	26 mins 27 secs
Wave 1	43 secs	2 mins 4 secs	20 mins 51 secs	25 mins 34 secs	26mins 46 secs
Wave 2	42 secs	1 min 54 secs	21 mins 54 secs	25 mins 13 secs	26 mins 40 secs
Wave 3	46 secs	1 min 55 secs	23 mins 39 secs	26 mins 58 secs	27 mins 21 secs
Wave 4	2 mins 55 secs	4 min 07 secs	29 mins 59 secs	25 mins 58 secs	28 mins 43 secs
Wave 5 (partial)	4 mins 47 secs	5 min 44 secs	33 mins 45 secs	28 mins 12 secs	26 mins 35 secs
Overall COVID-19 mean	1min 28secs	2 min 40secs	24mins 52secs	26 mins 11 secs	27 mins 30 secs

Appendix 4.13 - Distribution of ambulance time intervals between pre-COVID-19 and COVID-19 periods



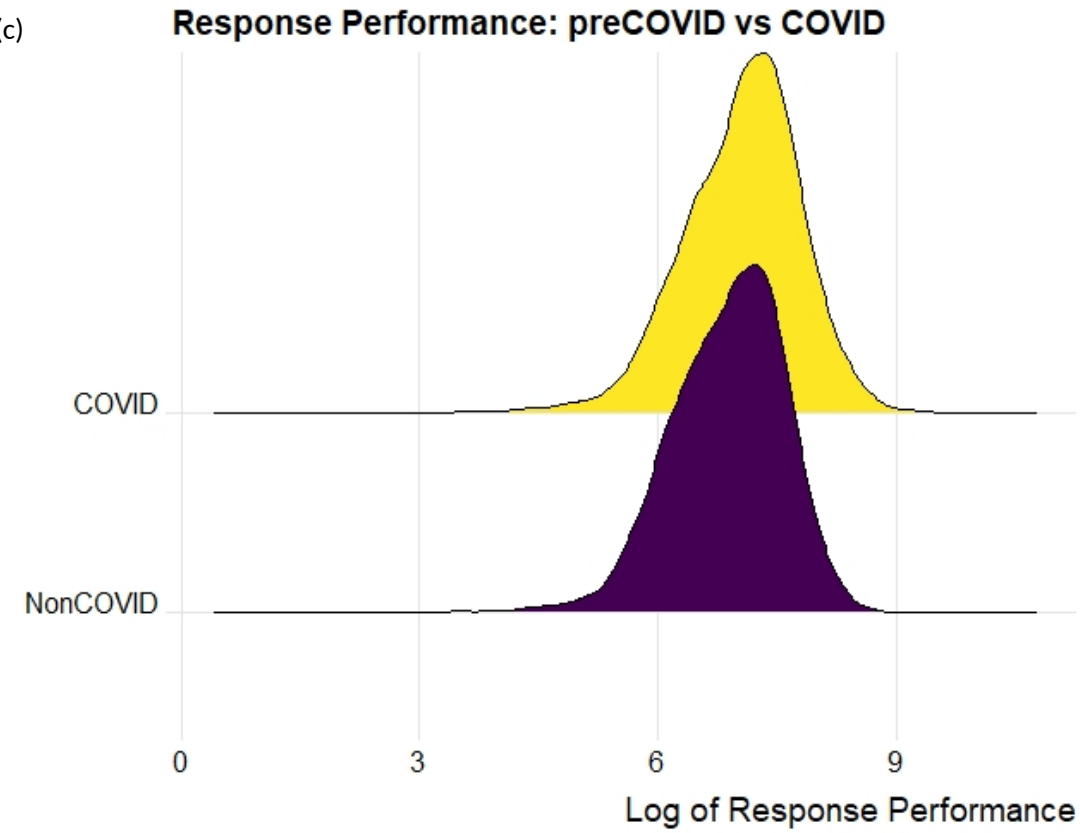
Appendix figure 4.13 (a) - Ridge plot of log of allocation performance during the pre-COVID-19 and COVID-19 periods

(b)



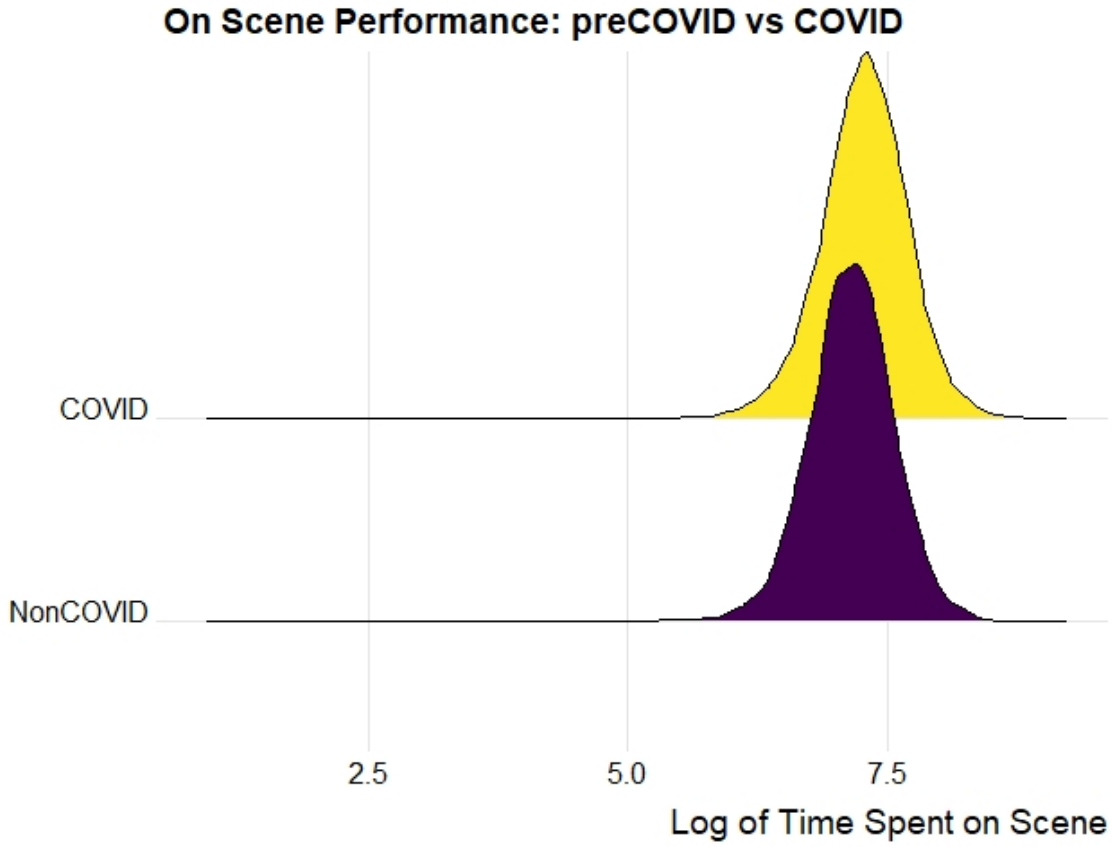
Appendix figure 4.13 (b) - Ridge plot of log of mobilisation performance during the pre-COVID-19 and COVID-19 periods

(c)



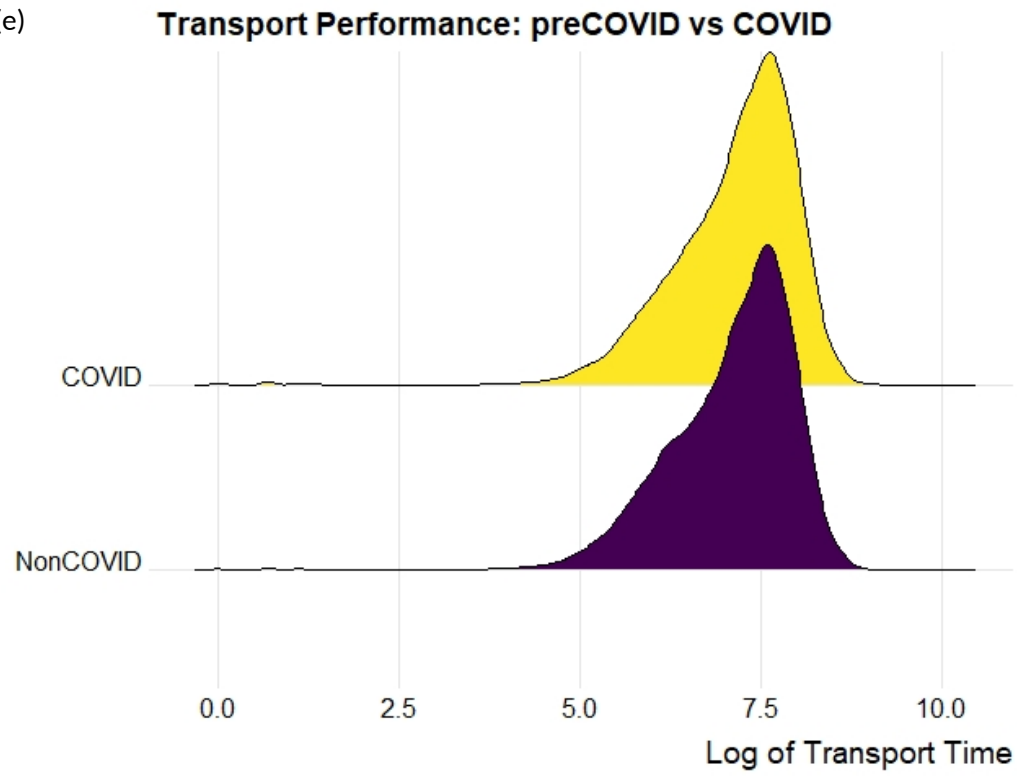
Appendix figure 3.13 (c) - Ridge plot of log of response performance during the pre-COVID-19 and COVID-19 periods

(d)



Appendix figure 4.13 (d) - Ridge plot of on scene time during the pre-COVID-19 and COVID-19 periods

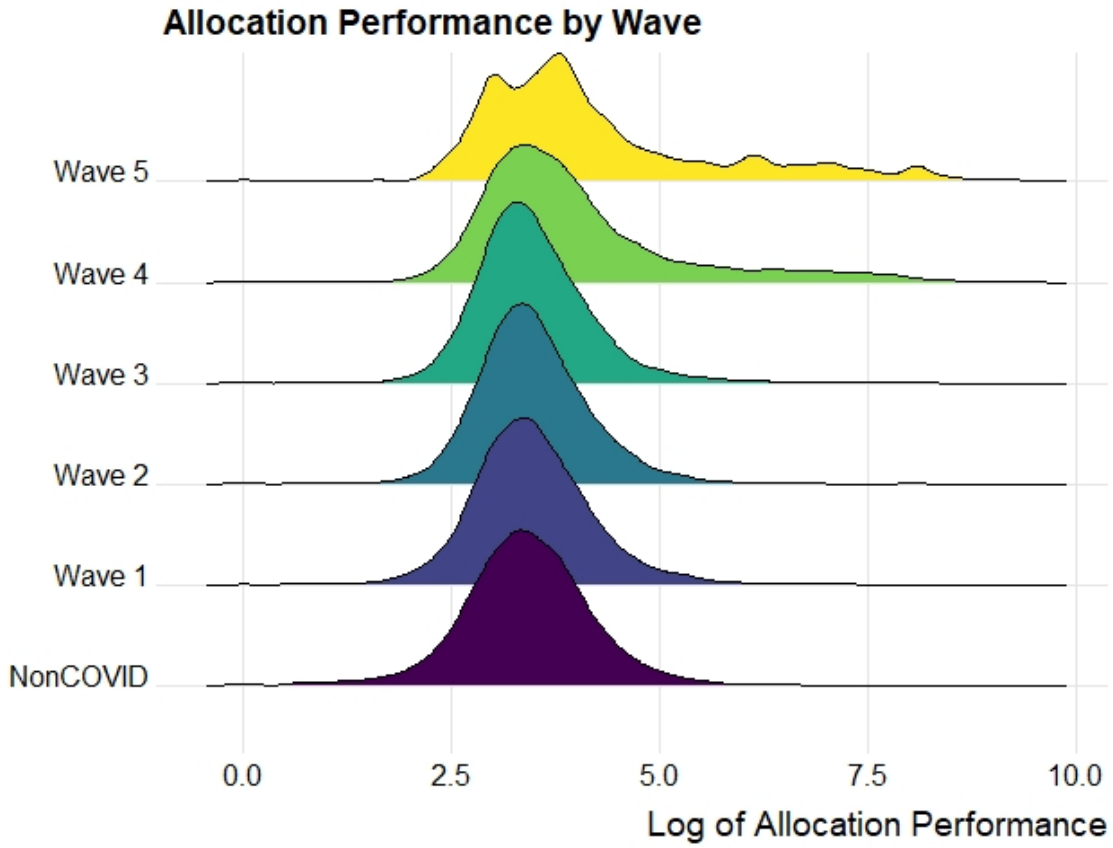
(e)



Appendix figure 4.13 (e) - Ridge plot of log of conveyance time during the pre-COVID-19 and COVID-19 periods

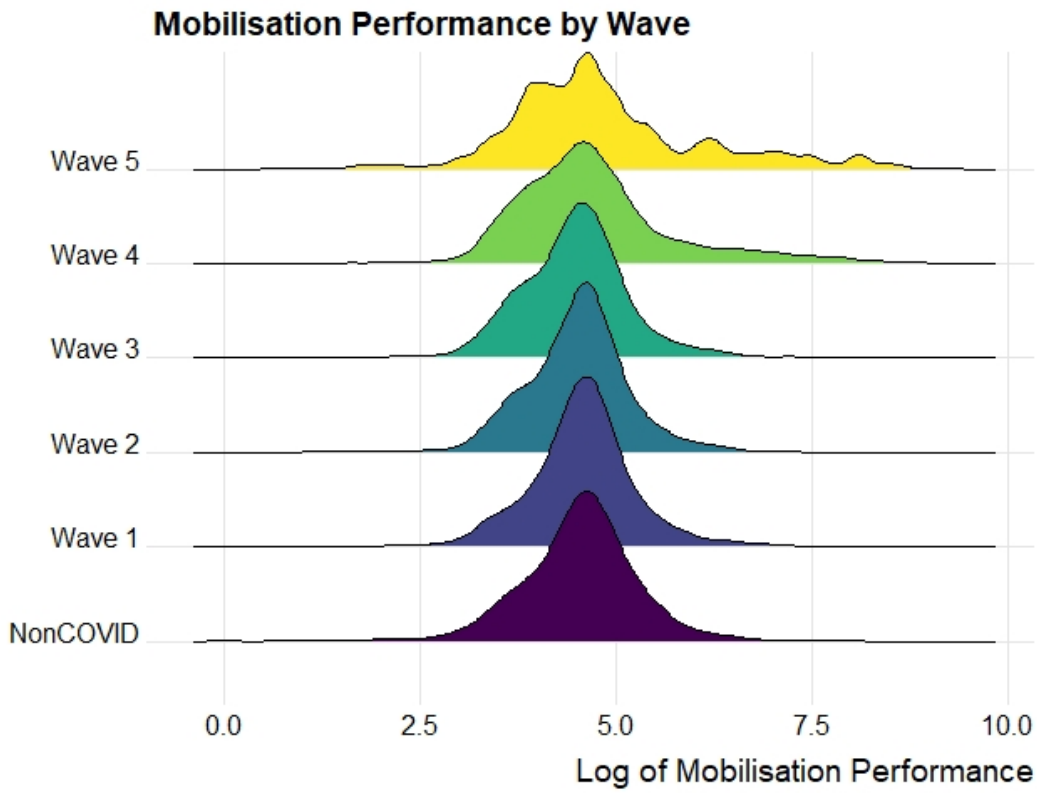
Appendix 4.14 - Distribution of ambulance time intervals between pre-COVID-19 and waves of COVID-19

(a)



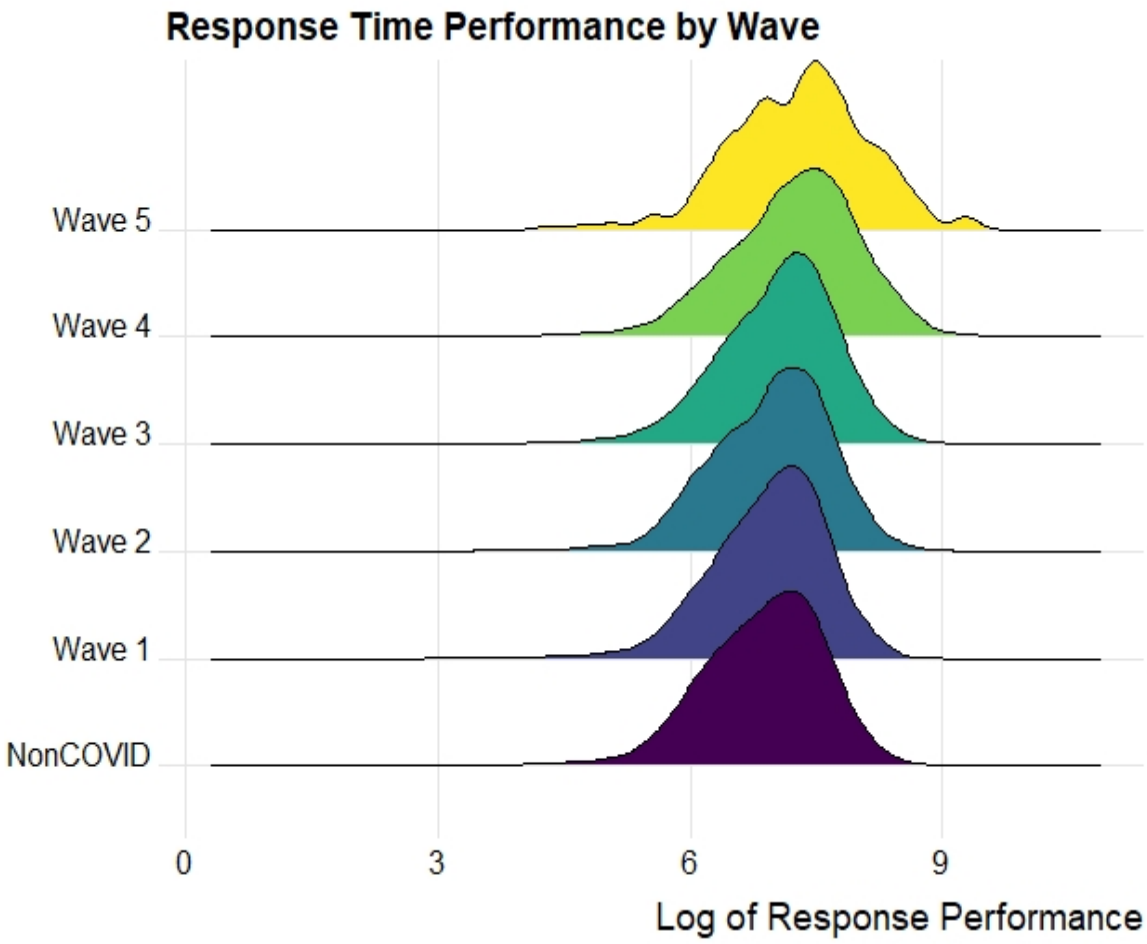
Appendix figure 4.14 (a) - Ridge plot of log of allocation performance during the pre-COVID-19 period and COVID-19 waves

(b)



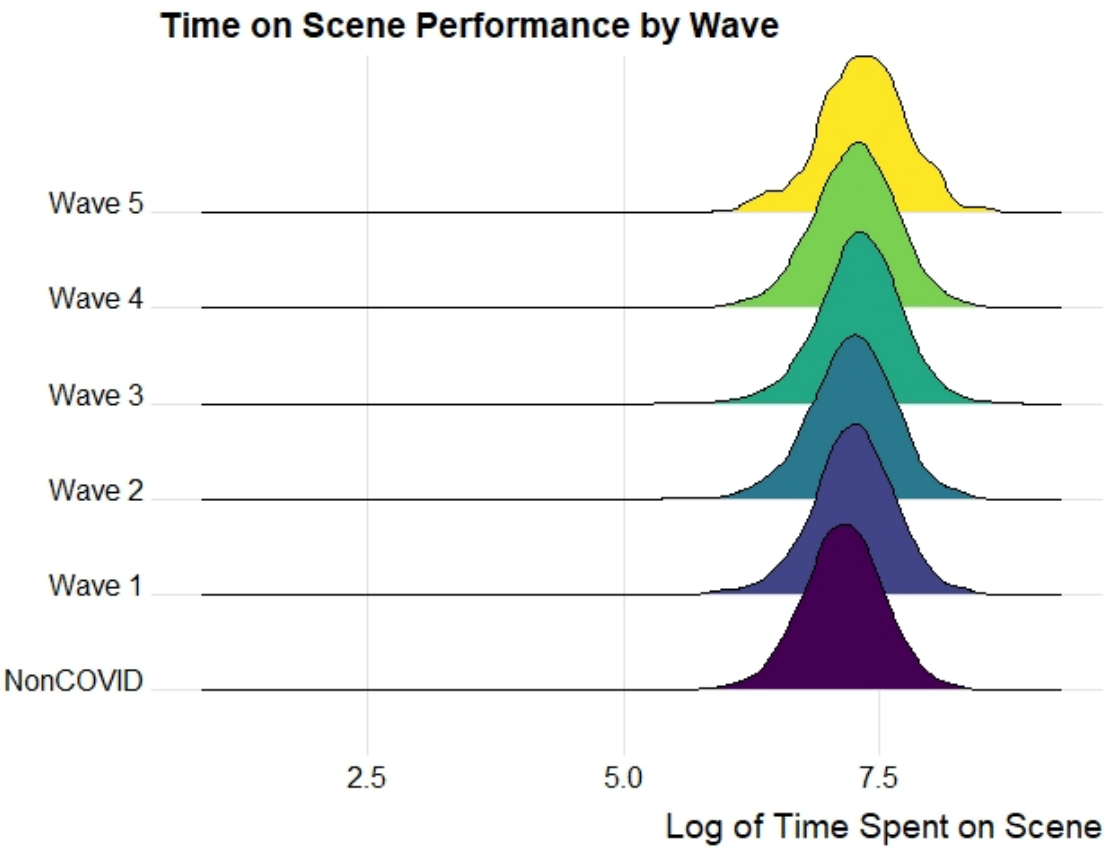
Appendix figure 4.14 (b) - Ridge plot of log of mobilisation performance during the pre-COVID-19 period and COVID-19 waves

(c)



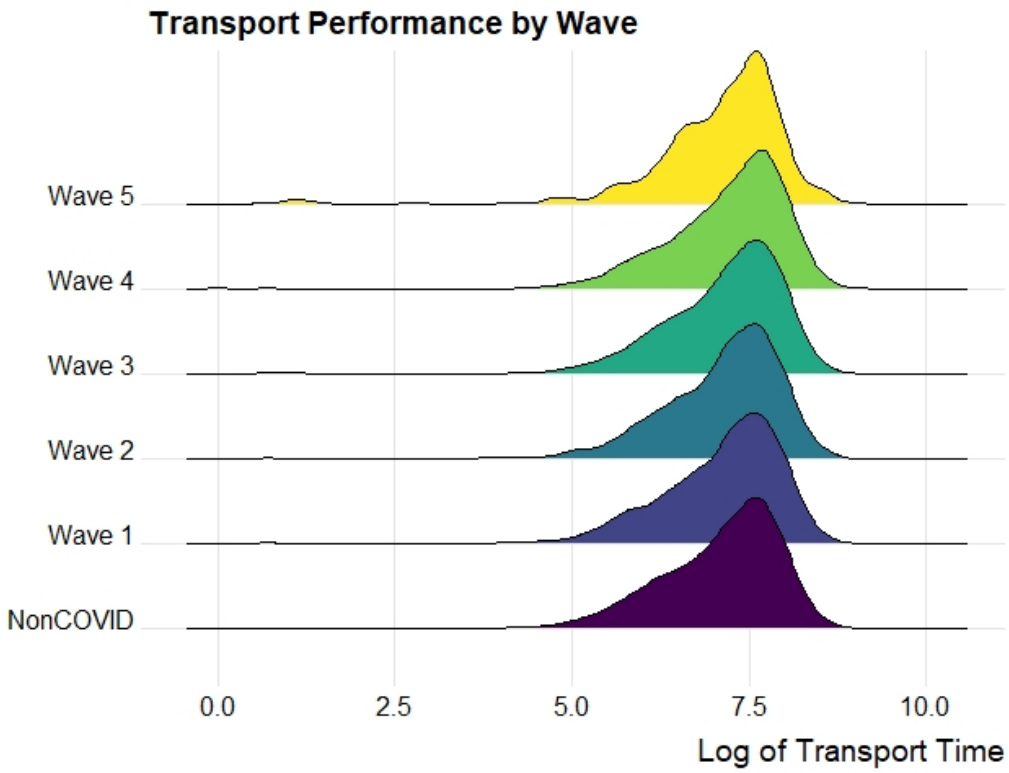
Appendix figure 4.14 (c) - Ridge plot of log of response performance during the pre-COVID-19 period and COVID-19 waves

(d)



Appendix figure 4.14 (d) - Ridge plot of log of on scene time during the pre-COVID-19 period and COVID-19 waves

(e)



Appendix figure 4.14 (e) - Ridge plot of log of conveyance performance during the pre-COVID-19 period and COVID-19 waves

Appendix 4.15 - Scatter plots of ambulance time intervals during the pre-COVID-19 versus COVID-19 periods

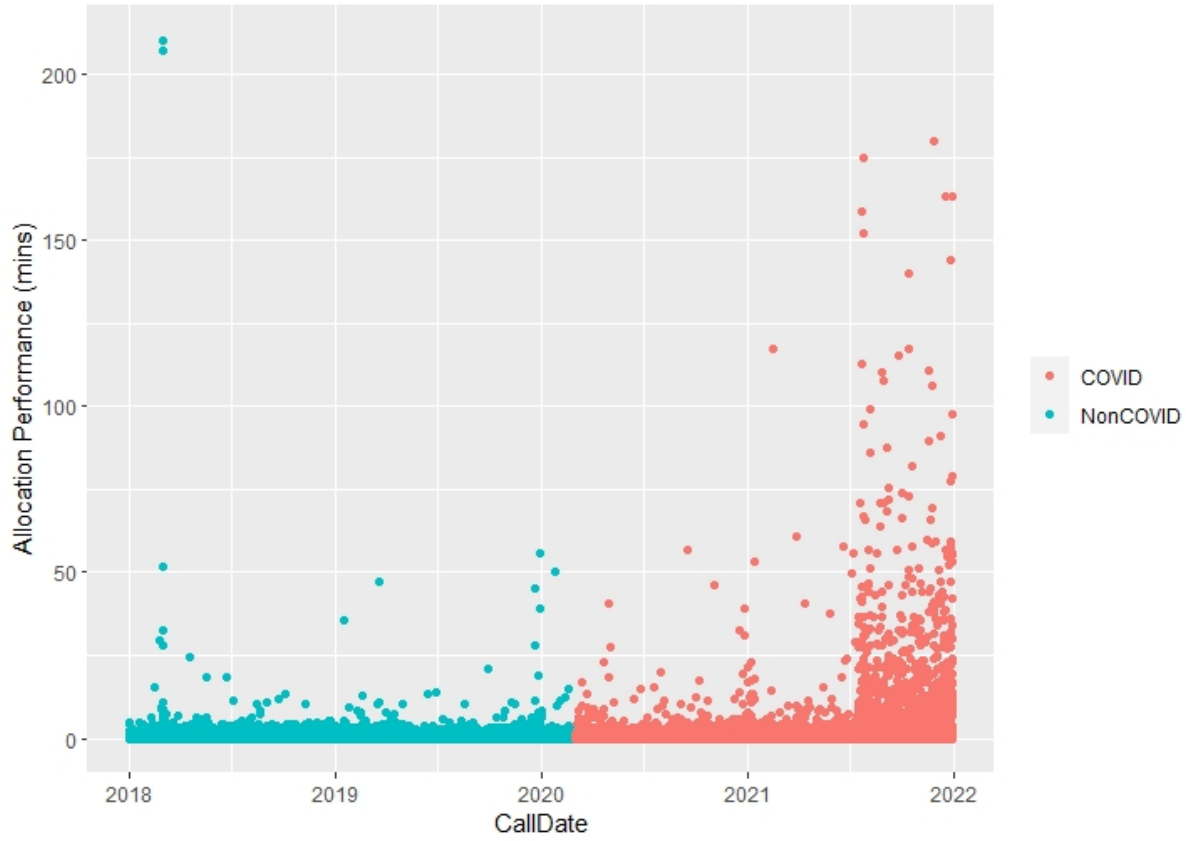
Allocation Performance

data: AllocationPerformance by CovidTime
t = 17.292, df = 26478, p-value < 0.00000000000000022
alternative hypothesis: true difference in means between group COVID and group NonCOVID is not equal to 0

95 percent confidence interval:
 42.90183 53.87101

sample estimates:
  mean in group COVID mean in group NonCOVID
             86.64729   38.26087

(a)



Appendix figure 4.15 (a) - Scatter plot of allocation performance during the pre-COVID-19 versus COVID-19 periods

Mobilisation performance

data: MobilisationPerformance by CovidTime

t = 12.848, df = 28990, p-value < 0.00000000000000022

alternative hypothesis: true difference in means between group COVID and group NonCOVID is not equal to 0

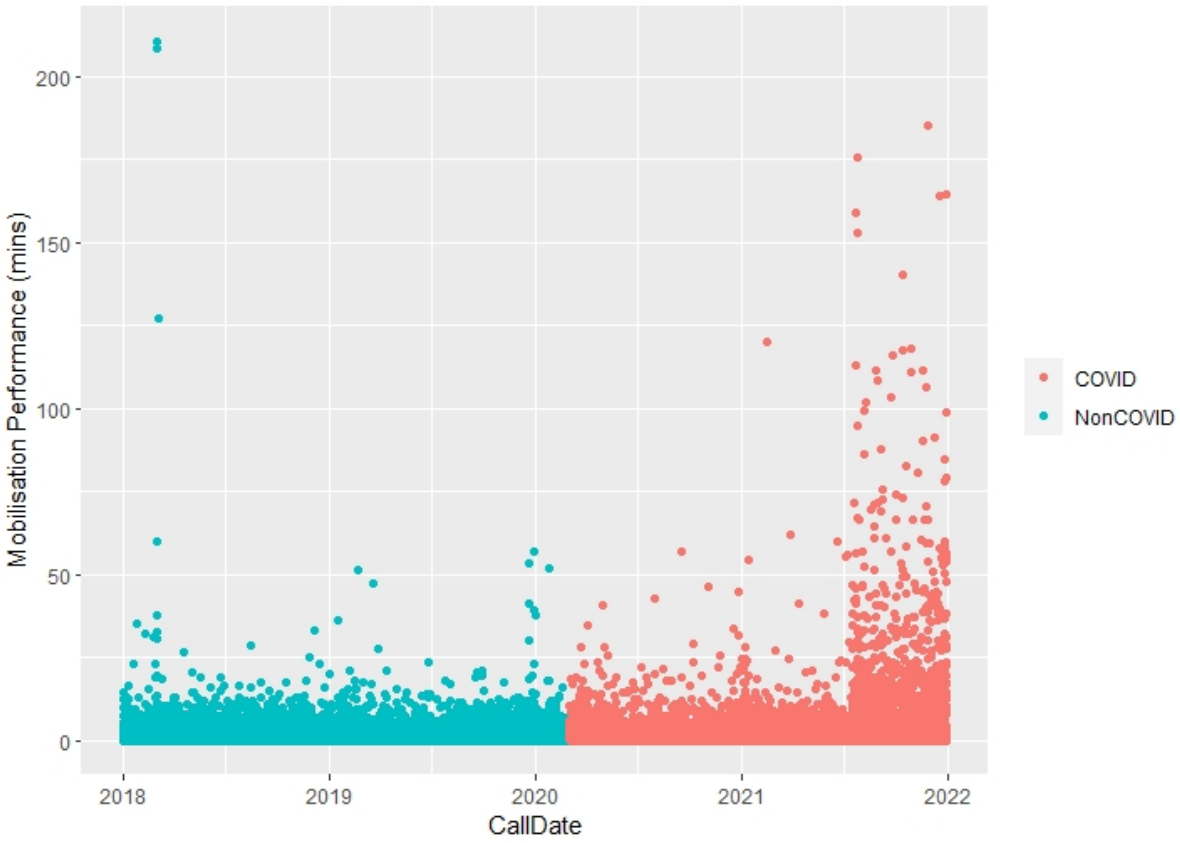
95 percent confidence interval:

33.78764 45.95207

sample estimates:

mean in group COVID	mean in group NonCOVID
159.2453	119.3754

(b)



Appendix figure 4.15 (b) - Scatter plot of mobilisation performance during the pre-COVID-19 versus COVID-19 periods

Response time

data: ResponseTime by CovidTime

t = 26.872, df = 37755, p-value < 0.00000000000000022

alternative hypothesis: true difference in means between group COVID and group NonCOVID is not equal to 0

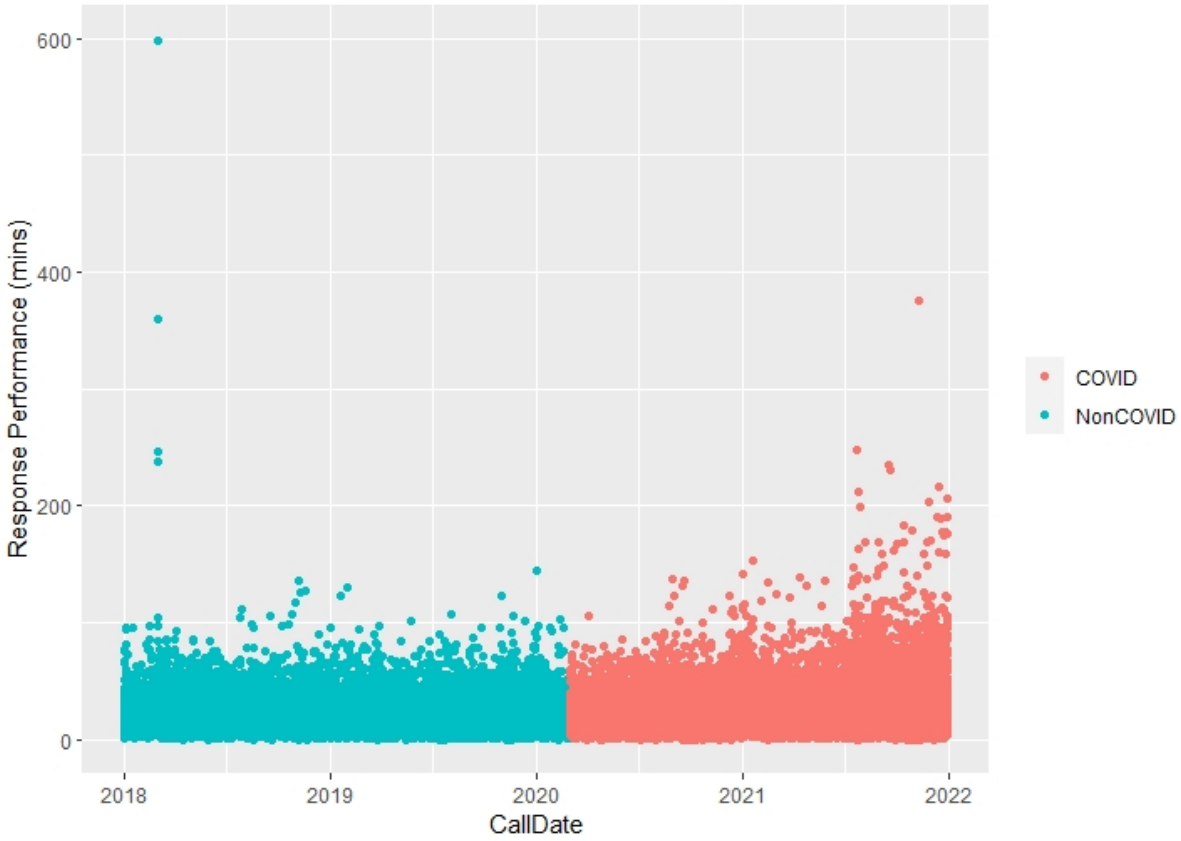
95 percent confidence interval:

252.9482 292.7506

sample estimates:

mean in group COVID	mean in group NonCOVID
1491.413	1218.563

(c)



Appendix figure 4.15 (c) - Scatter plot of response time during the pre-COVID-19 versus COVID-19 periods

On Scene Time

data: TimeonScene by CovidTime

t = 27.975, df = 36061, p-value < 0.00000000000000022

alternative hypothesis: true difference in means between group COVID and group NonCOVID is not equal to 0

95 percent confidence interval:

176.8572 203.5067

sample estimates:

mean in group COVID mean in group NonCOVID

1570.213 1380.031

(d)

Appendix 4.15 (d) - Scatter plot of on scene time during the pre-COVID-19 versus COVID-19 periods

Conveyance Time

data: ConveyanceTime by CovidTime
t = 5.5289, df = 36454, p-value = 0.00000003245
alternative hypothesis: true difference in means between group COVID and group NonCOVID is not equal to 0

95 percent confidence interval:
 41.28195 86.62670

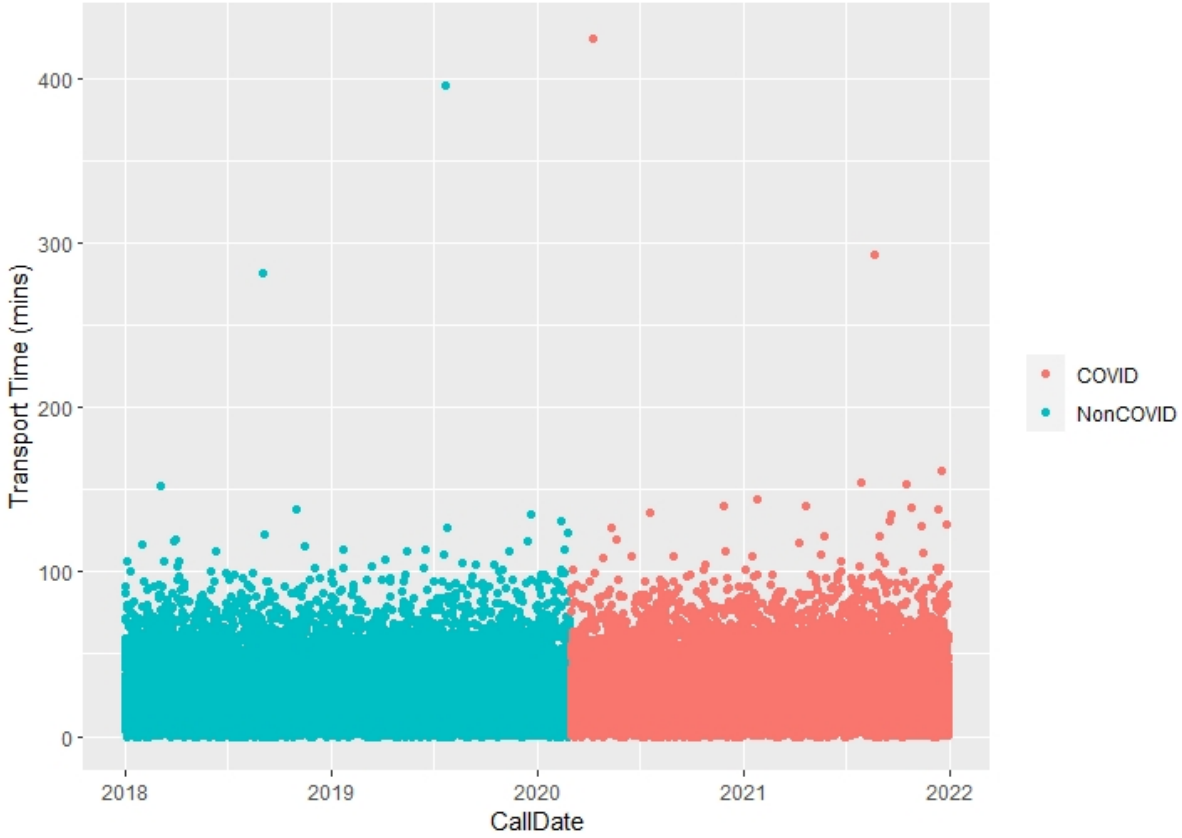
sample estimates:
  mean in group COVID mean in group NonCOVID
         1649.982   1586.027

There Is a significant difference in transport time between preCOVID and COVID. Transport time was faster preCOVID.

 (Intercept) WaveNumWave 1 WaveNumWave 2 WaveNumWave 3 WaveNumWave 4 WaveNumWave 5

 1586.027353   19.863214   13.184227   54.353053   136.888834   8.781001

(e)



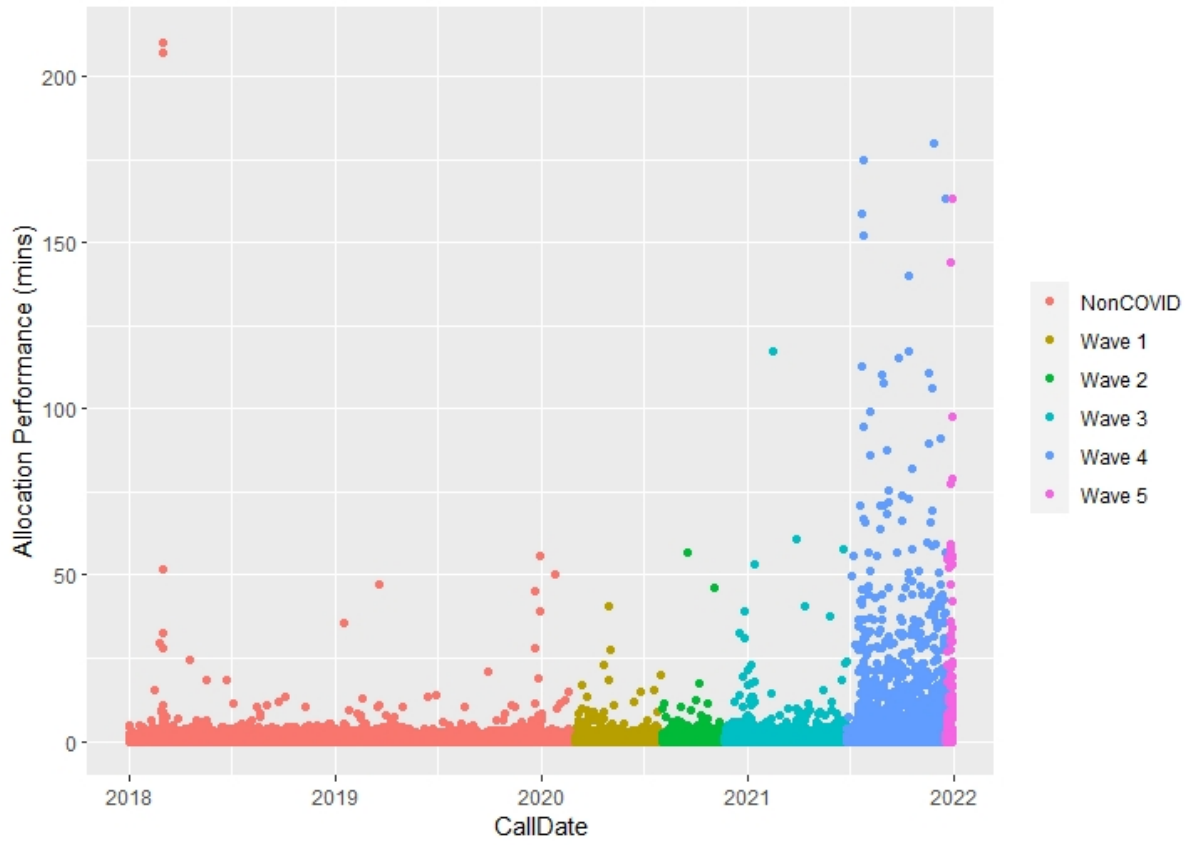
Appendix figure 4.15 (e) - Scatter plot of conveyance performance during the pre-COVID-19 versus COVID-19 periods

Allocation performance

```
 Intercept) WaveNumWave 1 WaveNumWave 2 WaveNumWave 3 WaveNumWave 4 WaveNumWave 5
  38.260870     4.239130     2.975542     7.442529   135.947982   247.796399

              Df     Sum Sq Mean Sq F Value             Pr(>F)
WaveNum        5 111434038 22286808   289.1 <0.0000000000000002 ***
Residuals  39995 3083676891    77102
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘’ 1
```

(f)



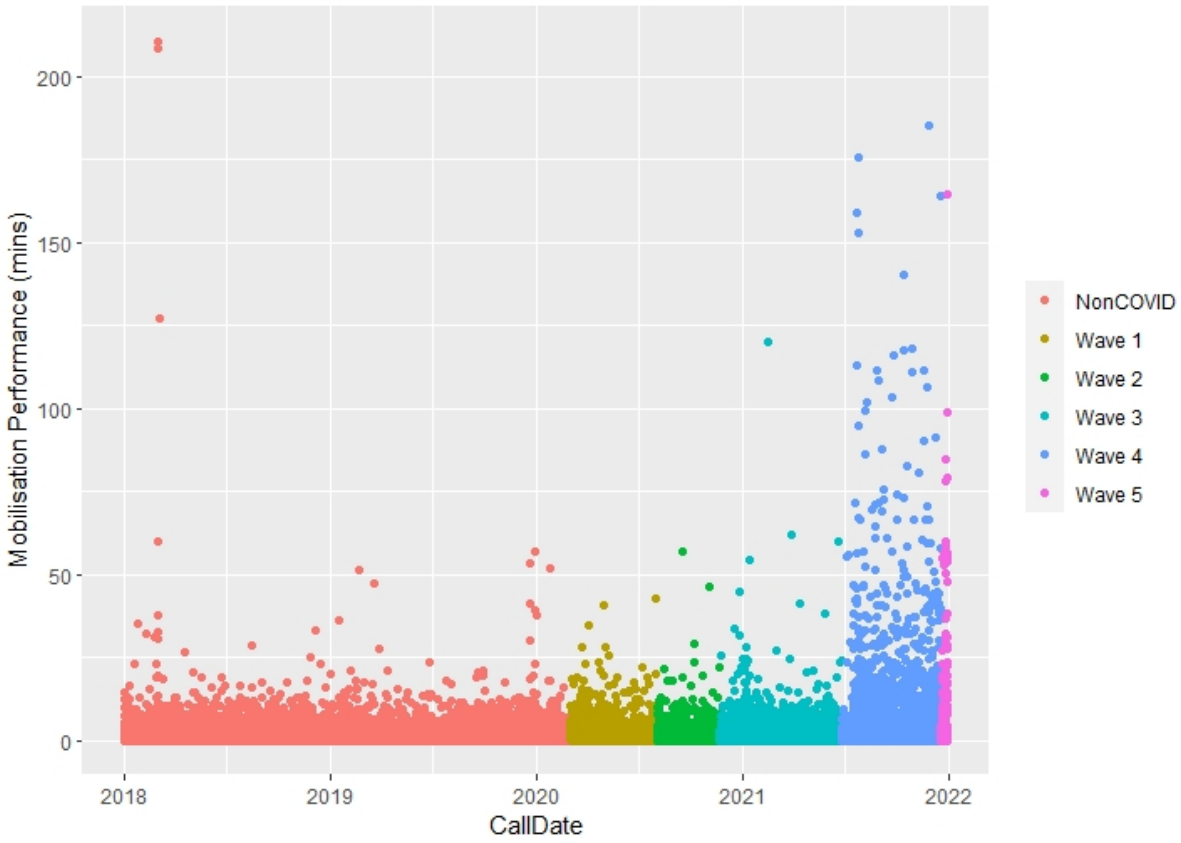
Appendix figure 4.15 (f) - Scatter plot of allocation performance during the pre-COVID-19 period versus the COVID-19 waves

Mobilisation Performance

```
(Intercept) WaveNumWave 1 WaveNumWave 2 WaveNumWave 3 WaveNumWave 4   WaveNumWave 5
119.375410     4.195838    -5.944500    -4.653992   127.300139   224.373489
```

```
              Df    Sum Sq Mean Sq F Value             Pr(>F)
WaveNum        5 100669185 20133837   211.5 <0.0000000000000002 ***
Residuals  39969 3804115951    95177
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘’ 1
```

(g)



Appendix figure 4.15 (g) - Scatter plot of mobilisation performance during the pre-COVID-19 period versus the COVID-19 waves

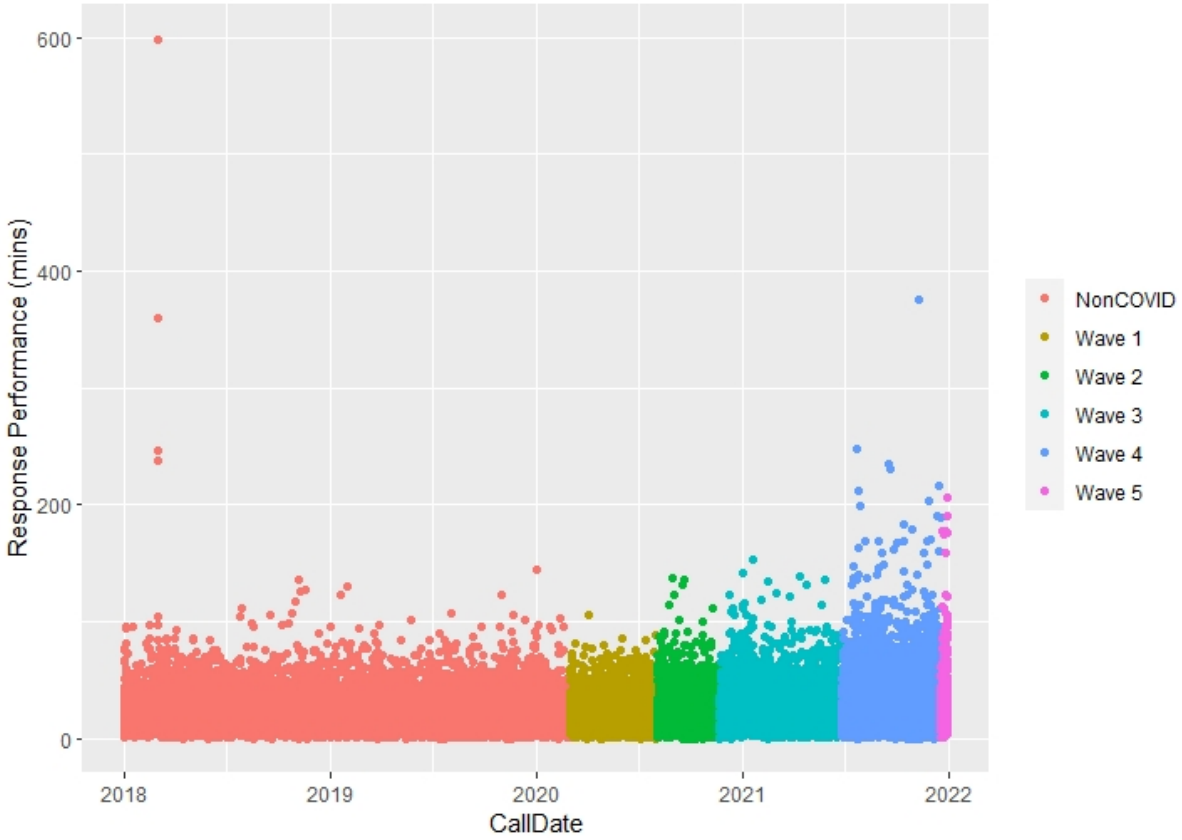
Response Time

(Intercept)	WaveNumWave 1	WaveNumWave 2	WaveNumWave 3	WaveNumWave 4	WaveNumWave 5
1218.56343	31.79199	95.21907	199.58949	580.13762	805.85267

	Df	Sum Sq	Mean Sq	F Value	Pr(>F)	
WaveNum	5	1764274973	352854995	353	<0.0000000000000002	***
Residuals	39637	39617951618	999519			

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(h)



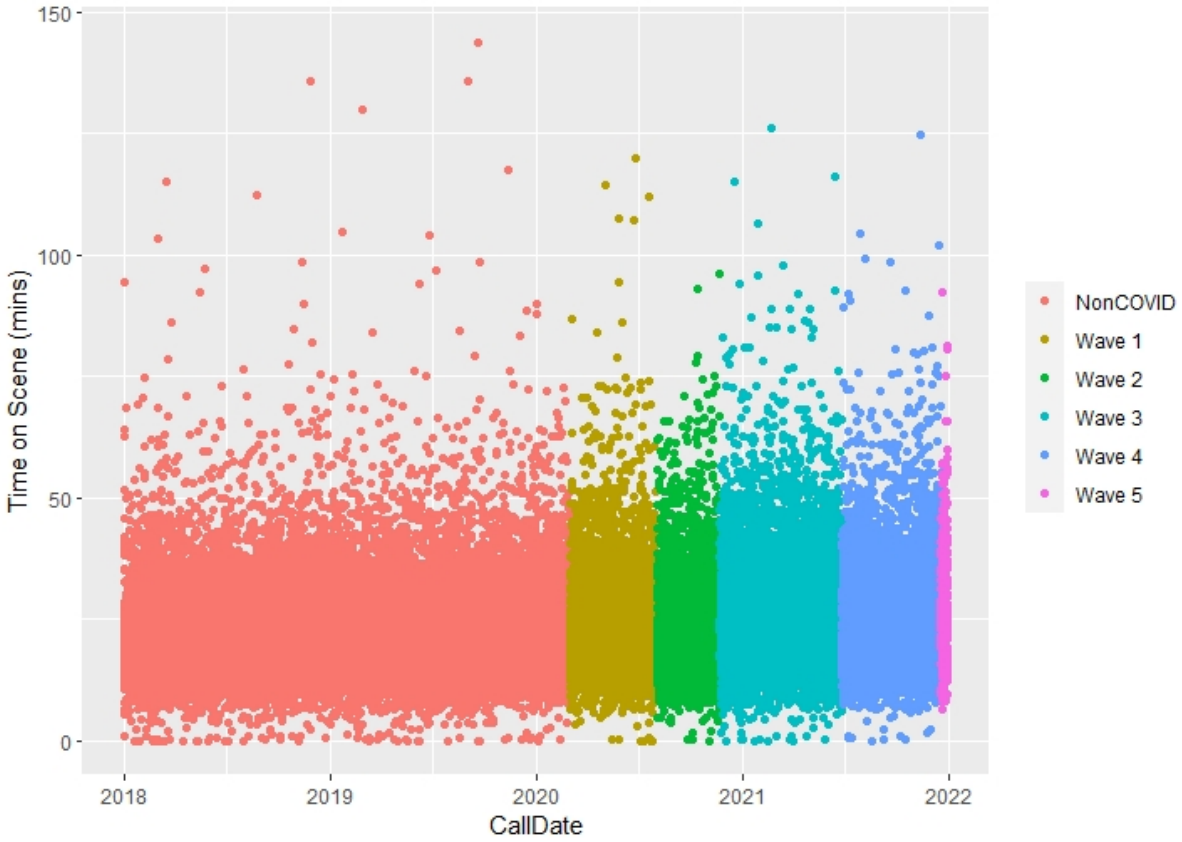
Appendix figure 4.15 (h) - Scatter plot of response time during the pre-COVID-19 period versus the COVID-19 waves

On scene time

```
(Intercept) WaveNumWave 1 WaveNumWave 2 WaveNumWave 3 WaveNumWave 4 WaveNumWave 5
  1380.0306     153.6506     134.2246     237.4035     177.7489     311.2028

              Df     Sum Sq Mean Sq F Value             Pr(>F)
WaveNum        5  364129521 72825904   173.1 <0.0000000000000002 ***
Residuals  36460 15339693603   420727
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘’ 1
```

(i)



Appendix figure 4.15 (i) - Scatter plot of time on scene during the pre-COVID-19 period versus the COVID-19 waves

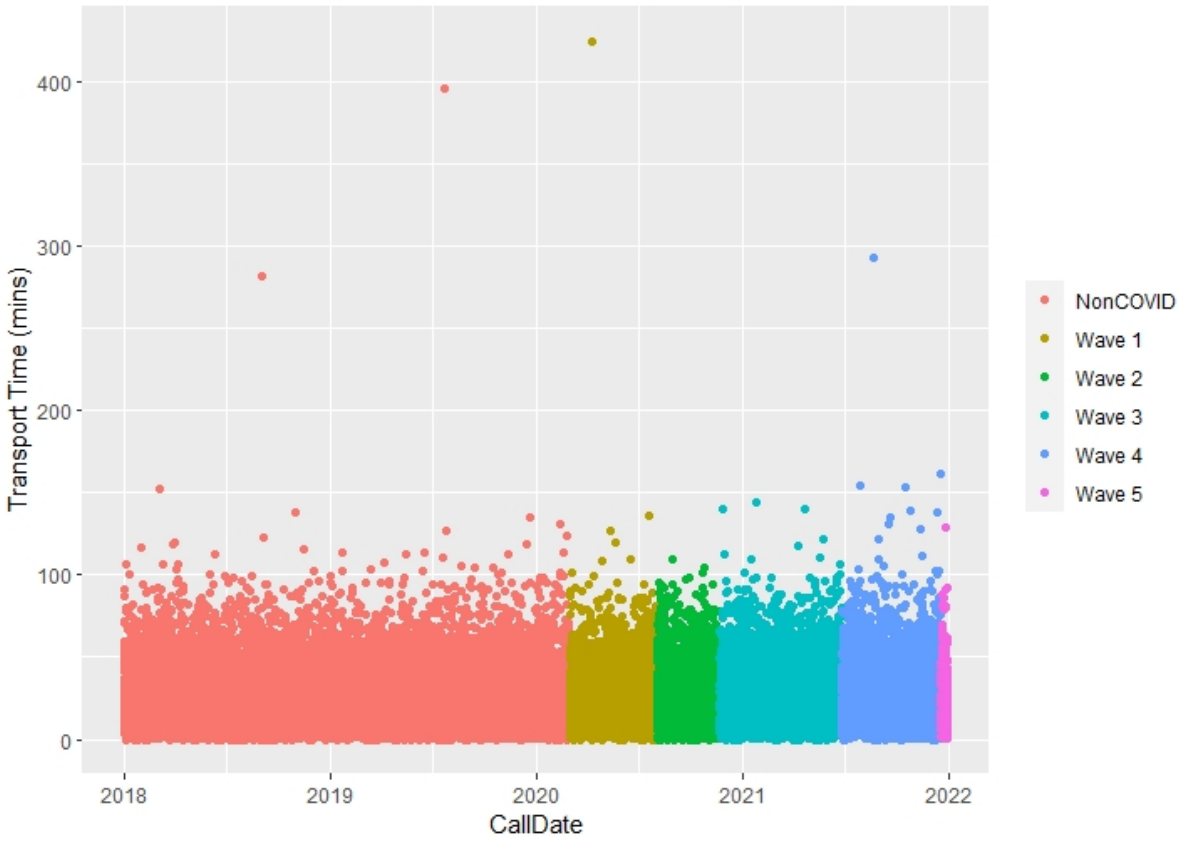
Conveyance Time

(Intercept) WaveNumWave 1 WaveNumWave 2 WaveNumWave 3 WaveNumWave 4 WaveNumWave 5
1586.027353 19.863214 13.184227 54.353053 136.888834 8.781001

	Df	Sum Sq	Mean Sq	F Value	Pr(>F)
WaveNum	5	80872763	16174553	13.27	0.000000000000599 ***
Residuals	36451	44416987754	1218540		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(j)



Appendix 4.15 (j) - Scatter plot of conveyance/performance time during the pre-COVID-19 period versus the COVID-19 waves

Appendix 4.16 - Results of the linear regressions models for the five-time intervals

Appendix table 3.16 (a) - Results of taking Log of Allocation Performance (removing 0 values with WaveNum)

Explanatory variable	Est.	S.E.	t-value	p-value
Intercept	3.21	0.03	114.32	<0.001
WaveNumWave 1	0.08	0.02	3.42	<0.001
WaveNumWave 2	0.07	0.02	2.95	<0.001
WaveNumWave 3	0.14	0.03	5.36	<0.001
WaveNumWave 4	0.63	0.03	20.99	<0.001
WaveNumWave 5	0.92	0.05	17.14	<0.001
DayQuarterAMLate	0.04	0.02	1.99	0.05
DayQuarterPMEarly	0.22	0.02	11.72	<0.001
DayQuarterPMLate	0.30	0.02	15.28	<0.001
CallMethodPublic Access	0.03	0.01	3.30	<0.001
NumResourceTwo or more	0.20	0.01	19.95	<0.001
StdTOCRed	0.16	0.17	0.96	0.34
LocationTypeRuralSettlement	-0.01	0.02	-0.74	0.46
LocationtypeUrban	0.01	0.01	1.45	1.15
AMPDSDescription Cerebrovascularhistory	0.02	0.03	0.79	0.43
AMPDSDescriptionNot Alert	-0.01	0.01	-0.48	0.63
AMPDSDescriptionSudden	0.03	0.01	2.01	0.04
AMPDSDescriptionUnknown	0.08	0.07	1.12	0.26
TimeStatusLess than 4 hours	-0.16	0.17	-0.91	0.36
TimeStatusUnknown	-0.03	0.02	-1.19	0.24
MonthlyEmergencyCalls	0.05	0.01	6.55	<0.001
MonthlyTraffic	-0.01	0.01	-1.71	0.09
NumDays	-0.00	0.00	-4.41	<0.001

*In this model when all other variables are held constant all the Wave Numbers show a significant increase in log of Allocation Performance compared to pre-COVID, while date of call is significantly negatively associated with log of Allocation Performance

MODEL INFO:

Observations: 35585

Dependent Variable: AllocationPerformance

Type: OLS linear regression

MODEL FIT:

F (22,35562) = 156.86, p = 0.00

R^2 = 0.09

Adj. R^2 = 0.09

Appendix Table 3.16 (b) - Results of taking Log of Mobilisation Performance (removing 0 values with WaveNum)

Explanatory variable	Est.	S.E.	t-value	p-value
Intercept	4.65	0.03	181.09	<0.001
WaveNumWave 1	0.08	0.02	3.74	<0.001
WaveNumWave 2	0.05	0.02	2.26	0.02
WaveNumWave 3	0.03	0.02	1.17	0.24
WaveNumWave 4	0.35	0.03	12.95	<0.001
WaveNumWave 5	0.44	0.05	8.92	<0.001
DayQuarterAMLate	-0.10	0.02	-5.53	<0.001
DayQuarterPMEarly	-0.11	0.02	-6.44	<0.001
DayQuarterPMLate	-0.03	0.02	-1.56	0.12
CallMethodPublic Access	-0.00	0.01	-0.05	0.96
NumResourceTwo or more	0.19	0.01	20.31	<0.001
StdTOCRed	-0.16	0.16	-1.01	0.31
LocationTypeRuralsettlement	0.00	0.01	0.03	0.98
LocationTypeUrban	-0.03	0.01	-3.34	<0.001
AMPDSDescription Cerebrovascularhistory	0.03	0.03	1.15	0.25
AMPDSDescriptionNot Alert	-0.01	0.01	-0.72	0.47
AMPDSDescriptionSudden	0.03	0.01	1.95	0.05
AMPDSDescriptionUnknown	0.02	0.06	0.27	0.79
TimeStatusLess than 4 hours	0.14	0.16	0.91	0.36
TimeStatusUnknown	-0.05	0.02	-2.09	0.04
MonthlyEmergencyCalls	-0.00	0.01	-0.27	0.79
MonthlyTraffic	-0.03	0.01	-5.83	<0.001
NumDays	-0.00	0.00	-6.31	<0.001

MODEL INFO:

Observations: 38324

Dependent Variable: MobilisationPerformance

Type: OLS linear regression

MODEL FIT:

F (22,38301) = 48.28, p = 0.00

R^2 = 0.03

Adj. R^2 = 0.03

Appendix Table 4.16 (c) - Results of taking Log of Response Time (removing 0 values with WaveNum)

Explanatory variable	Est.	S.E.	t-value	p-value
Intercept	7.22	0.02	335.30	<0.001
WaveNumWave 1	0.06	0.02	3.67	<0.001
WaveNumWave 2	0.10	0.02	5.14	<0.001
WaveNumWave 3	0.21	0.02	10.67	<0.001
WaveNumWave 4	0.38	0.02	16.76	<0.001
WaveNumWave 5	0.46	0.04	11.19	<0.001
DayQuarterAMLate	-0.02	0.01	-1.67	0.09
DayQuarterPMEarly	0.06	0.01	4.00	<0.001
DayQuarterPMLate	0.09	0.02	6.23	<0.001
CallMethodPublic Access	-0.02	0.01	-2.01	0.04
NumResourceTwo or more	0.18	0.01	23.79	<0.001
StdTOCRed	-0.23	0.13	-1.69	0.09
LocationTypeRuralsettlement	-0.06	0.01	-5.07	<0.001
LocationTypeUrban	-0.49	0.01	-65.26	<0.001
AMPDSDescription Cerebrovascularhistory	-0.02	0.02	-0.72	0.47
AMPDSDescriptionNot Alert	-0.05	0.01	-4.56	<0.001
AMPDSDescriptionSudden	-0.01	0.01	-0.81	0.42
AMPDSDescriptionUnknown	-0.17	0.05	-3.24	<0.001
TimeStatusLess than 4 hours	0.15	0.13	1.14	0.25
TimeStatusUnknown	-0.08	0.02	-4.49	<0.001
MonthlyEmergencyCalls	0.03	0.01	5.84	<0.001
MonthlyTraffic	-0.00	0.00	-0.94	0.35
NumDays	-0.00	0.00	-5.14	<0.001

MODEL INFO:

Observations: 39567

Dependent Variable: ResponseTime

Type: OLS linear regression

MODEL FIT:

F (22,39544) = 313.05, p = 0.00

R^2 = 0.15

Adj. R^2 = 0.15

Appendix Table 4.16 (d) - Results of taking Log of On Scene Time (removing 0 values with WaveNum)

Explanatory variable	Est.	S.E.	t-value	p-value
Intercept	7.17	0.01	488.36	<0.001
WaveNumWave 1	0.04	0.01	3.41	<0.001
WaveNumWave 2	0.02	0.01	1.70	0.09
WaveNumWave 3	0.06	0.01	4.71	<0.001
WaveNumWave 4	0.02	0.02	1.55	0.12
WaveNumWave 5	0.06	0.03	2.21	0.03
DayQuarterAMLate	-0.02	0.01	-1.78	0.08
DayQuarterPMEarly	-0.02	0.01	-2.40	0.02
DayQuarterPMLate	-0.02	0.01	-2.09	0.04
CallMethodPublic Access	0.02	0.01	4.42	<0.001
NumResourceTwo or more	-0.00	0.01	-0.07	0.95
StdTOCRed	0.22	0.10	-1.69	0.09
LocationTypeRuralsettlement	-0.05	0.01	-6.01	<0.001
LocationTypeUrban	-0.07	0.01	-14.42	<0.001
AMPDSDescription Cerebrovascularhistory	0.05	0.02	3.28	<0.001
AMPDSDescriptionNot Alert	0.08	0.01	10.81	<0.001
AMPDSDescriptionSudden	-0.05	0.01	-6.23	<0.001
AMPDSDescriptionUnknown	-0.02	0.04	-0.53	0.6
TimeStatusLess than 4 hours	-0.26	0.10	-2.49	0.01
TimeStatusUnknown	-0.08	0.02	-4.49	<0.001
MonthlyEmergencyCalls	-0.00	0.00	-0.76	0.45
MonthlyTraffic	-0.02	0.00	-5.30	<0.001
NumDays	0.00	0.00	6.75	<0.001

MODEL INFO:

Observations: 36394 (3537 missing obs. deleted)

Dependent Variable: TimeonScene

Type: OLS linear regression

MODEL FIT:

F (22,36371) = 85.05, p = 0.00

R^2 = 0.05

Adj. R^2 = 0.05

Appendix Table 4.16 (e) - Results of taking Log of Conveyance Time (removing 0 values with WaveNum)

Explanatory variable	Est.	S.E.	t-value	p-value
Intercept	7.50	0.03	273.57	<0.001
WaveNumWave 1	0.01	0.02	0.52	0.6
WaveNumWave 2	0.04	0.02	1.73	0.08
WaveNumWave 3	0.06	0.03	2.39	0.02
WaveNumWave 4	0.10	0.03	3.33	<0.001
WaveNumWave 5	0.08	0.05	1.50	0.13
DayQuarterAMLate	0.06	0.02	2.90	<0.001
DayQuarterPMEarly	0.13	0.02	7.14	<0.001
DayQuarterPMLate	-0.02	0.01	-2.09	0.04
CallMethodPublic Access	-0.05	0.01	-4.75	<0.001
NumResourceTwo or more	0.02	0.01	2.43	0.02
StdTOCRed	-0.09	0.19	-0.44	0.66
LocationTypeRuralsettlement	0.02	0.02	1.36	0.17
LocationTypeUrban	-0.74	0.01	-77.53	<0.001
AMPDSDescription Cerebrovascularhistory	-0.01	0.03	-0.28	0.78
AMPDSDescriptionNot Alert	-0.08	0.01	-5.59	<0.001
AMPDSDescriptionSudden	0.02	0.01	1.43	0.15
AMPDSDescriptionUnknown	0.05	0.07	0.73	0.46
TimeStatusLess than 4 hours	0.03	0.19	0.14	0.89
TimeStatusUnknown	-0.08	0.02	-3.13	<0.001
MonthlyEmergencyCalls	0.01	0.01	1.33	0.18
MonthlyTraffic	0.01	0.01	2.35	0.02
NumDays	00.00	0.00	-1.14	0.26

MODEL INFO:

Observations: 36336

Dependent Variable: TransportTime

Type: OLS linear regression

MODEL FIT:

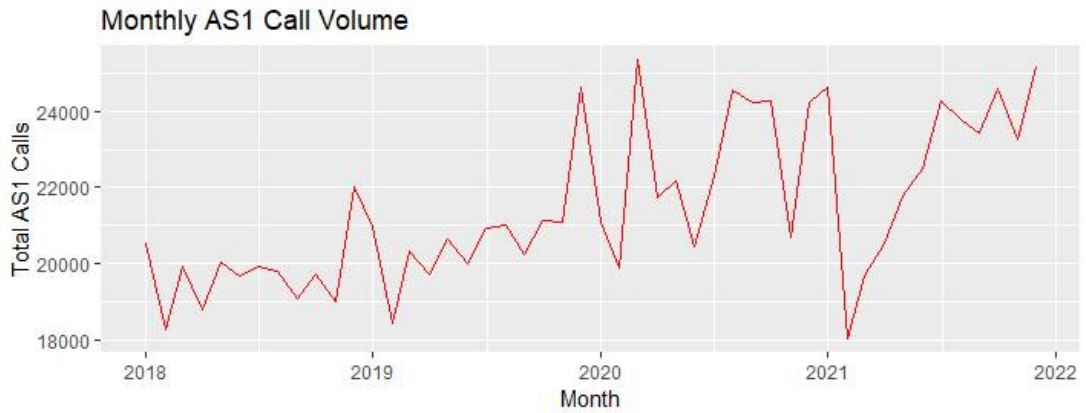
F (22,36313) = 336.48, p = 0.00

R^2 = 0.17

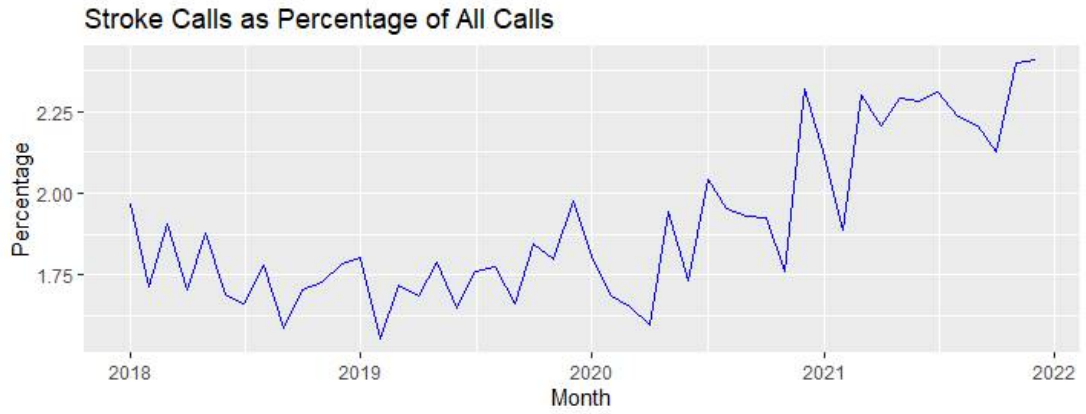
Adj. R^2 = 0.17

Appendix 4.17 - Total monthly emergency calls compared to monthly suspected stroke/TIA calls from 2018-2021

(a)

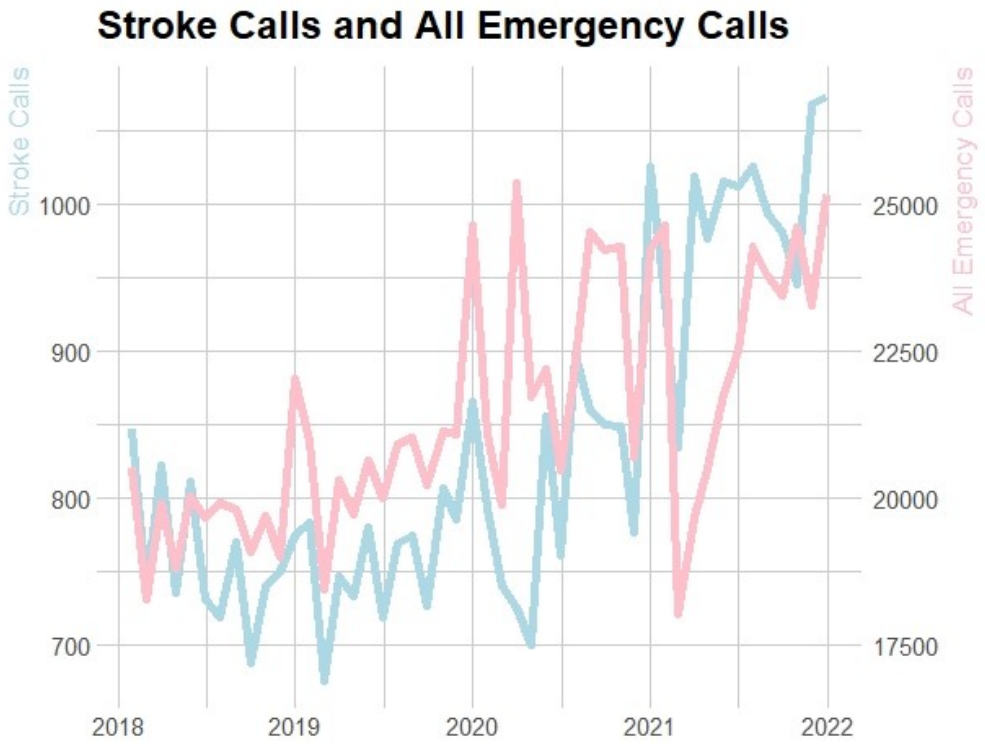


(b)

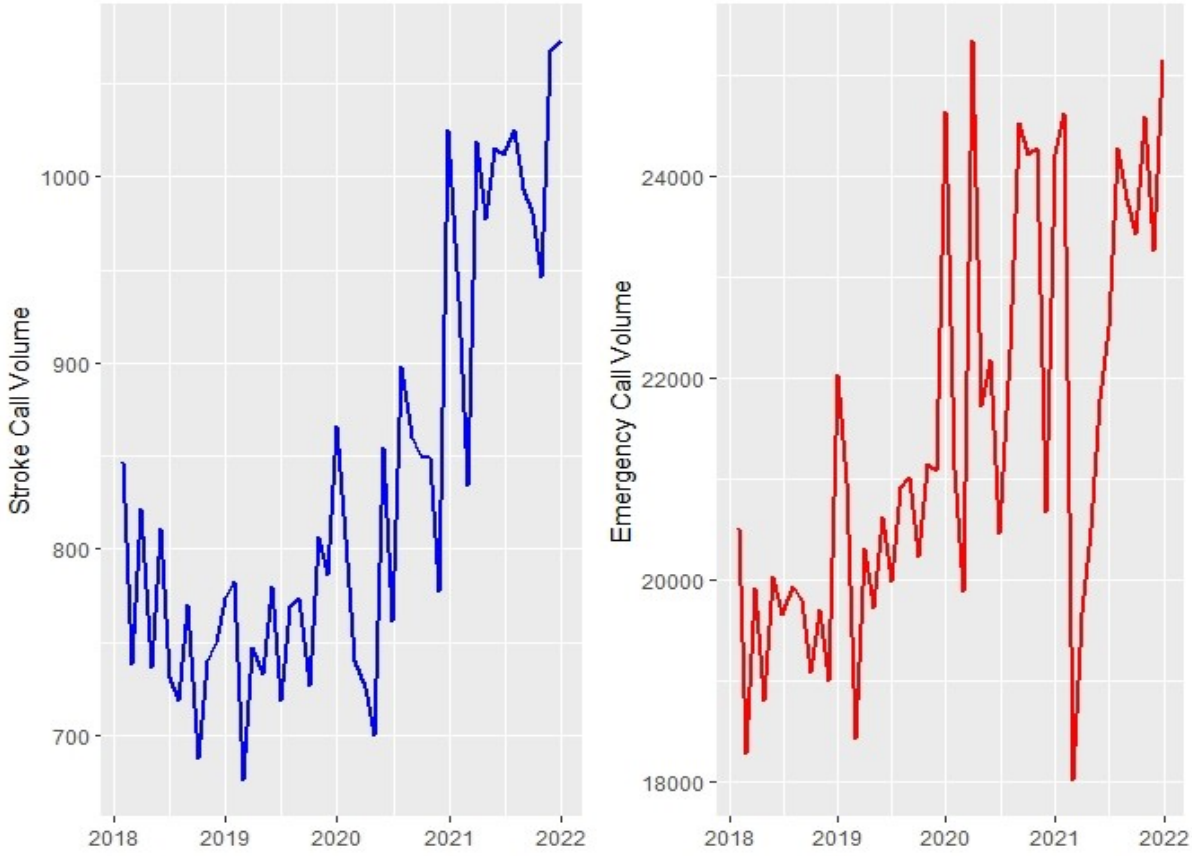


Appendix figure 4.17 (a) overall monthly emergency call volume for 2018-2021 (b) suspected stroke/TIA call volume for 2018-2021

(c)



(d)



Appendix figure 4.17 (c) and (d) monthly emergency stroke calls compared to monthly suspected stroke/TIA calls for 2018-2021

Appendix 4.18 - Weekly call volume per calendar week, ISO week, and epidemiological week for 2018-2021

ISO Year	ISO Week	Volume	Calendar Year	Calendar Week	Volume	Epidemiological Year	Epidemiological Week	Volume
2018	1	213	2018	1	213	2018	1	180
	2	175		2	175		2	185
	3	199		3	199		3	204
	4	184		4	184		4	178
	5	181		5	181		5	184
	6	185		6	185		6	178
	7	202		7	202		7	191
	8	181		8	181		8	201
	9	184		9	184		9	173
	10	197		10	197		10	199
	11	178		11	178		11	183
	12	187		12	187		12	184
	13	160		13	160		13	167
	14	188		14	188		14	180
	15	185		15	185		15	193
	16	174		16	174		16	169
	17	151		17	151		17	143
	18	171		18	171		18	178
	19	185		19	185		19	181
	20	208		20	208		20	200
	21	162		21	162		21	174
	22	165		22	165		22	164
	23	181		23	181		23	180
	24	176		24	176		24	179
	25	171		25	171		25	172
	26	174		26	174		26	165
	27	161		27	161		27	166
	28	156		28	156		28	160
	29	160		29	160		29	157
	30	164		30	164		30	172
	31	155		31	155		31	156
	32	168		32	168		32	163
	33	200		33	200		33	195
	34	174		34	174		34	179
	35	178		35	178		35	167
	36	159		36	159		36	167
	37	157		37	157		37	156
	38	162		38	162		38	157
	39	151		39	151		39	157
	40	173		40	173		40	172
	41	168		41	168		41	159
	42	166		42	166		42	182

	43	153		43	153		43	146
	44	179		44	179		44	185
	45	187		45	187		45	181
	46	172		46	172		46	170
	47	171		47	171		47	173
	48	173		48	173		48	173
	49	179		49	179		49	181
	50	166		50	166		50	167
	51	170		51	170		51	171
	52	187		52	187		52	188
2019	1	180		53	20	2019	1	184
	2	207	2019	1	195		2	195
	3	156		2	197		3	166
	4	160		3	145		4	153
	5	176		4	186		5	178
	6	170		5	159		6	172
	7	169		6	170		7	165
	8	173		7	179		8	183
	9	167		8	166		9	151
	10	168		9	163		10	182
	11	153		10	171		11	160
	12	172		11	152		12	162
	13	175		12	175		13	166
	14	184		13	171		14	185
	15	153		14	196		15	158
	16	174		15	138		16	170
	17	176		16	188		17	185
	18	163		17	165		18	160
	19	191		18	162		19	192
	20	178		19	192		20	169
	21	169		20	182		21	182
	22	171		21	171		22	165
	23	153		22	166		23	176
	24	154		23	155		24	133
	25	193		24	156		25	182
	26	173		25	199		26	182
	27	178		26	168		27	181
	28	168		27	168		28	155
	29	157		28	175		29	166
	30	177		29	152		30	170
	31	174		30	186		31	188
	32	164		31	159		32	150
	33	169		32	173		33	174
	34	197		33	185		34	201
	35	184		34	181		35	181
	36	178		35	190		36	174
	37	167		36	180		37	176
	38	164		37	151		38	154
	39	163		38	173		39	171

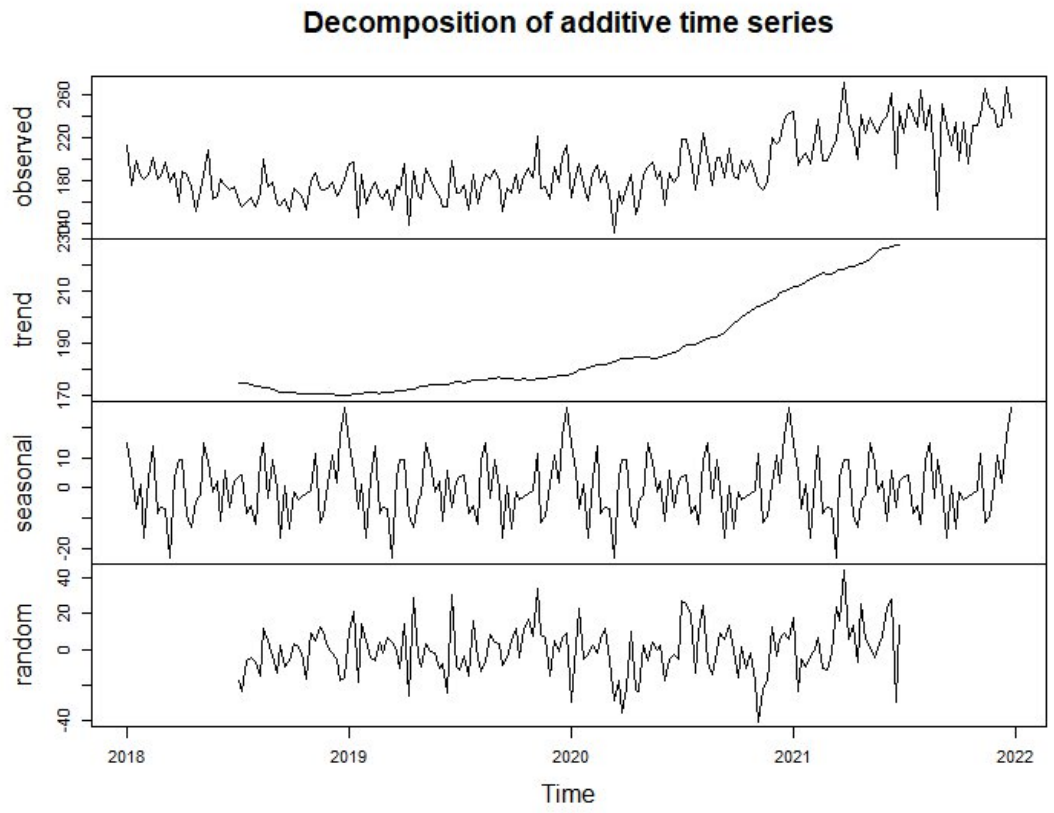
	40	187		39	168		40	178
	41	174		40	186		41	186
	42	181		41	168		42	171
	43	190		42	184		43	192
	44	182		43	191		44	185
	45	215		44	183		45	206
	46	185		45	222		46	201
	47	172		46	173		47	162
	48	162		47	174		48	164
	49	193		48	163		49	195
	50	174		49	193		50	166
	51	202		50	178		51	198
	52	203		51	201		52	216
2020	1	189		52	209	2020	1	192
	2	180		53	34		2	170
	3	193	2020	1	164		3	198
	4	166		2	186		4	190
	5	174		3	196		5	154
	6	190		4	176		6	183
	7	189		5	161		7	191
	8	183		6	187		8	184
	9	172		7	194		9	162
	10	188		8	179		10	196
	11	142		9	188		11	146
	12	145		10	169		12	140
	13	171		11	131		13	179
	14	168		12	170		14	169
	15	177		13	158		15	167
	16	161		14	172		16	167
	17	166		15	186		17	159
	18	169		16	149		18	163
	19	206		17	157		19	209
	20	171		18	185		20	183
	21	199		19	193		21	191
	22	184		20	197		22	188
	23	163		21	182		23	165
	24	191		22	189		24	186
	25	176		23	157		25	183
	26	177		24	187		26	180
	27	209		25	178		27	195
	28	219		26	184		28	222
	29	210		27	219		29	214
	30	157		28	219		30	158
	31	213		29	201		31	209
	32	208		30	171		32	201
	33	209		31	189		33	216
	34	172		32	225		34	177
	35	183		33	200		35	182
	36	210		34	175		36	210

	37	194		35	201		37	187
	38	205		36	202		38	209
	39	177		37	183		39	172
	40	199		38	210		40	201
	41	189		39	184		41	186
	42	206		40	182		42	213
	43	174		41	198		43	172
	44	198		42	188		44	204
	45	173		43	199		45	168
	46	173		44	185		46	180
	47	174		45	176		47	178
	48	212		46	171		48	201
	49	209		47	179		49	213
	50	236		48	220		50	231
	51	227		49	215		51	224
	52	219		50	217		52	222
	53	258		51	237		53	254
2021	1	219		52	230	2021	1	237
	2	200		53	83		2	184
	3	212	2021	1	244		3	219
	4	203		2	194		4	200
	5	205		3	200		5	204
	6	214		4	205		6	202
	7	230		5	195		7	235
	8	185		6	219		8	192
	9	205		7	237		9	208
	10	221		8	198		10	204
	11	236		9	199		11	232
	12	233		10	208		12	240
	13	267		11	218		13	273
	14	231		12	238		14	228
	15	214		13	272		15	214
	16	213		14	234		16	220
	17	229		15	225		17	231
	18	237		16	200		18	232
	19	247		17	242		19	234
	20	196		18	225		20	211
	21	246		19	239		21	239
	22	251		20	228		22	252
	23	233		21	225		23	232
	24	243		22	236		24	252
	25	210		23	240		25	195
	26	230		24	261		26	239
	27	248		25	192		27	255
	28	233		26	244		28	224
	29	231		27	224		29	229
	30	227		28	252		30	230
	31	242		29	242		31	246
	32	235		30	230		32	225

	33	249		31	264		33	255
	34	183		32	227		34	189
	35	197		33	250		35	197
	36	254		34	201		36	253
	37	228		35	153		37	238
	38	215		36	251		38	208
	39	212		37	231		39	237
	40	231		38	213		40	231
	41	206		39	234		41	206
	42	217		40	199		42	217
	43	218		41	235		43	218
	44	252		42	195		44	252
	45	256		43	231		45	256
	46	250		44	232		46	250
	47	235		45	242		47	235
	48	241		46	266		48	241
	49	234		47	249		49	234
	50	253		48	246		50	253
	51	248		49	227		51	248
	52	172		50	227		52	172
				51	266			
				52	240			
				53	32			

*Note that when graphing the above data, for the calendar weeks we have incorporated weeks 52 and 53 into the same week, adjusting for the extra days.

Appendix 4.19 - Graph of decomposition of the additive weekly time series of call volume from 2018-2021



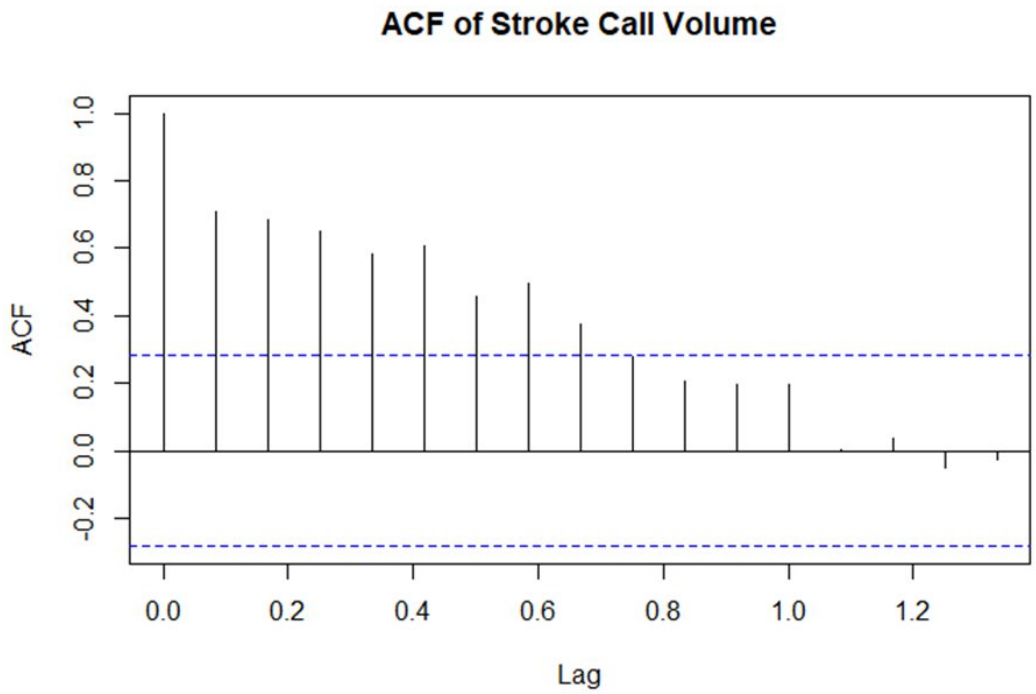
Appendix figure 4.19 - The above is a decomposition of the time series for weekly call volume. The trend indicates slow increase in stroke call volume for 2018 and 2019 with a much more rapid increase in volume during 2020 and particularly 2021.

Appendix 4.20 - Suspected adult stroke/TIA calls per day during the pre-COVID-19 and COVID-19 period

Time Period	Date From	Date To	Total days	Total Calls	Calls per Day
Pre-COVID-19	1/1/2018	29/2/2020	790	19826	25.1
Wave 1	1/03/2020	01/08/2020	154	3969	25.8
Wave 2	2/08/2020	21/11/2020	112	3056	27.3
Wave 3	22/11/2020	26/06/2021	217	6915	31.9
Wave 4	27/06/2021	18/12/2021	175	5784	33.1
Wave 5 (partial)	19/12/2021	31/12/2021	13	454	35
Total COVID-19 period	01/03/2020	31/12/2021	671	20178	30.1

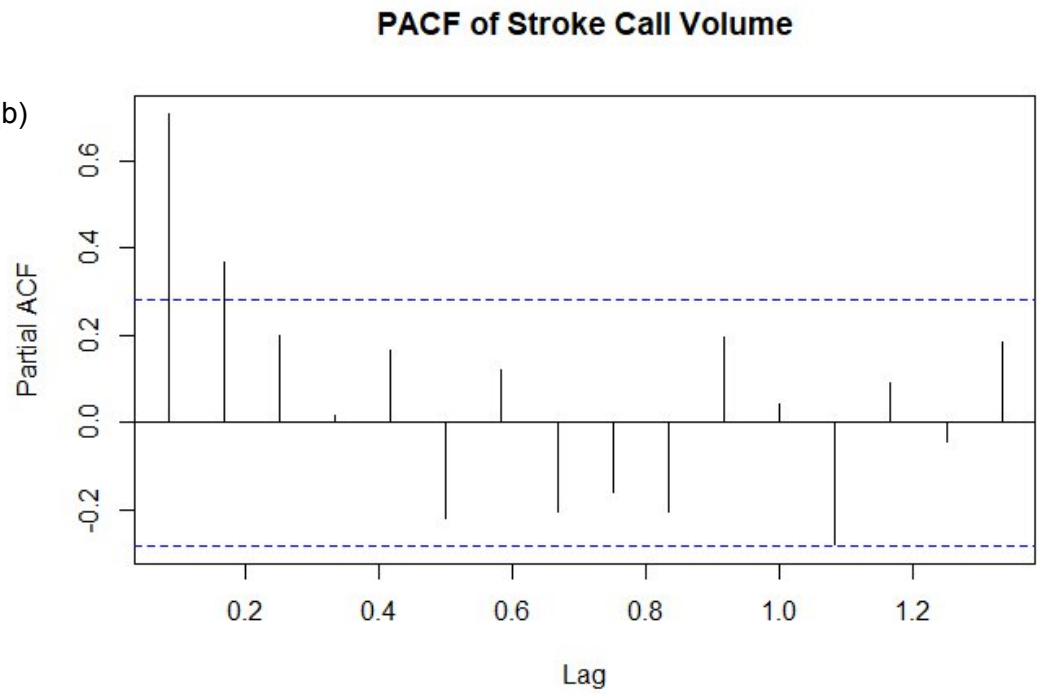
Appendix 4.21 - Graphs of the residuals from the ARIMA model on call volume

(a)



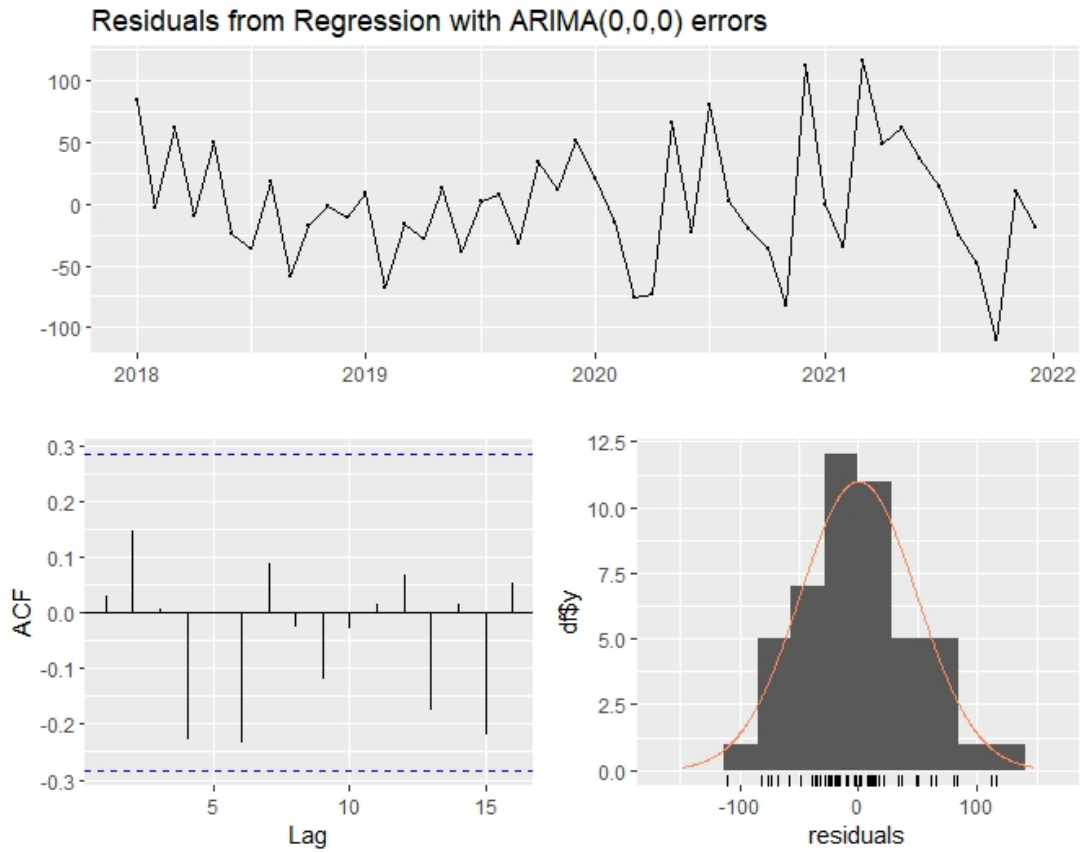
Appendix figure 4.21 (a) - Graph of the autocorrelation function (ACF) of the time series

(b)



Appendix figure 4.12 (b) - Graph of the partial autocorrelation function (PACF) of the time series

Appendix 4.22 - Residual plots from ARIMA model



Appendix figure 4.22 - Residual plots from ARIMA model

Appendix 4.23 - Results of the z test the coefficients of the ARIMA model of best fit for monthly “code 28” call volume between the COVID-19 and pre-COVID-19 period

Variable	Estimate	Std Error	z value	Pr(>|z|)
Intercept	519.64	94.03	5.53	0.001***
COVID Abrupt	-29.66	31.85	-0.93	0.352
COVID Gradual	13.80	1.79	7.7	0.001***
Total Emergency Calls	0.01	0.004	2.56	0.011*
Average Air Pollution	0.56	1.75	0.32	0.750

Significance codes ***0.001, **0.01, *0.05

Appendix 4.24 - ARIMA model (0,0,0) actual and predicted suspected stroke/TIA call volume for the COVID-19 period

Month	Actual	Predicted
March 2020	726	883
April 2020	700	792
May 2020	855	799
June 2020	761	757
July 2020	898	800
August 2020	860	857
September 2020	850	852
October 2020	849	855
November 2020	777	768
December 2020	1025	857
January 2021	934	870
February 2021	834	700
March 2021	1019	744
April 2021	977	768
May 2021	1015	794
June 2021	1012	811
July 2021	1025	858
August 2021	993	844
September 2021	981	838
October 2021	946	866
November 2021	1068	838
December 2021	1073	883

Appendix 4.25 - Outputs from chapter 4

Publications

Title	Date of Publication	Authors	Link
Temporal trends of ambulance time intervals for suspected stroke/transient ischaemic attack (TIA) before and during the COVID-19 pandemic in Ireland: a quasi-experimental study	20th March 2024 (paper)	Burton E Quinn R Crosbie-Staunton K Deasy C Masterson S O'Donnell C Merwick Á Willis D Kearney PM Mc Carthy VJC Buckley CM	Temporal trends of ambulance time intervals for suspected stroke/transient ischaemic attack (TIA) before and during the COVID-19 pandemic in Ireland: a quasi-experimental study | BMJ Open
Temporal trends of ambulance time intervals for suspected stroke/transient ischaemic attack (TIA) before and during the COVID-19 pandemic in Ireland: a quasi-experimental study	June 2023 (abstract)	Burton E Quinn R Crosbie-Staunton K Deasy C Masterson S O'Donnell C Merwick Á Willis D Kearney PM Mc Carthy VJC Buckley CM	Temporal Trends of Ambulance Times for Suspected Stroke/Transient Ischemic Attack (TIA) Before and During the COVID-19 Pandemic in Ireland: A Quasi-experimental Study | Prehospital and Disaster Medicine | Cambridge Core

Conferences

Title	Conference	Date	Type	Authors
Temporal trends of ambulance time intervals for suspected stroke/transient ischaemic attack (TIA) before and during the COVID-19 pandemic in Ireland: a quasi-experimental study	Prehospital Emergency Care Council Conference	November 2023	Poster presentation	Burton E Quinn R Crosbie-Staunton K Deasy C Masterson S O'Donnell C Merwick Á Willis D Kearney PM Mc Carthy VJC Buckley CM
Temporal trends of ambulance time intervals for suspected stroke/transient ischaemic attack (TIA) before and during the COVID-19 pandemic in Ireland: a quasi-experimental study	Prehospital Emergency Care Council	November 2023	Oral presentation	Burton E Quinn R Crosbie-Staunton K Deasy C Masterson S O'Donnell C Merwick Á Willis D Kearney PM Mc Carthy VJC Buckley CM
Temporal trends of ambulance time intervals for suspected stroke/transient ischaemic attack (TIA) before and during the COVID-19 pandemic in Ireland: a quasi-experimental study	University College Cork College of Medicine & Health Futures Conference	September 2023	Poster presentation	Burton E Quinn R Crosbie-Staunton K Deasy C Masterson S O'Donnell C Merwick Á Willis D Kearney PM Mc Carthy VJC

				Buckley CM
Temporal trends of ambulance time intervals for suspected stroke/transient ischaemic attack (TIA) before and during the COVID-19 pandemic in Ireland: a quasi-experimental study	World Association for Disaster and Emergency Medicine Conference	May 2023	Oral presentation	Burton E Quinn R Crosbie-Staunton K Deasy C Masterson S O'Donnell C Merwick Á Willis D Kearney PM Mc Carthy VJC Buckley CM
Temporal trends of ambulance time intervals for suspected stroke/transient ischaemic attack (TIA) before and during the COVID-19 pandemic in Ireland: a quasi-experimental study	Royal College of Physicians Ireland Faculty of Public Health Medicine Winter Scientific Meeting	December 2022	Oral presentation (preliminary results)	Burton E Quinn R Crosbie-Staunton K Deasy C Masterson S O'Donnell C Merwick Á Willis D Kearney PM Mc Carthy VJC Buckley CM
Temporal trends of ambulance time intervals for suspected stroke/transient ischaemic attack (TIA) before and during the COVID-19 pandemic in Ireland: a quasi-experimental study	IPERN (Irish Paramedicine Education and Research Network) Research Forum	December 2022	Oral presentation (preliminary results)	Burton E Quinn R Crosbie-Staunton K Deasy C Masterson S O'Donnell C Merwick Á Willis D Kearney PM Mc Carthy VJC

				Buckley CM

Lay Summary

Title	Date of publication	Authors	Link
Ambulance time intervals and number of emergencies calls for suspected stroke and TIA during the COVID-19 pandemic in Ireland – a national study	October 2024	Burton E Devoy C Foley N Madden D Mancini H Masterson O'Regan J Quinn M	Not yet available at time of submission

Policy Brief

Title	Date of publication	Authors	Link
Temporal trends of ambulance time intervals for suspected stroke/transient ischaemic attack (TIA) before and during the COVID-19 pandemic in Ireland: a quasi-experimental study	October 2024	Burton E Quinn R Crosbie-Staunton K Deasy C Masterson S O'Donnell C Merwick Á Willis D Kearney PM Mc Carthy VJC Buckley CM	Not yet available at time of submission

Chapter 5 Appendices

Appendix 5.1 – PPI in this study reported using the GRIPP2 checklist (short version)

1. Aim - Report the aim of PPI in this study

The primary objective of PPI in this study was to ensure that individuals with firsthand experience of stroke/TIA played a pivotal role in shaping every aspect of this study. Thus stroke/TIA survivors and caregivers were involved from the development of the research question to the dissemination of findings.

2. Methods - Provide a clear description of the methods used for PPI in the study

Throughout this study, we closely collaborated with a PPI panel of 13 stroke/TIA survivors and caregivers of stroke/TIA survivors. Among them were 6 stroke survivors, 2 TIA survivors, and 5 caregivers. EB met with most of the group on an online conference platform and interacted with other members over the phone and by email. EB met with the group on four occasions to discuss this study. Additionally, EB forwarded materials for review to the panel on numerous occasions throughout the duration of this work.

These individuals played a vital role in co-developing the research question, composing and piloting the topic guide, advising on and aiding with recruitment, analysing stroke/TIA survivor and caregiver data and preparing the lay summary for our study.

Research question development

Initially, the group actively participated in refining the research question, from its early stages. EB prompted the panel to deliberate on their priorities regarding their acute stroke/TIA journey. These discussions significantly influenced the fine-tuning of the research question and the identification of target participant groups.

Composing and piloting the topic guide

During one dedicated meeting, EB and the PPI panel discussed pertinent questions the group would ask interview participants. This involved group discussions, with EB circulating drafts of the topic guide to the group for further review and edits. One member of the PPI panel, a stroke survivor, partook in a pilot interview with EB. Thereafter additional feedback was offered on the topic guide and reviewed and refined by EB.

Recruitment

PPI contributors reviewed recruitment materials and disseminated same to their networks.

Analysing stroke/TIA survivor and caregiver data

As the study progressed, EB presented preliminary findings to the group and asked for direction and input on interpretation. Five members of the panel were involved in the coding and interpretation of the transcripts. After the transcripts were coded

by EB, AH and IF, between one to three excerpts of between one to three transcripts with the code applied by the research team was sent to these PPI contributors. The contributors reviewed the code applied and highlighted whether they agreed or disagreed with the assigned code. If they disagreed, they were asked to suggest an alternative code or "label". The contributors then met individually with EB to discuss their thoughts.

Lay Summary

When the final results of the study were available EB met with the panel to discuss the findings and their possible impact. As a result, the group co-designed a lay summary of the findings. The panel also highlighted potential channels for dissemination of this output.

3. Study results – Outcomes - Report the results of PPI in the study, including both positive and negative outcomes

Research question development

When discussing priorities, the group emphasised the critical role of time in stroke/TIA care. Members shared insights from their personal stroke/TIA experiences, particularly focusing on the immediate phase following symptom recognition, and underscored the significance of prehospital emergency services in this phase. Furthermore, they deliberated on the importance of education, stressing its value for both stroke/TIA survivors and bystanders in recognising potential stroke/TIA symptoms and knowing when to seek help. Thus, the research team focused on all stakeholders involved in the early/pre-treatment phase of acute

stroke/TIA care; stroke/TIA survivors, caregivers, prehospital practitioners, stroke nurses and doctors.

Composing and piloting the topic guide

Panel members stressed the importance of tailoring the topic guides to the intended group. However, as they believed all groups should consider the stroke/TIA survivor journey through the healthcare system as priority, the topic guide followed this sequence for all groups. The topic guide was updated after piloting to include more clarity on open ended questions such as "talk me through your stroke/TIA journey".

Recruitment

Panel members highlighted the importance of clear, legible and large font size on advertisement materials for stroke/TIA survivors and caregivers. They advised on additional locations to display these posters and flyers, including parish centres, shopping centre noticeboards and "Men's Sheds" or "Sister Sheds". Furthermore, recruitment was optimised through the sharing of recruitment materials on the social media of PPI contributors and as a result of the "snowball effect" amongst their networks.

Analysing stroke/TIA survivor and caregiver data

PPI contributors involved in this phase advised on recoding certain aspects of the transcripts. For example, one PPI contributor advised to re-code a discussion on the stroke nurse calling the stroke survivor's son from "experiences in the emergency

department" to "communication during COVID-19". All contributors highlighted the diversity and individuality of each stroke/TIA survivors' journey, compared to their own.

Lay Summary

The panel emphasised the importance of a lay summary being available for all research studies. They further advised that a link or QR code to the peer-reviewed journal article should be available on this summary.

Furthermore, following advice from the PPI contributors, we prioritised the term "stroke/TIA survivor" over "stroke/TIA patient" or "stroke/TIA victim" in our communication and dissemination of findings.

Additionally, the PPI panel highlighted several stroke/TIA survivors and patient organidations to which the summary could be forwarded. They also provided guidance on engaging practice and policy stakeholders throughout the project, as well as identifying organisations where the policy brief on findings could be distributed.

4. Discussions and conclusions - Outcomes - Comment on the extent to which PPI influenced the study overall. Describe positive and negative effects.

The PPI panel had a strong significant influence on the conceptualisation and comprehensive development of this study across all its phases. We aimed to involve the panel in as many stages of the process as feasible to enhance the study and maximise its value by integrating the lived experience. However, upon reflection, we acknowledge the potential for greater PPI input during the analysis phase. Involving some PPI contributors in the initial coding of the transcripts would have further enriched the interpretation of results. However, this would have required in-depth training to be delivered to interested panel members. Unfortunately, due to time and budget limitations inherent in this study as part of a doctoral project, this was not deemed possible.

5. Reflections/critical perspective. Comment critically on the study, reflecting on the things that went well and those that did not, so others can learn from this experience

Integrating PPI throughout this study proved to be a beneficial experience. We found that incorporating the lived experience of stroke/TIA significantly enhanced the study's purpose, impact, and implications. However, effective PPI demands considerable time and resources. Consequently, within the constraints of a PhD project, achieving optimal levels of PPI can be challenging.

Appendix 5.2 - Semi-structured interview topic guides for (a) stroke/TIA survivors, (b) caregivers and (c) healthcare professionals

(a) Semi-structured interview topic guide for stroke/mini-stroke (TIA) survivors

Explain purpose of interview study - to understand the patient, caregiver, healthcare professional and system factors that may have influenced stroke care from the time the person experiences stroke or mini-stroke (TIA) symptoms until the hospital-based stroke team decides on the treatment plan.

- Introductions
- Verbal consent to be obtained, confirm written consent already sent by email.
- Reminder the interview is being recorded on Microsoft Teams/Dictaphone
- Outline interview is confidential.
- Interview recording will begin after demographic information has been collected.

- Interview code: _____
- Gender: _____
- Age: _____
- When they had their stroke
- Hospital where they their stroke: _____
- Transport to hospital: _____

Question:

Can you start by talking me through your stroke/TIA journey during the pandemic?

Probes:

- Raising the alarm
- Motivators and demotivators to seeking medical attention
- Transport preferences/choices
- Journey to hospital
- Experience in hospital until scan

Question:

Can you talk to me about your priorities in stroke care, as a stroke/TIA survivor?

- Timely access to hospital
- Prehospital care
- Hospital care
- Support systems
- Changes in priorities due to COVID

Question:

Do you think people were still aware of the seriousness of a stroke/TIA during the pandemic?

Probes:

- Barriers and facilitators
- Interventions/awareness campaigns

Question

Do you feel that COVID-19 affected your access to acute stroke/TIA care?

Probes:

- Barriers and facilitators
- COVID-19 restrictions
- Pandemic wave/timing

Question:

Do you think the COVID-19 pandemic affected the provision of stroke care during the pandemic in Ireland?

Probes:

- COVID-19 policies in the hospital
- Communication and follow-up
- Support systems
- Technology

Question:

What do you think we should have learned about acute stroke care during the COVID-19 pandemic?

Probes:

- Strengths and weaknesses
- Potential improvement

(b) Semi-structured interview topic guide for caregivers

Explain purpose of interview study - to understand the patient, caregiver, healthcare professional and system factors that may have influenced stroke care from the time the person experiences stroke or mini-stroke (TIA) symptoms until the hospital-based stroke team decides on the treatment plan.

- Introductions
- Verbal consent to be obtained, confirm written consent already sent by email.
- Reminder the interview is being recorded on Microsoft Teams/Dictaphone
- Outline interview is confidential.
- Interview recording will begin after demographic information has been collected.

- Interview code: _____
- Gender: _____
- Age: _____
- When did the stroke survivor they are supporting have their stroke_____
- Hospital where the stroke survivor they are supporting had their stroke: _____
- Transport to hospital taken by the stroke survivor they are supporting: _____

Question:

Can you start by talking me through the stroke/TIA journey of the stroke/TIA survivor you support during the pandemic?

Probes:

- Raising the alarm
- Motivators and demotivators to seeking medical attention
- Transport preferences/choices
- Journey to hospital
- Experience in hospital until scan

Question:

Can you talk to me about your priorities in stroke care, as a caregiver for a stroke/TIA survivor?

- Timely access to hospital
- Prehospital care
- Hospital care
- Support systems
- Changes in priorities due to COVID

Question:

Do you think people were still aware of the seriousness of a stroke/TIA during the pandemic?

Probes:

- Barriers and facilitators
- Interventions/awareness campaigns

Question

Do you feel that COVID-19 affected access to stroke care of the stroke/TIA survivor you support?

Probes:

- Barriers and facilitators
- COVID-19 restrictions
- Pandemic wave/timing

Question:

Do you think the COVID-19 pandemic affected the provision of stroke care during the pandemic in Ireland?

Probes:

- COVID-19 policies in the hospital
- Communication and follow-up
- Support systems
- Technology

Question:

What do you think we should have learned about acute stroke care during the COVID-19 pandemic?

Probes:

- Strengths and weaknesses
- Potential improvements

(c)Semi-structured interview topic guide for Healthcare Professionals

Explain purpose of interview study - to understand the patient, caregiver, healthcare professional and system factors that influenced access and delivery of acute stroke and TIA care during the COVID-19 pandemic in Ireland.

- Introductions
- Verbal consent to be obtained, confirm written consent already sent by email.
- Reminder the interview is being recorded on Microsoft Teams/Dictaphone
- Outline interview is confidential.
- Interview recording will begin after demographic information has been collected.

- Interview code: _____
- Gender: _____
- Age: _____
- Health care role: _____
- Years in practice in this role: _____
- Hospital where they were practicing during the COVID-19 pandemic: _____

Question:

Can you start by explaining the importance of time in the provision of acute stroke care?

Probes:

- Public knowledge and awareness
- Barriers and facilitators to timely hospital presentation

Question:

Did you observe any changes in the healthcare seeking behaviour of patients with suspected stroke/TIA during the pandemic?

Probes:

- Barriers and facilitators to timely hospital presentation during COVID-19
- Stroke/TIA awareness during the pandemic
- Patterns of stroke/TIA presentations during the pandemic
- Patient transport preferences during the pandemic
- COVID-19 vaccination and presentation patterns

Question:

Do you think the COVID-19 pandemic affected the healthcare workforce involved in the provision of acute stroke care?

Probes:

- Staffing levels
- Redeployment

Question

How did acute stroke services/your service operate during the COVID-19 pandemic?

Probes:

- Acute stroke care pathways/triage during the pandemic
- Prehospital delays and potential causes
- Ambulance times and potential causes
- Emergency department handover times and potential causes
- Intra-hospital delays and possible causes

Question:

Do you feel your service/the acute stroke care system coped well with the COVID-19 pandemic?

Probes:

- Resource availability
- Acute stroke care data/audit
- Lessons learned during COVID
- Challenges to acute stroke care delivery during COVID-19
- Opportunities with acute stroke care delivery during COVID-19

- Potential improvements at system level

Appendix 5.3 - Reflexivity Statements of Researchers Involved in Analysis

EB: EB (BPharm, MPharm, MPSI) is a PhD scholar, clinical pharmacy lecturer, and clinical hospital pharmacist. As this study is part her PhD research programme, EB played a central role in the design, data collection and analysis phases of this research. EB conducted all interviews and analysed all transcripts. The researcher's clinical and research experience in stroke care and qualitative methodology facilitates an impartial approach to this topic.

IH: As a senior lecturer and a nurse, IH brings a wealth of experience in both clinical and academic realms, particularly in the field of stroke care. Irene has firsthand insights into the challenges and complexities faced by stroke survivors and their caregivers. Additionally, Irene's academic expertise supported critical engagement with the research process, ensuring rigor and validity in this study. However, IH acknowledged that her clinical background may influence her perspective and interpretation of the data. To mitigate bias, Irene remained vigilant in questioning assumptions and actively sought diverse perspectives from the research team.

AF: AF is a pharmacist and senior lecturer and brings a clinical and academic background to the research. AF is familiar with the stroke care services in the Republic of Ireland and the importance of timely care and appropriate treatment due to her background as a pharmacist. This was particularly significant due to her experience of practising in rural locations in the Republic of Ireland. This is offset by

her experience and expertise in qualitative research with patients and healthcare professionals across a range of clinical areas. AF ensured that all perspectives, experiences and locations of patients were considered and discussed with the research team during the analysis stage to reduce any bias.

Appendix 5.4 - Outputs from chapter 5

Publications

Title	Journal	Date of Publication	Authors
Stroke Survivors, Caregivers and Healthcare Professionals' Perspectives of Acute Stroke Care During COVID-19 In Ireland	European Stroke Journal (Abstract)	September 2024	Burton E Hartigan I Buckley CM Kearney PM Masterson S Merwick Á McCarthy VJC Fleming A
Healthcare professionals' perspectives of acute stroke care during the COVID-19 pandemic in Ireland: A qualitative descriptive study	Irish Medical Journal (Abstract)	July 2024	Burton E Hartigan I Buckley CM Kearney PM Masterson S Merwick Á McCarthy VJC Fleming A

Conferences

Title	Conference	Date	Type	Authors
Navigating Acute Stroke: Perspectives of Stroke and Transient Ischaemic Survivors, Caregivers, and Healthcare Professionals during the COVID-19 Pandemic in Ireland: A Qualitative Study	Irish Neurological Association Meeting	May 2024	Poster presentation	Burton E Hartigan I Buckley CM Kearney PM Masterson S Merwick Á McCarthy VJC Fleming A
Stroke survivors, caregivers and healthcare professionals' perspectives of acute stroke care during COVID-19 in Ireland	European Stroke Organisation	May 2024	Poster presentation	Burton E Hartigan I Buckley CM Kearney PM Masterson S Merwick Á McCarthy VJC Fleming A
Stroke/Transient Ischaemic Attack (TIA) Survivors and caregivers' perspectives of acute stroke care during the COVID-19 pandemic in Ireland: A qualitative descriptive study	Structured Population and Health Services Research Education (SPHeRE) Conference	February 2024	Oral presentation	Burton E Hartigan I Buckley CM Kearney PM Masterson S Merwick Á McCarthy VJC Fleming A

Title	Conference	Date	Type	Authors
Healthcare professionals' perspectives of acute stroke care during the COVID-19 pandemic in Ireland: A qualitative descriptive study	Royal College of Physicians Ireland Faculty of Public Health Medicine Winter Scientific Meeting	December 2023	Poster presentation	Burton E Hartigan I Buckley CM Kearney PM Masterson S Merwick Á McCarthy VJC Fleming A
Healthcare professionals' perspectives of acute stroke care during the COVID-19 pandemic in Ireland: A qualitative descriptive study	Prehospital Emergency Care Council Conference	November 2023	Poster presentation	Burton E Hartigan I Buckley CM Kearney PM Masterson S Merwick Á McCarthy VJC Fleming A

Lay Summary

Title	Date of publication	Authors	Link
Navigating The Acute Stroke/TIA Journey: Perspectives from Survivors, Caregivers, and Healthcare Professionals in Ireland During COVID-19	November 2024	Burton E Devoy C Foley N Madden D Mancini H Masterson O'Regan J Quinn M	Not yet available at time of submission

Policy Brief

Title	Date of publication	Authors	Link
Navigating Acute Stroke: Perspectives from Survivors, Caregivers, and Healthcare Professionals in Ireland During COVID-19: A Qualitative Study	November 2024	Burton E Hartigan I Buckley CM Kearney PM Masterson S Merwick Á McCarthy VJC Fleming A	Not yet available at time of submission

Chapter 6 Appendices

Appendix 6.1 - Questionnaire used in chapter 6a

Ambulance times and variables benchmarking exercise

This study is part of Edel Burton's PhD work on the impact of the COVID-19 pandemic on prehospital care for stroke/TIA. Edel is a Pharmacist and PhD Scholar in the School of Public Health, University College Cork.

This exercise is to allow accurate comparison between international ambulance times and system variables.

1. Please state the name of the ambulance service you are representing.

2. Please leave an email if you are happy to do so (required if follow up questions/clarifications are needed)

3. Which authority determines the time variables (and terminology for these) which your ambulance service collects?

4. When does clock start and clock stop time?

5. What term would you use to describe the hour that call taking commenced (hour value)?

6. What is the name of this variable in your Computer Aided Dispatching (CAD)/reporting system?

7. What term would you use to describe the time call taking commenced?

8. What is the name of this variable in your CAD/reporting system?

9. What term would you use to describe the time the ambulance resource went mobile to scene (time wheels start moving)?

10. What is the name of this variable in your CAD/reporting system?

11. What term would you use to describe the time between time resource mobile minus time call taking commenced?

12. What is the name of this variable in your CAD/reporting system?

13. What term would you use to describe the time the wheels stop on scene?

14. What is the name of this variable in your CAD/reporting system?

15. What term would you use to describe the time in minutes between time resource mobilised minus time resource arrived at scene?

16. What is the name of this variable in your CAD/reporting system?

17. What term would you use to describe the time wheels start moving from scene?

18. What is the name of this variable in your CAD/reporting system?

19. What term would you use to describe the time in minutes resource arrived at destination minus time left scene?

20. What is the name of this variable in your CAD/reporting system?

21. What term would you use to describe the time of arrival if brought to hospital?

22. What is the name of this variable in your CAD/reporting system?

23. What term would you use to describe the time resource arrived at destination minus time resource arrived at scene?

24. What is the name of this variable in your CAD/reporting system?

This content is neither created nor endorsed by Microsoft. The data you submit will be sent to the form owner.

Microsoft Forms

Appendix 6.2 - Outputs from chapter 6a

Publications

Title	Date of Publication	Authors	Link
International comparison of ambulance times terminology and definitions: a benchmarking study (paper)	July 2023 (Paper)	Burton E Willis D Boseley E Deasy C Franklin M Garrison D Henderson C Hutchinson H Kearney PM Krammel M Lloyd A Loudon W Quinn R Masterson S McCarthy VJC Merwick Á O'Donnell C Overton J Van de Pas H Wolfe JH Zavadsky M Crosbie-Staunton K Buckley CM	International Comparison of Ambulance Times Terminology and Definitions: A Benchmarking Study - AEDR Journal

Title	Date of Publication	Authors	Link
International comparison of ambulance times terminology and definitions: a benchmarking study (abstract)	June 2023 (Abstract)	Burton E Willis D Boseley E Deasy C Franklin M Garrison D Henderson C Hutchinson H Kearney PM Krammel M Lloyd A Loudon W Quinn R Masterson S McCarthy VJC Merwick Á O'Donnell C Overton J Van de Pas H Wolfe JH Zavadsky M Crosbie-Staunton K Buckley CM	International Comparison of Ambulance Times Terminology and Definitions: A Benchmarking Study | Prehospital and Disaster Medicine | Cambridge Core

Conferences

Title	Conference	Date	Type	Authors
International comparison of ambulance times terminology and definitions: a benchmarking study	World Association of Disaster and Emergency Medicine	May 2023	Poster presentation	Burton E Willis D Boseley E Deasy C Franklin M Garrison D Henderson C Hutchinson H Kearney PM Krammel M Lloyd A Loudon W Quinn R Masterson S McCarthy VJC Merwick Á O'Donnell C Overton J Van de Pas H Wolfe JH Zavadsky M Crosbie-Staunton K Buckley CM

Title	Conference	Date	Type	Authors
International comparison of ambulance times terminology and definitions: a benchmarking study	University College Cork Bright Futures College of Medicine and Health Postgraduate Conference	April 2023	Poster presentation	Burton E Willis D Boseley E Deasy C Franklin M Garrison D Henderson C Hutchinson H Kearney PM Krammel M Lloyd A Loudon W Quinn R Masterson S McCarthy VJC Merwick Á O'Donnell C Overton J Van de Pas H Wolfe JH Zavadsky M Crosbie-Staunton K Buckley CM

Title	Conference	Date	Type	Authors
International comparison of ambulance times terminology and definitions: a benchmarking study	International Academies of Emergency Dispatch Navigator Conference	April 2023	Poster presentation	Burton E Willis D Boseley E Deasy C Franklin M Garrison D Henderson C Hutchinson H Kearney PM Krammel M Lloyd A Loudon W Quinn R Masterson S McCarthy VJC Merwick Á O'Donnell C Overton J Van de Pas H Wolfe JH Zavadsky M Crosbie-Staunton K Buckley CM

Title	Conference	Date	Type	Authors
International comparison of ambulance times terminology and definitions: a benchmarking study	Structured Population and Health Services Research Education (SPHeRE) Conference	March 2023	Oral presentation	Burton E Willis D Boseley E Deasy C Franklin M Garrison D Henderson C Hutchinson H Kearney PM Krammel M Lloyd A Loudon W Quinn R Masterson S McCarthy VJC Merwick Á O'Donnell C Overton J Van de Pas H Wolfe JH Zavadsky M Crosbie-Staunton K Buckley CM

Lay Summary

Title	Date of publication	Authors	Link
Are we speaking the same language?	January 2024	Burton E Willis D Prehospital Care of Stroke (PHoCoS) consortium Devoy C Foley N Madden D Mancini H Masterson O'Regan J Quinn M	Are We Speaking the Same Language? - IAED Journal

Policy Brief

Title	Date of publication	Authors	Link
International comparison of ambulance times terminology and definitions: a benchmarking study	October 2024	Burton E Willis D Boseley E Deasy C Franklin M Garrison D Henderson C Hutchinson H Kearney PM Krammel M Lloyd A Loudon W Quinn R Masterson S McCarthy VJC Merwick Á O'Donnell C Overton J Van de Pas H Wolfe JH Zavadsky M Crosbie-Staunton K Buckley CM	Not yet available at time of submission

Podcast

Title	Date of publication	Authors	Link
Speaking the same language with Edel burton	February 2023	Burton E On behalf of the PHoCoS Consortium	Speaking the Same Language with Edel Burton - AEDR Journal

Appendix 6.3 - Ambulance times and intervals reported by the National Ambulance Service included in this study

Ambulance Time Interval	Definition	Constituent Ambulance Times	Definitions
Allocation performance	Allocation Time **minus** T5 Time	Despatch Code Established (T5 time)	The time the Despatch Code is established from ProQA (priority dispatch system software)
		Resource Allocation Time	The time a resource* has been allocated to an incident on the Computer Aided Dispatch (CAD) system
Mobilisation Performance	Mobile Time **minus** T5 Time	Despatch Code Established (T5 time)	The time the Despatch Code is established from ProQA
		Resource Mobile Time	The time the resource goes mobile on the incident, either through radio selective call (selcall) by the crew, voice or Automatic Vehicle Location (AVL) update
Response Time	Resource at Scene Time **minus** T5 Time	Despatch Code Established (T5 time)	The time the Despatch Code is established from ProQA
		Resource At Scene Time	The time the resource arrives at the scene of the incident. This is captured by a selcall** 'At Scene' from the crew, by voice or by AVL update
On Scene Time	Resource Left Scene Time **minus** Resource at Scene Time	Resource At Scene Time	The time the resource arrives at the scene of the incident. This is captured by a selcall 'At Scene' from the crew, by voice or by AVL update
		Resource Left Scene Time	The time the responding crew have completed treatment, have the patient on board and are about to leave the scene for hospital. Given through Selcall 'Left Scene', by voice or AVL update
Conveyance Time	At Hospital Time **minus** Left Scene Time	Resource At Hospital Time	The time the resource arrives at the hospital. Given via Selcall 'At Hospital', by voice or AVL update
		Resource Left Scene Time	The time the responding crew have completed treatment, have the patient on board and are about to leave the scene for hospital. Given through Selcall 'Left Scene', by voice or AVL update

Appendix 6.4 - Description of urban and rural scales and definitions used by each included service

Country	Urban	Rural	Reference
Australia	***Major Urban***	***Bounded Locality***	Section of State | Australian Bureau of Statistics (abs.gov.au)
	Definition: represents a combination of all urban centres with a population of 100,000 or more	Definition: represents a combination of all localities. Can include some large localities with a population over 1,000	
	Other Urban	***Rural Balance***	
	Definition: represents a combination of all urban centres with a population less than or equal to 99,999	Definition: represents the Remainder of State/Territory	

Country	**Urban**	**Rural**	**Reference**
Austria	Definition: consist of cities – defined as densely populated local units with at least 50 000 inhabitants – and adjacent local units connected to the city (commuting zones) in terms of commuting flows	Service only operates in city of Vienna. No rural calls made by the service.	Austria (oecd.org)
New Zealand	***U1***	***R1***	Whitehead J, Davie G, de Graaf B, Crengle S,

	Definition: Major urban areas and places within 25 minutes of major urban areas (Major urban area – communities of 100,000 or more residents)	Definition: Medium urban areas: 0-25 minutes from medium urban area, 25-60 minutes from major urban areas. 20-50 minutes from large urban areas (Medium urban areas- communities of 10,000 – 29,999 residents)	Lawrenson R, Miller R, et al. Unmasking hidden disparities: a comparative observational study examining the impact of different rurality classifications for health research in Aotearoa New Zealand. BMJ Open. 2023;13(4): e067927.
	U2	***R2***	
	Large urban areas and places within 20 minutes of large urban areas (Large urban area – communities of 30,000 – 99,999 residents)	Definition: small urban areas (1,000 – 9,999 residents), 0-25 minutes from small urban areas, 60-90 minutes from major urban areas, 50-80 minutes from large urban areas, 25-60	

		minutes from medium urban areas ***R3*** More than 90 minutes from major urban areas, more than 80 minutes from large urban areas, more than 60 minutes from medium urban areas, more than 25 minutes from small urban areas	
Country	**Urban**	**Rural**	**Reference**
Northern Ireland	***Urban*** Definition: Belfast and Derry city. Large town (population 18,000+), Medium town (population 10,000-17,999), Small town	***Rural*** Intermediate settlement (population 2,500 – 4,999) Village (population 1,000 – 2,499) Populations of less than 1,000 and open	review-of-the-statistical-classification-and-delineation-of-settlements-march-2015 (1).pdf (nisra.gov.uk)

	(population 5,000 – 9,999)	countryside	
Scotland	***Large Urban Areas***	***Accessible Rural***	Scottish Government Urban Rural Classification 2020 - gov.scot (www.gov.scot)
	Definition: populations of 125,000 or more	Definition: populations less than 3,000 and within 30-minute drive time to a settlement with a population of 10,000 or more	
	Other Urban Areas	***Remote Small Towns***	
	Definition: populations of 10,000 to 124,999	Definition: populations of 3,000 to 9,999 and areas that have a drive time between 30 and 60 minutes from a settlement with a population of 10,000 or more	
	Accessible Small Towns	***Remote Rural***	

	Definition: population of 3,000 to 9,999 and within 30-minute drive time to a settlement with a population of 10,000 or more	Definition: populations less than 3,000 and areas that have a drive time between 30 and 60 minutes from a fettlement with a population of 10,000 or more	
		Very Remote Rural	
		Definition: populations less than 3,000 and have a 60-minute drive time from a Settlement with a population of 10,000 or more	
		Very Remote Small Towns	
		Settlements of 3,000 to 9,999 people, and with a drive time of over 60 minutes to a settlement of 10,000 or more.	
Country	**Urban**		**Rural**
The Netherlands	• Likert scale from 1-5		Statistics Netherlands | CBS

<table>
<tr><td></td><td colspan="2">• 1 Most Urban, 5 most rural</td><td></td></tr>
<tr><td rowspan="4">The Republic of Ireland</td><td>Urban settlement</td><td>Rural settlement</td><td rowspan="4">Settlements Ungeneralised - National Statistical Boundaries - 2015 | Surveying Open Data Portal (arcgis.com)</td></tr>
<tr><td rowspan="3">Definition: a town with a total population of 1500 or more</td><td>Definition: a town with a population of less than 1500</td></tr>
<tr><td>Rural</td></tr>
<tr><td>Any calls with latitude and longitude outside of a settlement were classed as rural.</td></tr>
</table>

Appendix 6.5 - Categorisation of the 13-stroke code protocol determinant descriptors into 5 categories

Not alert	28-C-1	Not alert
Unknown status/other codes not applicable	28-C-12	Other
Stroke charlie override	28-C-00	
Breathing normally <35	28-A-1	Breathing
Breathing normally greater than or equal to 35	28-C-11	
Abnormal breathing	28-C-2	
Sudden speech problems	28-C-3	Sudden onset of stroke/TIA symptoms
Sudden weakness or numbness	28-C-4	
Sudden paralysis or facial drop	28-C-5	
Sudden loss of balance or co-ordination	28-C-6	
Sudden vision problems	28-C-7	
Sudden onset of severe headache	28-C-8	
Stroke history	28-C-9	History of cerebrovascular disease
TIA history	28-C-10	

Appendix 6.6 - Patient and Public Involvement in this study reported using the GRIPP2 checklist (short version)

1. ***Aim - Report the aim of PPI in this study***

The primary aim of PPI in this study was to ensure that individuals with lived experience of stroke/TIA played a key role in influencing all aspects of the research. Therefore, stroke/TIA survivors and caregivers were engaged in all stages from developing the research questions to sharing the findings.

2. Methods - Provide a clear description of the methods used for PPI in the study

Throughout this study, we closely collaborated with a PPI panel consisting of 13 stroke/TIA survivors and caregivers. This group included 6 stroke survivors, 2 TIA survivors, and 5 caregivers (6 female, 7 male). EB communicated with most of the group through online meetings. EB met with the group four times to discuss the study. Others were contacted via phone and email. EB sent materials for review to the panel multiple times during the project.

These individuals were involved in co-developing the research question, selecting appropriate countries to involve in this international comparison, interpreting the results and preparing the lay summary for our study.

Research question development

From the beginning, the group actively contributed to refining the research question. EB encouraged the panel to discuss their priorities related to their acute stroke/TIA experiences. These discussions also involved considered the benefits of international benchmarking and comparisons within healthcare. The panel also deliberated on including countries where valuable and meaningful comparisons with the Republic of Ireland could be made.

Lay Summary

Once the study results were available, EB met with the panel to discuss the findings and their potential impact. Consequently, the group co-designed a lay summary of the findings.

3. Study results – Outcomes - Report the results of PPI in the study, including both positive and negative outcomes

Research question development

When discussing priorities, the group highlighted the crucial role of time in stroke care. Members drew from their personal experiences with stroke/TIA, particularly emphasising the immediate phase following symptom recognition. They highlighted the importance of prehospital emergency services during this phase.

Furthermore, the panel believed that inter country comparisons fostered a sense of shared learning. In essence, a study such as this may reveal pathways of care or other practices that optimise care processes or improve patient outcomes. Thus, they felt that patients could benefit from these results as could potentially receive more innovative or effective care.

Lay Summary

The panel emphasised the necessity of having a lay summary accessible for all research studies. They further recommended that the summary should include a link or QR code directing readers to the peer-reviewed journal article. Additionally, following advice from the PPI contributors, we prioritised using the term "stroke/TIA survivor" over "stroke/TIA patient" or "stroke/TIA victim" in our communication and dissemination of findings.

Moreover, the PPI panel highlighted several stroke/TIA survivor and patient organisations to which the summary could be sent. They also provided guidance on engaging practice and policy stakeholders throughout the project, as well as identifying organisations where the policy brief on findings could be distributed. Most of this panel are based in the Republic of Ireland. However, due to the international nature of this study, there was opportunity to disseminate this summary to international patient organisations, using social media and international partners (members of the PHoCoS Consortium).

4. Discussions and conclusions – Outcomes - Comment on the extent to which PPI influenced the study overall. Describe positive and negative effects

The PPI panel had a significant and pivotal role in the conceptualisation and comprehensive development of this study throughout all its phases. Our goal was to involve the panel at as many stages of the process as possible, enriching the study and maximising its value by incorporating their lived experiences. However, upon reflection, we recognise the potential for greater international PPI representation. Unfortunately, due to time and budget constraints inherent in this study as part of a doctoral project, this was not feasible.

5. *Reflections/critical perspective - Comment critically on the study, reflecting on the things that went well and those that did not, so others can learn from this experience*

Incorporating PPI throughout this study was highly beneficial. The inclusion of lived experiences of stroke/TIA significantly improved the study's purpose, impact, and implications. However, effective PPI requires substantial time and resources, which can make achieving optimal levels difficult within the confines of a PhD project.

Appendix 6.7 - Details on each of the seven ambulance services included in this study

Country	Region	Service	Description	Number of stations	Geographical representation
Australia	Queensland	Queensland Ambulance Service Queensland Ambulance Service - About QAS	The Queensland Ambulance Service operates as a statewide service within Queensland Health, with responsibilities including the delivery of pre-hospital ambulance response services, emergency and non-emergency pre-hospital patient care and transport services, inter-facility ambulance transport, casualty room services, and planning and coordination of multi-casualty incidents and disasters.	302 response locations across the state	Statewide - organised into North Queensland and South Queensland, which encompass eight geographical regions consisting of 17 districts

Country	Region	Service	Description	Number of stations	Geographical representation
Austria	Vienna	EMS Vienna Municipal Department 70 Professional Rescue Vienna (wien.gv.at)	The Vienna Professional Rescue Service (Municipal Department 70), commonly known in Vienna simply as the rescue service, serves as the designated public rescue service organisation for the City of Vienna. It fulfils its statutory mandate by providing emergency response services, including the majority of ambulances deployed in Vienna, as well as operating the control centre and dispatching services.	12 stations	Main prehospital provided in Vienna

Country	Region	Service	Description	Number of stations	Geographical representation
New Zealand	National*	Hate Hone St. John's Ambulance Service A quick snapshot of St John activities	Delivering ambulance services throughout New Zealand offering emergency services throughout 97% of Aotearoa, operating 24/7 and catering to 90% of the population.	206 stations	Wellington Free Ambulance Service provides prehospital services to New Zealand's capital, Wellington.
Northern Ireland	National	Northern Ireland Ambulance Service About the Trust | NIAS (hscni.net)	Provider of emergency, urgent, and primary care services across the entirety of Northern Ireland.	46 stations	1.9 million people of Northern Ireland.
Scotland	National	Scottish Ambulance Service Emergency Care (scottishambulance.com)	It serves as the exclusive public emergency medical service for Scotland's mainland and islands, offering a paramedic-led accident and emergency service to respond to 999 calls.	152 stations	National - five divisions - North, East Central, West Central, Southeast, Southwest.
Country	**Region**	**Service**	**Description**	**Number of**	**Geographical**

				stations	representation
The Netherlands	Regional	RAV Brabant Midden-West-Noord	RAV Brabant Midden-West-Noord is the designated ambulance service provider for the province, except the southeast part.	12 stations	The Provence of North-Brabant.
The Republic of Ireland	National*	National Ambulance Service Our Services - National Ambulance Service	The National Ambulance Service of Ireland is the mandated provider of EMS in the Republic of Ireland. In Dublin city and county, EMS is delivered by NAS and the Dublin Fire Brigade, while in the remainder of the country, NAS is the sole provider of EMS.	102 stations	National coverage – Dublin Fire Brigade also provides prehospital services to capital city; Dublin.

*The Republic of Ireland and New Zealand have both a national ambulance service and a service that covers their capital city only.

In New Zealand that is the Wellington Free Ambulance Service and in the Republic of Ireland it is Dublin Fire Brigade. For these countries only the national service is included here.

Appendix 6.8 - Time of day of call and determinant descriptor during pre-COVID-19 and COVID-19 periods

Service Location	Time Period		Time of day of call					Determinant descriptor					
			00:00 - 5:59	06:00-11:59	12:00-17:59	18:00-23:59	p-value	Not Alert	Other	Breathing	Sudden Onset/TIA History	Cerebrovascular Disease History	p-value
Australia	Pre-COVID-19	(N=27469) [a]	2197 (8%)	9778 (35.6%)	9238 (33.7%)	6238 (22.7%)	<0.01	7834 (28.5%)	146 (0.5%)	4780 (17.4%)	13627 (49.6%)	1082 (4.0%)	<0.001
	COVID-19	(N=32520) [a]	2532 (7.8%)	11592 (35.6%)	11317 (34.8%)	7078 (21.8%)		9421 (29%)	120 (0.4%)	5816 (17.9%)	16147 (49.7%)	1016 (3.0%)	
Austria	Pre-COVID-19	(N=7807)	557 (7.1%)	2749 (35.2%)	2744 (35.2%)	1757 (22.5%)	0.6	1293 (16.6%)	519 (6.7%)	1281 (16.4%)	4422 (56.6%)	292 (3.7%)	<0.01
	COVID-19	(N=7857)	320 (7.6%)	1451 (34.3%)	1476 (34.9%)	979 (23.2%)		1264 (16.1%)	592 (7.5%)	1243 (15.8%)	4535 (57.7%)	223 (2.8%)	
New Zealand	Pre-COVID-19	(N=18531)	1445 (7.8%)	6598 (35.6%)	6336 (34.2%)	4152 (22.4%)	0.9	6763 (36.5%)	211 (1.1%)	3215 (17.4%)	7747 (41.8%)	595 (3.2%)	<0.001
	COVID-19	(N=23351)	1815 (7.8%)	8289 (35.5%)	8063 (34.5%)	5184 (22.2%)		8212 (35.2%)	120 (0.5%)	4341 (18.6%)	10165 (43.5%)	513 (2.2%)	
Northern Ireland	Pre-COVID-19	(N=10820)	786 (7.3%)	3451 (31.9%)	3983 (36.8%)	2600 (24%)	0.34	354[b] (45.6%)	3 (0.4%)	109 (14%)	291 (37.4%)	20 (2.6%)	0.13
	COVID-19	(N=11256)	858 (7.6%)	3471 (30.8%)	4185 (37.2%)	2742 (24.4%)		4879 (43.4%)	21 (0.2%)	1435 (12.8%)	4686 (41.6%)	235 (2.1%)	
Scotland	Pre-COVID-19	(N=38488)	3082 (8.1%)	12557 (32.6%)	13794 (35.8%)	9055 (23.5%)	0.1	16206 (42.1%)	2362 (6.1%)	5550 (14.4%)	13275 (34.5%)	1095 (2.9%)	<0.001
	COVID-19	(N=44771)	3539 (7.9%)	14644 (32.7%)	16334 (36.5%)	10254 (22.9%)		18250 (40.8%)	1627 (3.6%)	6178 (13.8%)	17673 (39.5%)	1043 (2.3%)	
The Netherlands	Pre-COVID-19	(N=5545)	529 (9.5%)	1656 (29.9%)	1928 (34.8%)	1432 (25.8%)	0.5	1670 (30.1%)	13 (0.2%)	821 (14.8%)	2820 (50.9%)	221 (4%)	0.03
	COVID-19	(N=4943)	430 (8.7%)	1507 (30.5%)	1728 (35%)	1278 (25.8%)		1407 (28.5%)	8 (0.2%)	679 (13.7%)	2666 (53.9%)	183 (3.7%)	
The Republic of Ireland	Pre-COVID-19	(N=19,826)	1295 (6.5%)	5565 (28.1%)	7793 (39.3%)	5173 (26.1%)	<0.05	7549 (38.0%)	116 (0.6%)	2582 (13.0%)	9019 (45.5%)	560 (2.8%)	<0.001
	COVID-19	(N=20,178)	1415 (7.0%)	5692 (28.2%)	8016 (39.7%)	5055 (25.1%)		7286 (36.1%)	88 (0.44%)	2762 (13.67%)	9546 (47.3%)	496 (2.5%)	

Missing data for time of day of call - [a] pre-COVID-19 (n=18); COVID-19 (n=1), Austria - COVID-19 (n=3631)

[b] For AMPDS determinant descriptor pre-COVID-19 = January and February 2020 only, due to data warehousing policies

Appendix 6.9 - Geographical location of calls across the seven included services during the pre-COVID-19 and COVID-19 period

Service Location	Time Period		Incident location								p-value
Australia			**Bounded Locality**	**Major Urban**	**Other Urban**	**Rural Balance**					0.02
	Pre-COVID-19	(N=27469) [d]	818 (3%)	18861 (68.7%)	4899 (17.8%)	2869 (10.5%)					
	COVID-19	(N=32520) [d]	997 (3.1%)	21970 (67.6%)	5964 (18.3%)	3579 (11%)					
New Zealand			**Urban 1 (U1)**	**Urban 2 (U2)**	**Rural 1 (R1)**	**Rural 2 (R2)**	**Rural 3 (R3)**				0.01
	Pre-COVID-19	(N=18531) [e]	9939 (53.7%)	4239 (22.9%)	2725 (14.7%)	1383 (7.5%)	225 (1.2%)				
	COVID-19	(N=23351) [e]	12762 (54.7%)	5065 (21.7%)	3566 (15.3%)	1679 (7.2%)	255 (1.1%)				
Northern Ireland[f]			**Urban**	**Rural**							0.08
	Pre-COVID-19	(N=777)	515 (66.8%)	256 (33.2%)							
	COVID-19	(N=11256)	7794 (69.9%)	3369 (30.1%)							
Scotland			**Accessible Rural**	**Accessible Small Towns**	**Large Urban Areas**	**Other Urban Areas**	**Remote Rural**	**Remote Small Towns**	**Very Remote Rural**	**Very Remote Small Towns**	
	Pre-COVID-19	(N=38488)	3993 (10.4%)	3147 (8.2%)	14096 (36.8%)	13941 (36.4%)	1078 (2.8%)	649 (1.7%)	865 (2.3%)	565 (1.4%)	<0.001
	COVID-19	(N=44771)	4982 (11.2%)	3858 (8.7%)	15299 (34.4%)	16338 (36.8%)	1295 (2.8%)	830 (1.9%)	1146 (2.6%)	697 (1.6%)	
The Netherlands			**1 (Most urban)**	**2**	**3**	**4**	**5 (Most Rural)**				0.79
	Pre-COVID-19	(N=5545)	767 (13.9%)	1548 (28%)	1287 (23.3%)	1058 (19.1%)	873 (15.7%)				
	COVID-19	(N=4943)	672 (13.7%)	1331 (27.1%)	1148 (23.4%)	976 (19.8%)	789 (16.0%)				
The Republic of Ireland			**Urban**	**Rural settlement**	**Rural**						<0.001
	Pre-COVID-19	(N=19,826)	11252 (56.8%)	2042 (10.3%)	6532 (32.9%)						
	COVID-19	(N=20,178)	11064 (54.8%)	2125 (10.5%)	6989 (34.6%)						

[c]All calls from Austria were from urban locations, due to the geographical area covered by the service.

[d] Missing data for incident location – pre-COVID-19 (n=22); COVID-19 (n=40); [e] pre-COVID-19 (n=20); COVID-19 (n=24), Scotland pre-COVID-19 (n=154); COVID-19 (n=326), Netherlands pre-COVID-19 (n= 12); COVID-19 (n= 27)

[f] For incident location pre-COVID-19 = January and February 2020 only, due to data warehousing policies; missing data pre-COVID-19 (n=6); COVID-19 (n=93)

Appendix 6.10 - Results from the linear regression analyses on time intervals

Appendix table 6.10.1 - Results of Multivariable Regression on Allocation Performance for Australia

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	-0.27	0.15	-0.57	0.03	-1.79	0.07
COVID-19	2.33	0.09	2.17	2.50	27.42	<0.001
Location	1.31	0.14	1.04	1.58	9.57	<0.001
Breathing	0.65	0.13	0.40	0.90	5.12	<0.001
History of Cerebrovascular Disease	0.88	0.24	0.40	1.35	3.62	<0.001
Sudden of Onset/TIA	1.16	0.10	0.97	1.36	11.76	<0.001
Other	-0.01	0.64	-1.27	1.25	-0.02	0.99

F (6, 58425) = 163, R-Squared=0.017, Adjusted R-Squared=0.016

Appendix table 6.10.2 - Results of Multivariable Regression on Mobilisation Performance for Australia

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	1.15	0.15	0.85	1.45	7.56	<0.001
COVID-19	2.23	0.08	2.06	2.40	26.28	<0.001
Location	0.74	0.14	0.47	1.00	5.41	<0.001
Breathing	0.64	0.13	0.39	0.89	4.99	<0.001
History of Cerebrovascular Disease	0.89	0.24	0.42	1.36	3.71	<0.001
Sudden of Onset/TIA	1.16	0.10	0.97	1.35	11.74	<0.001
Other	0.02	0.64	-1.25	1.28	0.02	0.98

F (6, 58234) =142.57, R-Squared=0.015, Adjusted R-Squared=0.014

Appendix table 6.10.3 - Results of Multivariable Regression on Response Time for Australia

F (6, 59922) =450.67, R-Squared=0.043 Adjusted R-Squared=0.043

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	14.12	0.11	13.90	14.34	127.01	<0.001
COVID-19	1.61	0.06	1.49	1.73	26.08	<0.001
Location	-4.26	0.10	-4.45	-4.06	-42.83	<0.001
Breathing	0.30	0.09	0.12	0.48	3.24	<0.001
History of Cerebrovascular Disease	1.09	0.17	0.75	1.43	6.25	<0.001
Sudden of Onset/TIA	0.84	0.07	0.70	0.98	11.69	<0.001
Other	-0.90	0.47	-1.81	0.02	-1.92	0.06

Appendix table 6.10.4 - Results of Multivariable Regression on On Scene Time for Australia

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	25.76	0.18	25.41	26.12	143.28	<0.001
COVID-19	1.58	0.10	1.38	1.77	15.80	<0.001
Location	-0.43	0.16	-0.74	-0.11	-2.66	0.01
Breathing	-3.24	0.15	-3.53	-2.94	-21.57	<0.001
History of Cerebrovascular Disease	-2.27	0.28	-2.82	-1.72	-8.07	<0.001
Sudden of Onset/TIA	-4.09	0.12	-4.31	-3.86	-35.20	<0.001
Other	0.77	0.81	-0.82	2.35	0.95	0.34

F (6, 54274) =257.27, R-Squared=0.028 Adjusted R-Squared=0.028

Appendix table 6.10.5 - Results of Multivariable Regression on Conveyance Time for Australia

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	24.70	0.21	24.30	25.11	120.25	<0.001
COVID-19	0.62	0.11	0.39	0.84	5.42	<0.001
Location	-6.14	0.18	-6.50	-5.78	-33.39	<0.001
Breathing	-0.27	0.17	-0.61	0.06	-1.60	0.11
History of Cerebrovascular Disease	0.28	0.32	-0.35	0.91	0.86	0.39
Sudden of Onset/TIA	0.01	0.13	-0.25	0.27	0.10	0.92
Other	-1.55	0.92	-3.36	0.26	-1.68	0.09

F (6, 54268) =192.75, R-Squared=0.021 Adjusted R-Squared=0.021

Appendix table 6.10.6 - Results of Multivariable Regression on Allocation Performance for Austria

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	1.52	0.04	1.44	1.59	38.52	<0.001
COVID-19	-0.15	0.03	-0.21	-0.10	-5.45	<0.001
>=5 hours	-0.02	0.03	-0.09	0.05	-0.59	0.55
Unknown	0.11	0.05	0.02	0.20	2.38	0.02
Breathing	-0.05	0.05	-0.15	0.04	-1.06	0.29
History of Cerebrovascular Disease	0.15	0.09	-0.02	0.32	1.78	0.08
Sudden of Onset/TIA	-0.07	0.04	-0.15	0.01	-1.76	0.08
Other	-0.10	0.06	-0.22	0.02	-1.57	0.12

F (7, 14870) =7.37, R-Squared=0.004, Adjusted R-Squared=0.003

Appendix table 6.10.7 - Results of Multivariable Regression on Mobilisation Performance for Austria

F (7, 14870) =7.56, R-Squared=0.004, Adjusted R-Squared=0.003

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	0.54	0.02	0.50	0.59	23.18	<0.001
COVID-19	-0.11	0.02	-0.15	-0.08	-6.73	<0.001
>=5 hours	0.05	0.02	0.01	0.09	2.29	0.02
Unknown	0.03	0.03	-0.02	0.09	1.29	0.2
Breathing	0.03	0.03	-0.03	0.09	0.93	0.35
History of Cerebrovascular Disease	-0.01	0.05	-0.11	0.09	-0.17	0.87
Sudden of Onset/TIA	0.03	0.02	-0.02	0.08	1.24	0.22
Other	-0.02	0.04	-0.09	0.05	-0.54	0.59

Appendix table 6.10.8 - Results of Multivariable Regression on Response Time for Austria

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	7.03	0.11	6.83	7.24	66.01	<0.001
COVID-19	0.80	0.08	0.65	0.95	10.41	<0.001
>=5 hours	0.14	0.09	-0.04	0.32	1.47	0.14
Unknown	0.05	0.12	-0.19	0.29	0.40	0.69
Breathing	0.01	0.13	-0.26	0.27	0.04	0.97
History of Cerebrovascular Disease	-0.17	0.23	-0.63	0.28	-0.76	0.45
Sudden of Onset/TIA	-0.10	0.11	-0.31	0.11	-0.91	0.36
Other	-0.23	0.17	-0.56	0.11	-1.32	0.19

F (7, 14870) =16.60, R-Squared=0.007, Adjusted R-Squared=0.007

Appendix table 6.10.9 - Results of Multivariable Regression on on scene Time for Austria

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	32.20	0.30	31.62	32.78	108.11	<0.001
COVID-19	3.78	0.22	3.36	4.20	17.57	<0.001
>=5 hours	1.38	0.26	0.88	1.89	5.37	<0.001
Unknown	2.12	0.34	1.45	2.79	6.20	<0.001
Breathing	-4.71	0.38	-5.44	-3.97	-12.54	<0.001
History of Cerebrovascular Disease	-5.52	0.65	-6.78	-4.25	-8.54	<0.001
Sudden of Onset/TIA	-6.52	0.30	-7.11	-5.93	-21.69	<0.001
Other	-5.68	0.48	-6.62	-4.74	-11.83	<0.001

F (7, 14870) =121.44, R-Squared=0.054, Adjusted R-Squared=0.054

Appendix table 6.10.10 - Results of Multivariable Regression on Conveyance Time for Austria

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	20.94	0.27	20.42	21.46	78.93	<0.001
COVID-19	0.08	0.19	-0.30	0.45	0.41	0.68
>=5 hours	-0.17	0.23	-0.62	0.28	-0.73	0.47
Unknown	0.04	0.30	-0.56	0.63	0.13	0.90
Breathing	-1.21	0.33	-1.87	-0.56	-3.62	<0.001
History of Cerebrovascular Disease	-2.16	0.58	-3.29	-1.03	-3.75	<0.001
Sudden of Onset/TIA	-1.06	0.27	-1.59	-0.54	-3.98	<0.001
Other	-0.44	0.43	-1.28	0.40	-1.02	0.31

F (7, 14870) =3.71, R-Squared=0.002, Adjusted R-Squared=0.001

Appendix figure 6.10.11 - Results of Multivariable Regression on Allocation Performance for Northern Ireland

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	-0.73	1.43	-3.54	2.08	-0.51	0.61
COVID-19	8.02	1.33	5.42	10.63	6.04	<0.001
Location	4.31	0.73	2.88	5.73	5.92	<0.001
>=4 hours	14.53	0.89	12.79	16.28	16.35	<0.001
Unknown	-1.37	1.67	-4.65	1.91	-0.82	0.41
Breathing	4.23	1.08	2.10	6.35	3.90	<0.001
History of Cerebrovascular Disease	0.31	2.42	-4.43	5.05	0.13	0.90
Sudden of Onset/TIA	3.57	0.73	2.15	5.00	4.92	<0.001
Other	-4.35	7.98	-20.00	11.30	-0.54	<0.001

F (8, 10844) =45.54, R-Squared=0.033, Adjusted R-Squared=0.033

Appendix table 6.10.12 - Results of Multivariable Regression on Mobilisation Performance for Northern Ireland

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	0.28	1.46	-2.59	3.14	0.19	0.85
COVID-19	8.22	1.35	5.56	10.87	6.07	<0.001
Location	4.31	0.74	2.85	5.76	5.81	<0.001
>=4 hours	14.96	0.91	16.52	13.18	16.74	<0.001
Unknown	-1.14	1.71	-0.67	-4.49	2.20	0.50
Breathing	4.76	1.10	2.60	6.92	4.31	<0.001
History of Cerebrovascular Disease	0.32	2.46	-4.51	5.14	0.13	0.90
Sudden of Onset/TIA	3.66	0.74	2.21	5.11	4.94	<0.001
Other	-4.47	8.33	-20.81	11.87	-0.54	0.59

F (8, 10828) =47.29, R-Squared=0.033, Adjusted R-Squared=0.033

Appendix table 6.10.13 - Results of Multivariable Regression on Response time for Northern Ireland

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	16.98	1.58	13.89	20.08	10.75	<0.001
COVID-19	9.13	1.46	6.26	12.00	6.24	<0.001
Location	-2.34	0.81	-3.92	-0.76	-2.90	<0.001
>=4 hours	16.64	0.98	14.72	18.57	16.95	<0.001
Unknown	-1.01	1.85	-4.63	2.62	-0.54	0.59
Breathing	5.24	1.20	2.88	7.60	4.35	<0.001
History of Cerebrovascular Disease	0.27	2.70	-5.02	5.56	0.10	0.92
Sudden of Onset/TIA	4.09	0.80	2.51	5.66	5.09	<0.001
Other	-3.53	9.46	-22.07	15.01	-0.37	0.71

F (8, 10623) =44.99, R-Squared=0.033, Adjusted R-Squared=0.032

Appendix table 6.10.13 - Results of Multivariable Regression on On Scene Time for Northern Ireland

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	30.80	0.68	29.47	32.12	45.51	<0.001
COVID-19	3.06	0.63	1.83	4.29	4.88	<0.001
Location	0.51	0.35	-0.17	1.19	1.46	0.14
>=4 hours	2.53	0.42	1.71	3.36	6.01	<0.001
Unknown	1.28	0.85	-0.39	2.95	1.50	0.13
Breathing	-1.48	0.54	-2.53	-0.43	-2.76	0.01
History of Cerebrovascular Disease	-2.96	1.21	-5.34	-0.58	-2.44	0.02
Sudden of Onset/TIA	-2.62	0.35	-3.30	-1.94	-7.58	<0.001
Other	-1.35	4.24	-9.65	6.96	-0.32	0.75

F (8, 8654) =15.52, R-Squared=0.014, Adjusted R-Squared=0.013

Appendix table 6.10.15 - Results of Multivariable Regression on Conveyance Time for Northern Ireland

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	26.63	0.58	25.50	27.77	46.02	<0.001
COVID-19	-0.06	0.54	-1.11	0.99	-0.11	0.91
Location	-10.84	0.30	-11.42	-10.26	-36.53	<0.001
>=4 hours	1.46	0.36	0.75	2.17	4.05	<0.001
Unknown	0.81	0.73	-0.62	2.23	1.11	0.27
Breathing	0.51	0.46	-0.39	1.40	1.11	0.27
History of Cerebrovascular Disease	0.91	1.04	-1.12	2.94	0.88	0.38
Sudden of Onset/TIA	0.79	0.30	0.21	1.37	2.68	0.01
Other	8.32	3.62	1.23	15.41	2.30	0.02

F (8, 8625) =170.09, R-Squared=0.136, Adjusted R-Squared=0.136

Appendix table 6.10.16 - Results of Multivariable Regression on Allocation Performance for Scotland

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	-1.79	0.29	-2.35	-1.23	-6.22	<0.001
COVID-19	8.01	0.21	7.60	8.41	38.58	<0.001
Location	4.47	0.26	3.96	4.98	17.12	<0.001
Breathing	3.20	0.32	2.58	3.82	10.06	<0.001
History of Cerebrovascular Disease	2.60	0.66	1.30	3.90	3.93	<0.001
Sudden of Onset/TIA	1.95	0.23	1.50	2.41	8.37	<0.001
Other	11.41	0.50	10.43	12.39	22.89	<0.001

F (6, 82772) =373.45, R-Squared=0.026, Adjusted R-Squared=0.026

Appendix table 6.10.17 - Results of Multivariable Regression on Mobilisation Performance for Scotland

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	-0.28	0.27	-0.81	0.25	-1.04	0.30
COVID-19	7.38	0.19	7.00	7.76	38.07	<0.001
Location	3.55	0.24	3.07	4.02	14.56	<0.001
Breathing	2.89	0.30	2.31	3.47	9.72	<0.001
History of Cerebrovascular Disease	2.77	0.62	1.56	3.99	4.48	<0.001
Sudden of Onset/TIA	1.82	0.22	1.40	2.25	8.37	<0.001
Other	10.41	0.47	9.50	11.33	22.37	<0.001

F (6, 82772) =350.69, R-Squared=0.025, Adjusted R-Squared=0.025

Appendix table 6.10.18 - Results of Multivariable Regression on Response Time for Scotland

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	10.44	0.26	9.93	10.95	40.41	<0.001
COVID-19	6.76	0.19	6.39	7.12	36.27	<0.001
Location	-0.64	0.23	-1.10	-0.18	-2.72	0.01
Breathing	2.43	0.29	1.87	2.99	8.51	<0.001
History of Cerebrovascular Disease	2.55	0.60	1.38	3.71	4.28	<0.001
Sudden of Onset/TIA	1.59	0.21	1.18	2.00	7.61	<0.001
Other	7.89	0.45	7.02	8.77	17.64	<0.001

F (6, 82772) =271.89, R-Squared=0.019, Adjusted R-Squared=0.019

Appendix table 6.10.19 - Results of Multivariable Regression on On Scene Time for Scotland

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	24.46	0.18	24.11	24.81	136.16	<0.001
COVID-19	1.05	0.13	0.80	1.30	8.11	<0.001
Location	0.90	0.16	0.58	1.22	5.51	<0.001
Breathing	-3.57	0.20	-3.96	-3.18	-17.98	<0.001
History of Cerebrovascular Disease	-3.78	0.41	-4.59	-2.97	-9.13	<0.001
Sudden of Onset/TIA	-3.67	0.15	-3.96	-3.39	-25.23	<0.001
Other	-3.56	0.31	-4.17	-2.95	-11.43	<0.001

F (6, 82772) =144.00, R-Squared=0.010, Adjusted R-Squared=0.010

Appendix table 6.10.20 - Results of Multivariable Regression on Conveyance Time for Scotland

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	20.69	0.12	20.45	20.94	165.91	<0.001
COVID-19	-0.27	0.09	-0.45	-0.10	-3.02	<0.001
Location	-8.10	0.11	-8.32	-7.88	-71.66	<0.001
Breathing	-0.99	0.14	-1.26	-0.72	-7.14	<0.001
History of Cerebrovascular Disease	-0.87	0.29	-1.43	-0.30	-3.02	<0.001
Sudden of Onset/TIA	0.09	0.10	-0.10	0.29	0.93	0.35
Other	-1.47	0.22	-1.89	-1.04	-6.80	<0.001

F (6, 82772) =874.52, R-Squared=0.060, Adjusted R-Squared=0.060

Appendix table 6.10.21 - Results of Multivariable Regression on Allocation Performance for the Republic of Ireland

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	0.53	0.05	0.43	0.64	9.91	<0.001
during COVID	0.81	0.05	0.71	0.90	17.14	<0.001
Location	0.09	0.05	0.00	0.18	1.92	0.06
>=4 hours	0.04	0.05	-0.06	0.14	0.73	0.46
Unknown	-0.06	0.12	-0.30	0.18	-0.49	0.62
Breathing	-0.05	0.07	-0.20	0.10	-0.68	0.49
History of Cerebrovascular Disease	0.12	0.15	-0.17	0.41	0.80	0.42
Sudden of Onset/TIA	0.10	0.05	0.00	0.21	2.03	0.04
Other	-0.12	0.34	-0.79	0.54	-0.36	0.72

F (8, 39995) =38.4, R-Squared=0.008, Adjusted R-Squared=0.007

Appendix table 6.10.22 - Results of Multivariable Regression on Mobilisation Performance for the Republic of Ireland

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	1.87	0.06	1.76	1.99	31.37	<0.001
COVID-19	0.66	0.05	0.56	0.76	12.67	<0.001
Location	0.04	0.05	-0.06	0.15	0.84	0.40
>=4 hours	0.11	0.06	-0.01	0.22	1.84	0.07
Unknown	-0.07	0.13	-0.33	0.20	-0.49	0.62
Breathing	-0.02	0.08	-0.18	0.14	-0.23	0.82
History of Cerebrovascular Disease	0.14	0.17	-0.19	0.46	0.84	0.40
Sudden of Onset/TIA	0.14	0.06	0.03	0.25	2.43	0.02
Other	-0.08	0.38	-0.81	0.66	-0.20	0.84

F (8, 39995) =22.02, R-Squared=0.004, Adjusted R-Squared=0.004

Appendix table 6.10.23 - Results of Multivariable Regression on Response Time for the Republic of Ireland

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	23.96	0.19	23.59	24.33	127.34	<0.001
COVID-19	4.20	0.16	3.88	4.52	25.61	<0.001
Location	-8.47	0.17	-8.79	-8.15	-51.30	<0.001
>=4 hours	2.12	0.18	1.77	2.48	11.66	<0.001
Unknown	-0.20	0.43	-1.03	0.63	-0.47	0.64
Breathing	0.77	0.26	0.26	1.28	2.94	<0.001
History of Cerebrovascular Disease	-0.03	0.52	-1.05	1.00	-0.05	0.96
Sudden of Onset/TIA	0.71	0.18	0.36	1.07	3.96	<0.001
Other	0.23	1.18	-2.09	2.55	0.20	0.85

F (8, 39995) =441.88, R-Squared=0.081, Adjusted R-Squared=0.081

Appendix table 6.10.24 - Results of Multivariable Regression on On Scene Time for the Republic of Ireland

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	23.28	0.14	23.00	23.55	163.81	<0.001
COVID-19	2.61	0.12	2.36	2.85	21.05	<0.001
Location	-1.82	0.12	-2.07	-1.58	-14.62	<0.001
>=4 hours	1.69	0.14	1.42	1.96	12.26	<0.001
Unknown	-0.34	0.32	-0.97	0.29	-1.07	0.28
Breathing	-2.29	0.20	-2.67	-1.90	-11.58	<0.001
History of Cerebrovascular Disease	-1.12	0.39	-1.90	-0.35	-2.85	<0.001
Sudden of Onset/TIA	-2.77	0.14	-3.04	-2.50	-20.32	<0.001
Other	-2.65	0.89	-4.41	-0.90	-2.97	<0.001

F (8, 39995) =157.74, R-Squared=0.031, Adjusted R-Squared=0.030

Appendix table 6.10.25 - Results of Multivariable Regression on Conveyance Time for the Republic of Ireland

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	30.90	0.20	30.50	31.30	151.67	<0.001
during COVID	0.31	0.18	-0.04	0.66	1.76	0.08
Location	-14.43	0.18	-14.78	-14.08	-80.71	<0.001
>=4 hours	2.41	0.20	2.03	2.80	12.23	<0.001
Unknown	-0.20	0.46	-1.10	0.70	-0.43	0.66
Breathing	0.42	0.28	-0.14	0.97	1.48	0.14
History of Cerebrovascular Disease	0.68	0.56	-0.42	1.79	1.21	0.23
Sudden of Onset/TIA	1.73	0.20	1.35	2.12	8.87	<0.001
Other	-0.40	1.28	-2.91	2.12	-0.31	0.76

F (8, 39995) =847.73, R-Squared=0.145, Adjusted R-Squared=0.145

Appendix table 6.10.26 - Results of Multivariable Regression on Allocation Performance for New Zealand

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	1.64	0.12	1.40	1.88	13.31	<0.001
COVID-19	-0.85	0.08	-1.00	-0.69	-10.87	<0.001
Location	0.80	0.11	0.58	1.02	7.09	<0.001
>=4 hours	3.25	0.09	3.07	3.43	35.77	<0.001
Unknown	1.45	0.18	1.11	1.80	8.26	<0.001
Breathing	0.53	0.11	0.31	0.74	4.71	<0.001
History of Cerebrovascular Disease	0.71	0.25	0.23	1.19	2.88	<0.001
Sudden of Onset/TIA	0.69	0.09	0.52	0.86	7.88	<0.001
Other	0.97	0.45	0.08	1.86	2.14	0.03

F (11, 41750) =142.88, R-Squared=0.036, Adjusted R-Squared=0.036

Appendix table 6.10.27 - Results of Multivariable Regression on Mobilisation Performance for New Zealand

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	3.12	0.15	2.82	3.43	20.15	<0.001
COVID-19	-1.01	0.10	-1.20	-0.81	-10.25	<0.001
Location	0.42	0.14	0.14	0.70	2.95	<0.001
>=4 hours	3.55	0.11	3.32	3.77	31.02	<0.001
Unknown	1.52	0.22	1.08	1.95	6.85	<0.001
Breathing	0.73	0.14	0.45	1.00	5.19	<0.001
History of Cerebrovascular Disease	0.88	0.31	0.27	1.49	2.84	<0.001
Sudden of Onset/TIA	0.85	0.11	0.63	1.06	7.66	<0.001
Other	1.12	0.57	0.00	2.24	1.96	0.05

F (11, 41748) =106.67, R-Squared=0.027, Adjusted R-Squared=0.027

Appendix table 6.10.28 - Results of Multivariable Regression on Response Time for New Zealand

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	16.73	0.24	16.26	17.21	69.20	<0.001
during COVID	-1.57	0.15	-1.87	-1.27	-10.28	<0.001
Location	-2.11	0.22	-2.54	-1.67	-9.52	<0.001
>=4 hours	6.22	0.18	5.87	6.57	34.86	<0.001
Unknown	1.64	0.35	0.97	2.32	4.76	<0.001
Breathing	1.14	0.22	0.71	1.57	5.21	<0.001
History of Cerebrovascular Disease	1.80	0.48	0.85	2.75	3.72	<0.001
Sudden of Onset/TIA	1.56	0.17	1.22	1.90	9.07	<0.001
Other	1.42	0.89	-0.33	3.17	1.59	0.11

F (11, 41761) =229.28, R-Squared=0.057, Adjusted R-Squared=0.057

Appendix table 6.10.29 - Results of Multivariable Regression on On Scene Time for New Zealand

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	29.86	0.24	29.39	30.33	124.72	<0.001
COVID-19	1.70	0.15	1.40	2.00	11.21	<0.001
Location	-5.52	0.22	-5.95	-5.09	-25.07	<0.001
>=4 hours	1.06	0.18	0.72	1.41	6.02	<0.001
Unknown	1.38	0.35	0.70	2.07	3.96	<0.001
Breathing	-1.52	0.22	-1.95	-1.09	-6.95	<0.001
History of Cerebrovascular Disease	-1.71	0.49	-2.67	-0.76	-3.50	<0.001
Sudden of Onset/TIA	-3.08	0.17	-3.41	-2.75	-18.15	<0.001
Other	1.05	0.92	-0.74	2.85	1.15	0.25

F (11, 36202) =376.74, R-Squared=0.103, Adjusted R-Squared=0.102

Appendix table 6.10.30 - Results of Multivariable Regression on Conveyance Time for New Zealand

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	39.23	3.88	31.62	46.83	10.11	<0.001
COVID-19	5.12	2.46	0.30	9.94	2.08	0.04
Location	-17.15	3.57	-24.14	-10.15	-4.81	<0.001
>=4 hours	-2.62	2.86	-8.22	2.99	-0.91	0.37
Unknown	2.18	5.66	-8.92	13.28	0.38	0.70
Breathing	-2.30	3.54	-9.24	4.63	-0.65	0.52
History of Cerebrovascular Disease	-3.97	7.92	-19.50	11.57	-0.50	0.62
Sudden of Onset/TIA	0.14	2.75	-5.25	5.53	0.05	0.96
Other	-6.71	14.89	-35.89	22.47	-0.45	0.65

F (11, 36082) =6.27, R-Squared=0.002, Adjusted R-Squared=0.002

Appendix table 6.10.31 - Results of Multivariable Regression on Allocation Performance for the Netherlands

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	1.51	0.07	1.37	1.66	20.54	<0.001
COVID-19	0.4	0.05	0.31	0.49	8.82	<0.001
Location	-0.17	0.08	-0.33	-0.01	-2.07	<0.05
>=24 hours	0.2	0.11	-0.01	0.42	1.84	0.07
Unknown	0.11	0.1	-0.09	0.31	1.05	0.29
Breathing	0.06	0.07	-0.08	0.2	0.84	0.4
History of Cerebrovascular Disease	-0.13	0.12	-0.37	0.11	-1.03	0.3
Sudden of Onset/TIA	-0.02	0.05	-0.12	0.08	-0.4	0.69
Other	0.26	0.5	-0.01	0.42	0.51	0.61

F (11,10437) =8.72, R-Squared=0.009, Adjusted R-Squared=0.008

Appendix table 6.10.32 - Results of Multivariable Regression on Mobilisation Performance for the Netherlands

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	6.89	0.14	6.61	7.16	49.25	<0.001
COVID-19	0.11	0.09	-0.06	0.27	1.23	0.22
Location	3.63	0.16	3.32	3.94	23.03	<0.001
>=24 hours	1.33	0.21	0.91	1.75	0.00	<0.001
Unknown	-0.09	0.20	-0.48	0.29	0.64	0.64
Breathing	0.04	0.14	-0.23	0.31	0.28	0.78
History of Cerebrovascular Disease	0.28	0.23	-0.17	0.74	1.23	0.22
Sudden of Onset/TIA	0.00	0.10	-0.19	0.20	0.02	0.99
Other	1.51	0.95	-0.34	3.37	1.6	0.11

F (11, 10150) =65.8, R-Squared=0.066, Adjusted R-Squared=0.066

Appendix table 6.10.33 - Results of Multivariable Regression on Response Time for the Netherlands

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	8.39	0.16	8.07	8.70	52.15	<0.001
COVID-19	0.50	0.10	0.31	0.69	5.05	<0.001
Location	3.46	0.18	3.10	3.82	19.08	<0.001
>=24 hours	1.51	0.24	1.03	1.99	6.19	<0.001
Unknown	0.01	0.23	-0.43	0.46	0.06	0.95
Breathing	0.10	0.16	-0.21	0.42	0.66	0.51
History of Cerebrovascular Disease	0.14	0.27	-0.38	0.66	0.52	0.60
Sudden of Onset/TIA	-0.02	0.11	-0.24	0.20	-0.17	0.87
Other	1.78	1.09	-0.36	3.92	1.63	0.10

F (11, 10150) =47.21, R-Squared=0.049, Adjusted R-Squared=0.048

Appendix table 6.10.34 - Results of Multivariable Regression on On Scene Time for the Netherlands

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	21.65	0.39	20.89	22.41	55.91	<0.001
COVID-19	1.36	0.24	0.89	1.83	5.69	<0.001
Location	-1.03	0.44	-1.89	-0.17	-2.34	0.02
>=24 hours	3.12	0.59	1.97	4.27	5.30	<0.001
Unknown	2.31	0.54	1.25	3.37	4.26	<0.001
Breathing	0.61	0.39	-0.15	1.36	1.57	0.12
History of Cerebrovascular Disease	0.36	0.65	-0.91	1.63	0.55	0.58
Sudden of Onset/TIA	-2.09	0.28	-2.63	-1.55	-7.59	<0.001
Other	-0.56	2.69	-5.84	4.72	-0.21	0.84

F (11, 9580) =17.77, R-Squared=0.02, Adjusted R-Squared=0.019

Appendix table 6.10.35 - Results of Multivariable Regression on Conveyance Time for the Netherlands

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	7.22	0.27	6.69	7.74	26.89	<0.001
COVID-19	-0.01	0.17	-0.33	0.32	-0.05	0.96
Location	6.30	0.30	5.71	6.89	20.81	<0.001
>=24 hours	-0.18	0.41	-0.97	0.62	-0.44	0.66
Unknown	0.06	0.37	-0.67	0.80	0.16	0.87
Breathing	-0.44	0.27	-0.97	0.08	-1.65	0.10
History of Cerebrovascular Disease	-0.06	0.45	-0.94	0.81	-0.14	0.89
Sudden of Onset/TIA	0.09	0.19	-0.28	0.47	0.49	0.62
Other	-1.69	1.90	-5.41	2.02	-0.89	0.37

F (11, 9402) =50.96, R-Squared=0.056, Adjusted R-Squared=0.057

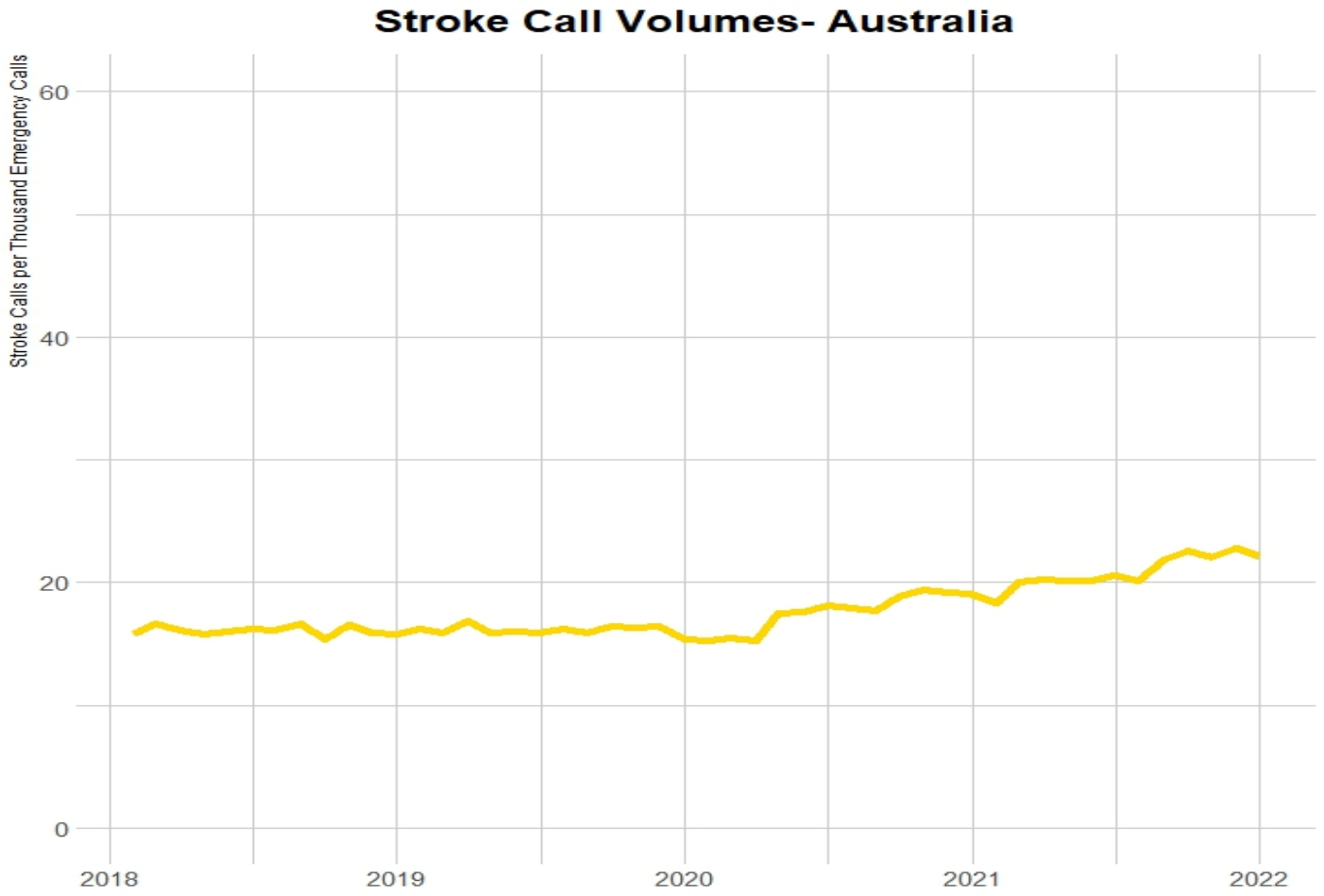
Appendix 6.11 - Monthly suspected stroke/TIA calls per 1,000 emergency calls from 2018-2021 for the seven services included in this study

Year	Month	Australia	Austria	New Zealand	Northern Ireland	Scotland	The Netherlands	The Republic of Ireland
2018	Jan	16	19	22	17	29	20	41
2018	Feb	17	19	22	20	30	25	40
2018	Mar	16	22	22	20	30	26	41
2018	Apr	16	22	23	18	28	25	39
2018	May	16	21	22	16	28	18	40
2018	Jun	16	22	23	23	26	22	37
2018	Jul	16	22	24	23	26	23	36
2018	Aug	17	20	26	23	27	21	39
2018	Sep	15	22	26	25	25	23	36
2018	Oct	17	22	25	24	29	25	38
2018	Nov	16	18	26	27	28	24	39
2018	Dec	16	17	25	23	27	26	35
2019	Jan	16	18	24	26	29	25	37
2019	Feb	16	19	25	26	27	23	37
2019	Mar	17	18	25	25	29	22	37
2019	Apr	16	18	26	25	27	25	37
2019	May	16	18	25	24	26	22	38
2019	Jun	16	15	26	24	27	24	36
2019	Jul	16	18	27	24	27	21	37
2019	Aug	16	16	26	21	26	22	37
2019	Sep	16	21	27	25	26	22	36
2019	Oct	16	13	27	24	29	23	38
2019	Nov	16	21	27	24	31	25	37
2019	Dec	15	20	28	23	31	29	35
2020	Jan	15	19	27	22	30	28	38
2020	Feb	16	19	25	21	32	27	37
2020	Mar	15	16	28	23	32	22	29
2020	Apr	18	20	33	20	35	16	32
2020	May	18	21	34	23	36	22	39
2020	Jun	18	19	33	23	38	20	37
2020	Jul	18	19	30	23	37	21	40
2020	Aug	18	19	31	23	34	21	35
2020	Sep	19	24	32	22	37	26	35

2020	Oct	19	21	31	25	37	23	35
2020	Nov	19	26	32	23	40	25	38
2020	Dec	19	24	33	23	39	25	42
2021	Jan	18	24	31	25	37	23	38
2021	Feb	20	23	32	30	40	23	46
2021	Mar	20	21	33	26	41	27	52
2021	Apr	20	24	32	29	41	23	48
2021	May	20	22	31	27	38	29	47
2021	Jun	21	18	32	24	37	28	45
2021	Jul	20	21	34	22	37	29	42
2021	Aug	22	19	35	24	37	25	42
2021	Sep	23	20	36	28	34	26	42
2021	Oct	22	22	35	25	36	26	38
2021	Nov	23	19	36	27	37	27	46
2021	Dec	22	19	35	29	38	32	43

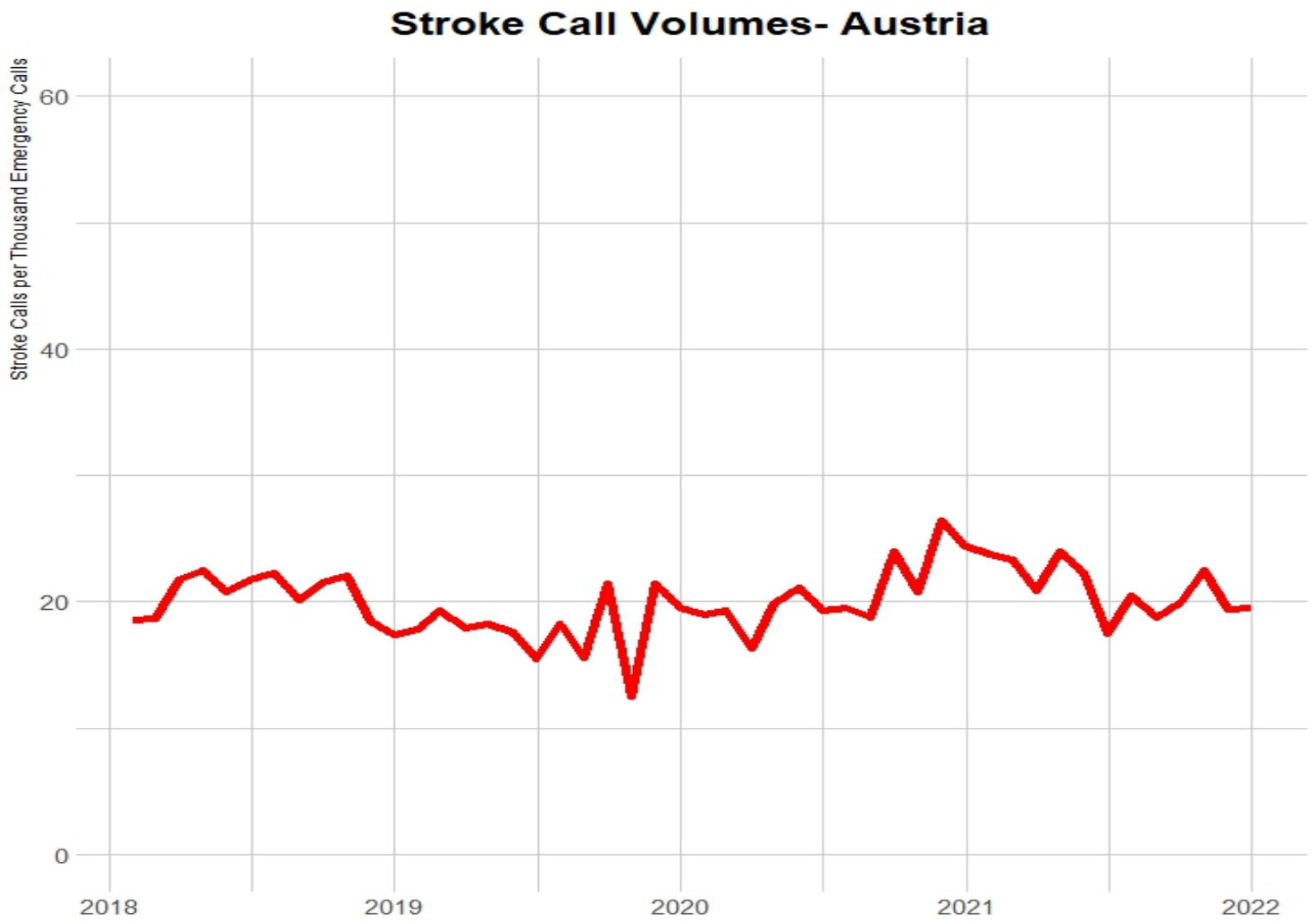
Appendix 6.12 - Graphs of monthly suspected stroke/TIA calls per 1,000 emergency calls for each country from 2018-2021

(a)



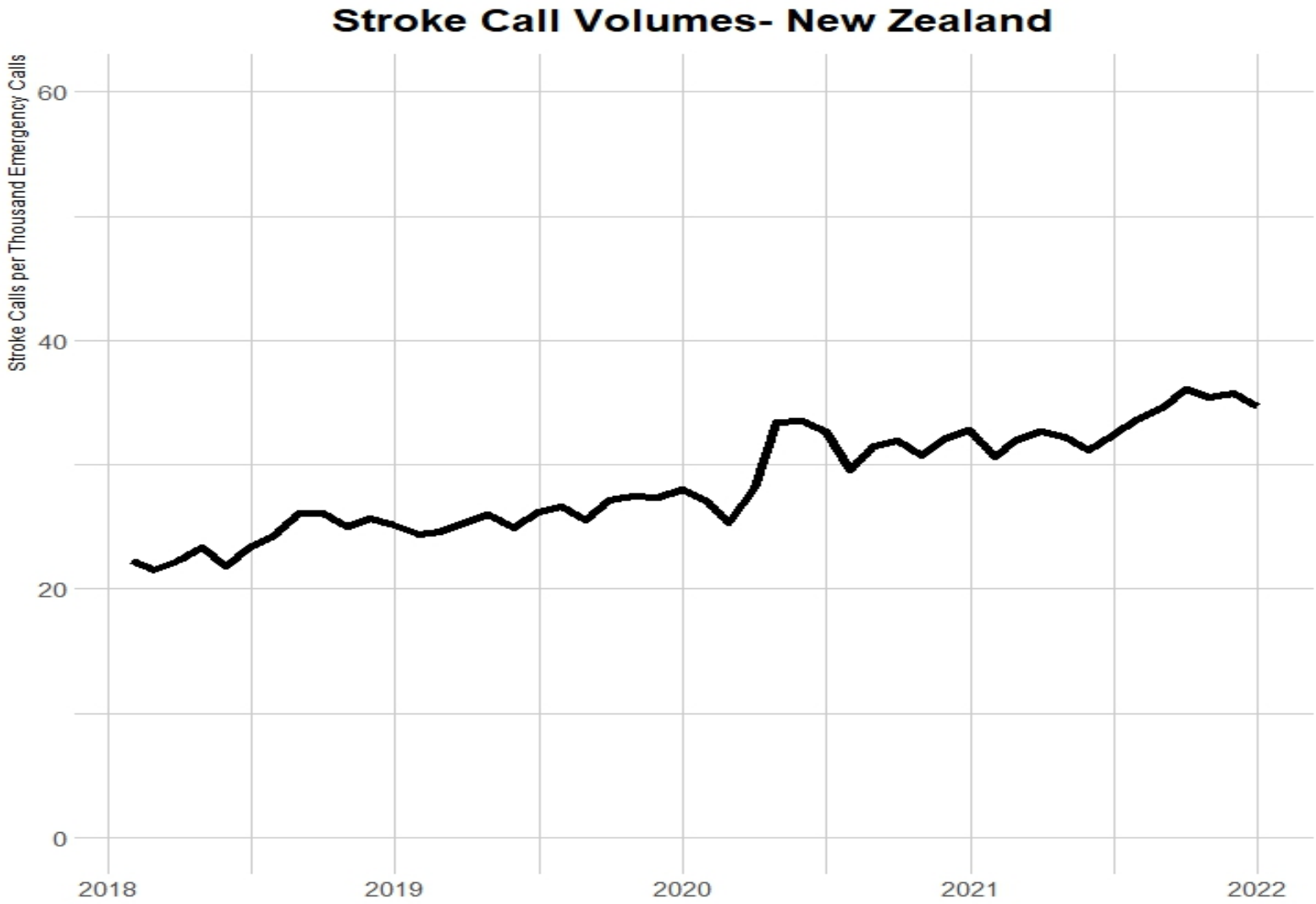
Appendix figure 6.12 (a) - Monthly suspected stroke/TIA calls per 1,000 emergency calls for Australia from 2018-2021

(b)



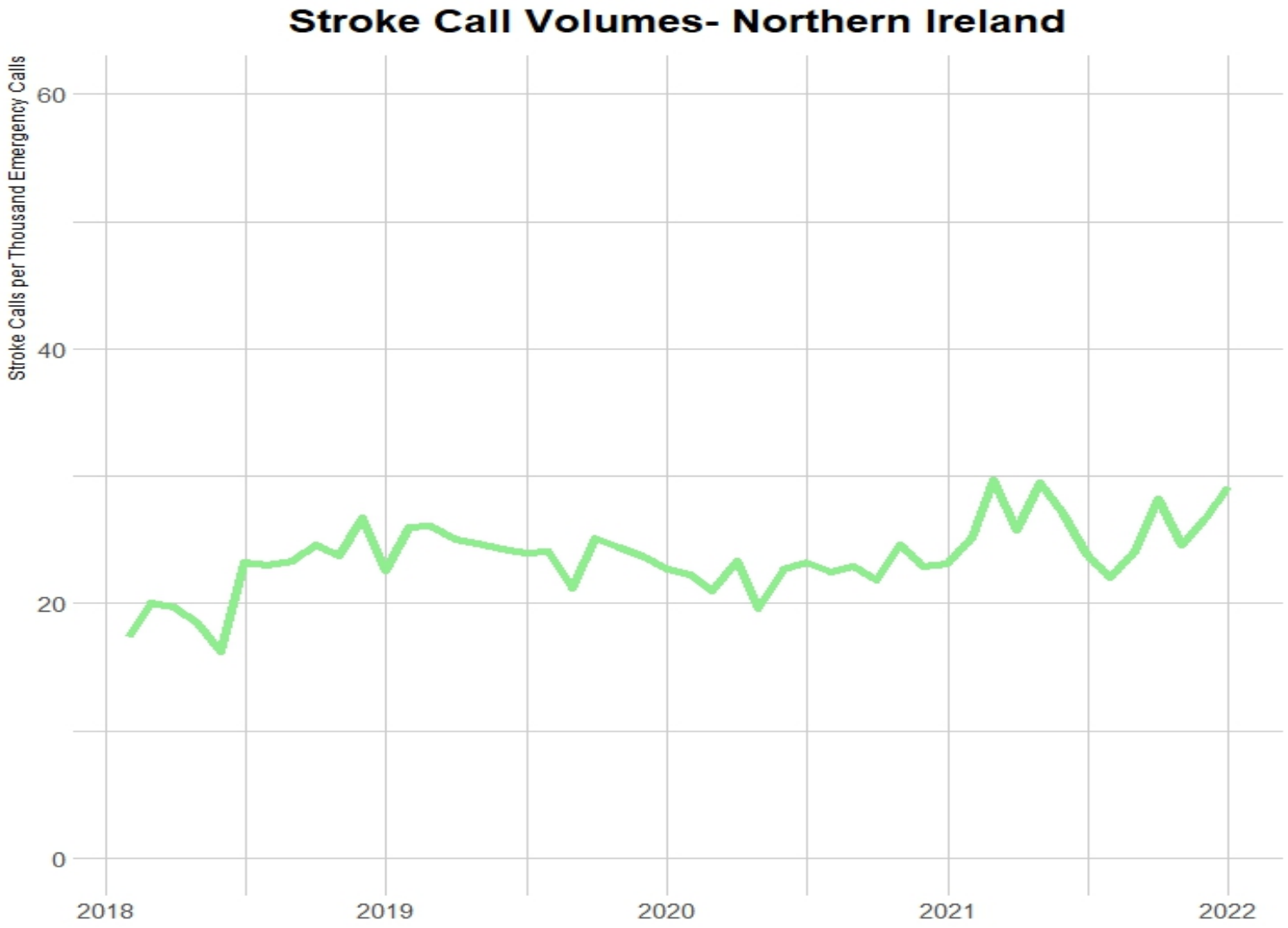
Appendix figure 6.12 (b) - Monthly suspected stroke/TIA calls per 1,000 emergency calls for Austria from 2018-2021

(c)



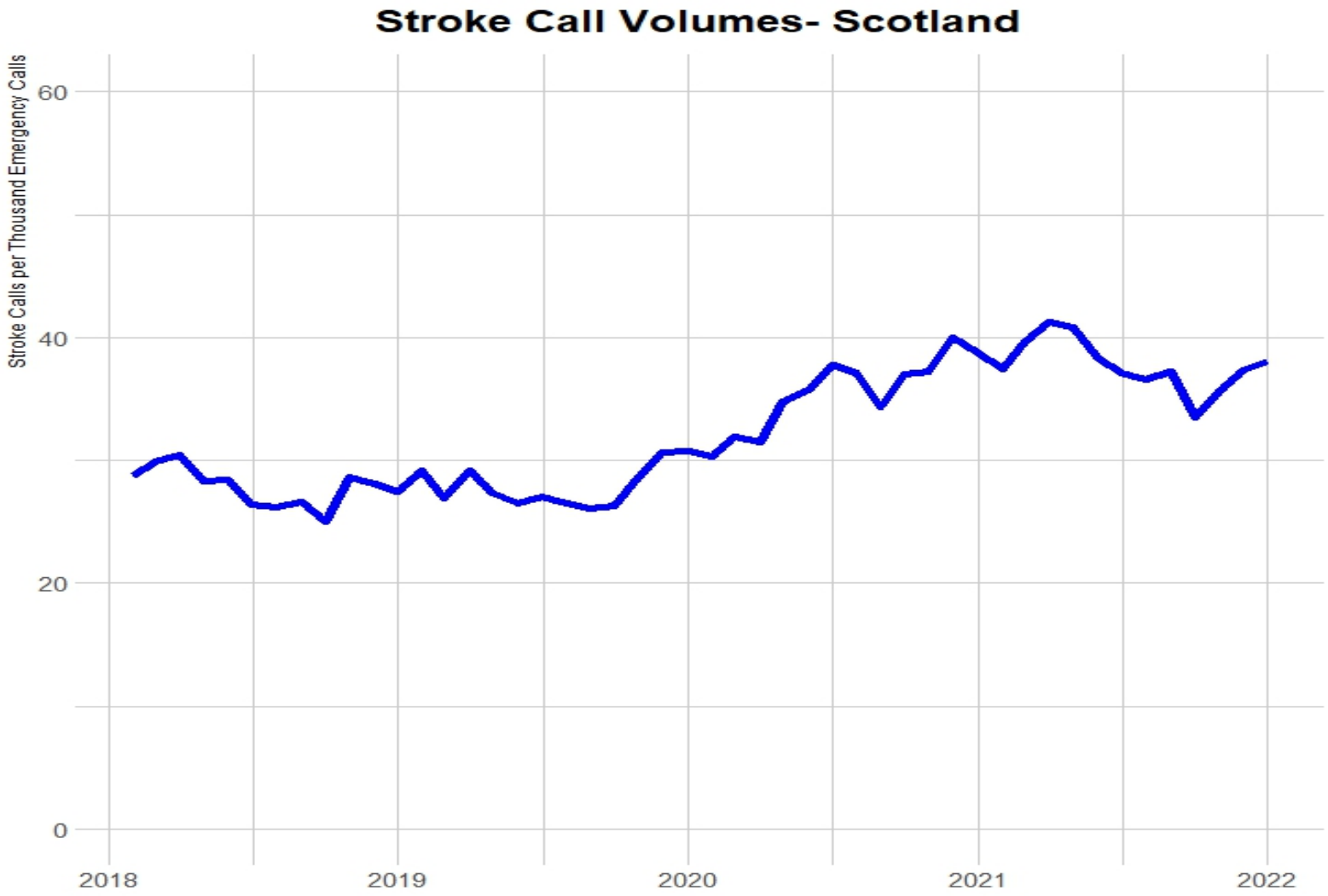
Appendix figure 6.12 (c) - Monthly suspected stroke/TIA calls per 1,000 emergency calls for New Zealand from 2018-2021

(d)



Appendix figure 3.12 (d) - Monthly suspected stroke/TIA calls per 1,000 emergency calls for Northern Ireland from 2018-2021

(e)

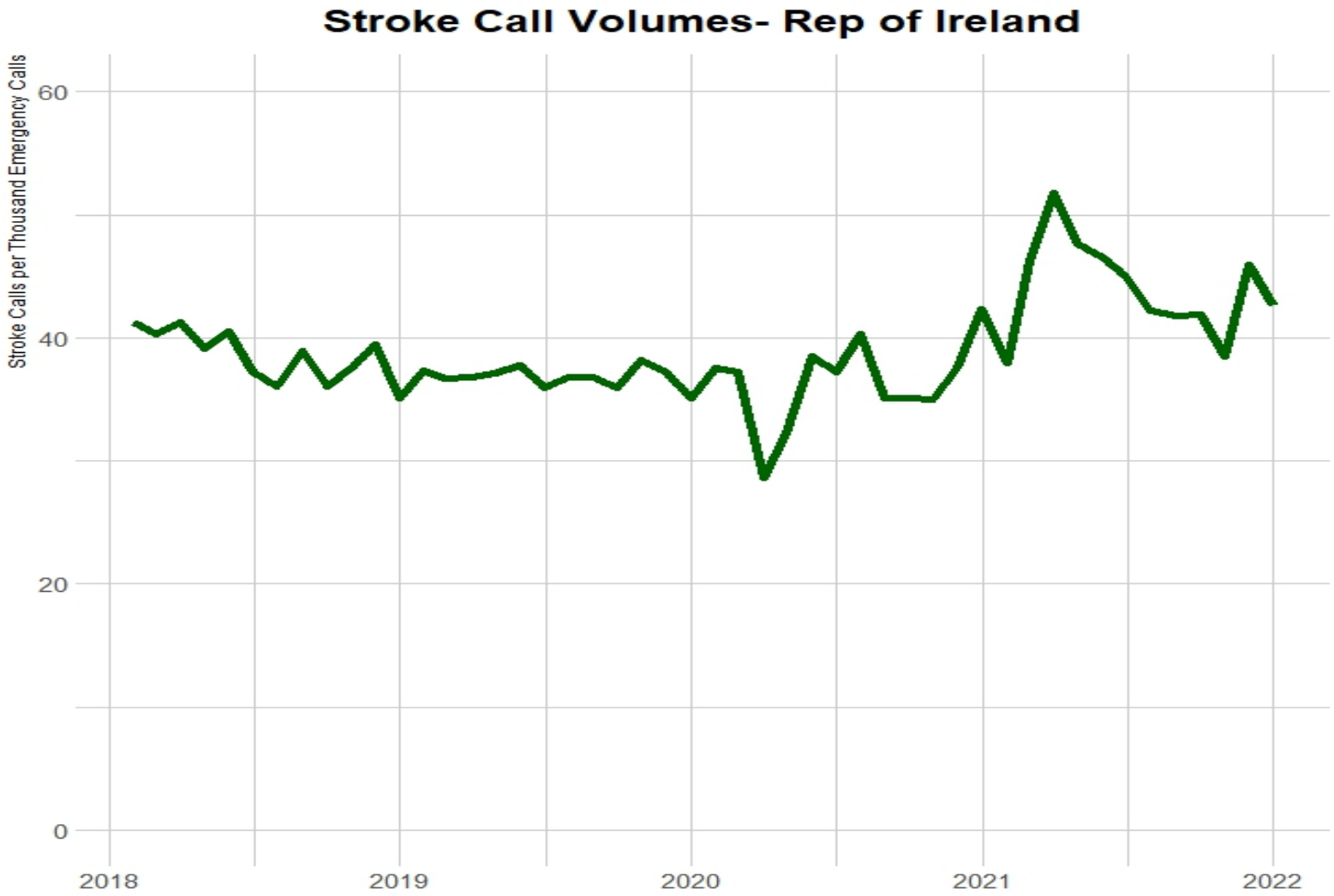


656 Appendix figure 6.12 (e) - Monthly suspected stroke/TIA calls per 1,000 emergency calls for Scotland from 2018-2021

(f)

657 Appendix figure 6.12 (f) - Monthly suspected stroke/TIA calls per 1,000 emergency calls for the Netherlands from 2018-2021

(g)



Appendix figure 6.12 (g) - Monthly suspected stroke/TIA calls per 1,000 emergency calls for the Republic of Ireland from 2018-2021

Appendix 6.13 - Results of the Mann-Kendall Trend test

Country	Test Statistic	p-value
Austria	z=1.13	p=0.13
Australia	z=6.04	p<.001
New Zealand	z=7.83	p<.001
Northern Ireland	z=2.77	p<.01
Scotland	z=5.62	P<.001
The Netherlands	z=2.66	p<.01
The Republic of Ireland	z=1.77	p<.05

Appendix 6.14 - Results of the linear regression analyses of call volume

Appendix table 6.14.1 - Results of the Univariable Regression on Call Volume for Austria

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	19.19	0.47	18.23	20.14	40.77	<0.001
COVID-19	1.76	0.70	0.36	3.16	2.53	0.02

F (1,46) = 6.42, R-Squared = 0.1225, Adjusted R-Squared = 0.1035

Appendix table 6.14.2 - Results of Univariable Regression on Call Volume for Northern Ireland

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	22.81	0.53	21.74	23.88	42.88	<0.001
COVID-19	1.92	0.79	0.34	3.5	2.444	0.02

F (1, 46) =5.97, R-Squared=0.1149, Adjusted R-Squared=0.0956

Appendix table 6.14.3 - Results of Univariable Regression on Call Volume for the Republic of Ireland

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	37.62	0.78	36.05	39.18	48.36	<0.001
COVID-19	2.88	1.15	0.57	5.20	2.51	0.02

F (1, 46) =6.3, R-Squared=0.1205, Adjusted R-Squared=0.1014

Appendix table 6.14.4 - Results of Univariable Regression on Call Volume for the Netherlands

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	23.69	0.59	22.50	24.89	39.84	<0.001
COVID-19	0.81	0.88	-0.96	2.58	0.92	0.36

F (1, 46) =0.85, R-Squared=0.018, Adjusted R-Squared=-0.0033

Appendix table 6.14.5 - Results of Univariable Regression on Call Volume for New Zealand

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	25.04	0.37	24.29	25.78	67.26	<0.001
COVID-19	7.64	0.55	6.54	8.76	13.9	<0.001

F (1, 46) =193.23, R-Squared=0.8077, Adjusted R-Squared=0.8035

Appendix table 6.14.6 - Results of Univariable Regression on Call Volume for Australia

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	16.04	0.30	15.44	16.64	54.21	<0.001
COVID-19	3.43	0.43	2.58	4.30	8.04	<0.001

F (1, 46) =64.69, R-Squared=0.5844, Adjusted R-Squared=0.5754

Appendix table 6.14.7 - Results of Univariable Regression on Call Volume for Scotland

Effect	Estimate	SE	95% CI		t	p - value
			LL	UL		
Constant	28.08	0.40	27.27	28.88	70.24	<0.001
COVID-19	9.10	0.60	7.92	10.29	15.42	<0.001

F (1, 46) =237.77, R-Squared=0.8379, Adjusted R-Squared=0.8344

Appendix 6.15 – Outputs from Chapter 6b

Publications

Title	Journal	Date of Publication	Authors
International Comparison of Ambulance Time Intervals for Stroke/Tia Across Seven Countries Before and During the Covid-19 Pandemic	European Stoke Journal (Abstract)	September 2024	Burton E Quinn R Boseley E Deasy C Henderson C Hutchinson H Krammel M Lloyd A Loudon W Quinn T Masterson S O'Donnell C Overton J Van de Pas H Willis D Wolfe JH Crosbie-Staunton K Merwick Á McCarthy VJC Kearney PM Buckley CM

Conferences

Title	Conference	Date	Type	Authors

Title	Conference	Date	Type	Authors
International Comparison of Ambulance Time Intervals for Stroke/Transient Ischaemic Attack Across Seven Countries Before and During the COVID-19 Pandemic	European Society for Emergency Medicine Conference	October 2024	Oral presentation	Burton E Quinn R Boseley E Deasy C Henderson C Hutchinson H Krammel M Lloyd A Loudon W Quinn T Masterson S O'Donnell C Overton J Van de Pas H Willis D Wolfe JH Crosbie-Staunton K Merwick Á McCarthy VJC Kearney PM Buckley CM

Title	Conference	Date	Type	Authors
International Comparison of Emergency Call Volume for Stroke/Transient Ischaemic Attack in The Republic of Ireland, Northern Ireland and Scotland Before and During The COVID-19 Pandemic	Royal College of Paramedics Conference	May 2024	Moderated poster presentation	Burton E Quinn R Boseley E Deasy C Henderson C Hutchinson H Krammel M Lloyd A Loudon W Quinn T Masterson S O'Donnell C Overton J Van de Pas H Willis D Wolfe JH Crosbie-Staunton K Merwick Á McCarthy VJC Kearney PM Buckley CM

Title	Conference	Date	Type	Authors
International comparison of emergency call volume for stroke/transient ischaemic attack across seven countries before and during the COVID-19 pandemic	Irish Neurological Association Meeting	May 2024	Oral presentation	Burton E Quinn R Boseley E Deasy C Henderson C Hutchinson H Krammel M Lloyd A Loudon W Quinn T Masterson S O'Donnell C Overton J Van de Pas H Willis D Wolfe JH Crosbie-Staunton K Merwick Á McCarthy VJC Kearney PM Buckley CM

International Comparison of Ambulance Time Intervals for Stroke/TIA Across Seven Countries Before and During The COVID-19 Pandemic	European Stroke Organisation	May 2024	Poster presentation	Burton E Quinn R Boseley E Deasy C Henderson C Hutchinson H Krammel M Lloyd A Loudon W Quinn T Masterson S O'Donnell C Overton J Van de Pas H Willis D Wolfe JH Crosbie-Staunton K Merwick Á McCarthy VJC Kearney PM Buckley CM

Podcast

Title	Date of publication	Authors	Link
Global Insights: Ambulance Response Times for Stroke and TIA Across Seven Services - A Pre- and Post-Pandemic Analysis	November 2024	Burton E On behalf of the PHoCoS Consortium	Not yet available at time of submission

Policy Brief

Title	Date of publication	Authors	Link
International Comparison of Ambulance Time Intervals For Suspected Stroke/Transient Ischaemic Attack (TIA) Across Seven Services Before And During The COVID-19 Pandemic	December 2024	Burton E Quinn R Boseley E Deasy C Henderson C Hutchinson H Krammel M Lloyd A Loudon W Quinn T Masterson S O'Donnell C Overton J Van de Pas H Willis D Wolfe JH Crosbie-Staunton K Merwick Á McCarthy VJC Kearney PM Buckley CM	Not yet available at time of submission

Lay Summary

Title	Date of publication	Authors	Link
How Ambulance Response Times for Stroke and TIA Changed Before and During the COVID-19 Pandemic: A Global Comparison of Seven International Ambulance Services	December 2024	Burton E PHoCoS Consortium Devoy C Foley N Madden D Mancini H Masterson O'Regan J Quinn M	Not yet available at time of submission

Published Papers from this thesis

Academic activities conducted during thesis

PhD-related outputs

Publications

Title	Journal	Date of Publication	Authors
Ambulance Duration at Hospital for Stroke Calls Before and During The COVID-19 Pandemic in Ireland	European Stroke Journal (Abstract)	September 2024	McCarthy E. Burton E. Quinn R. Crosbie-Staunton K Deasy C Merwick Á Kearney P.M. McCarthy V.J.C. Buckley C.M. Willis D. Masterson S. O'Donnell C.

Title	Organisation	Date	Author(s)
Review of compliance with	National	February	Burton E.

Reports/Guidance

management, administration and requisition policies for morphine in a National Ambulance Service Area	Ambulance Service Clinical Directorate	2023	Willis D.
Guidelines for the Collaborative Doctoral Programme in Chronic Disease Prevention (CDP-CDP) mentoring scheme https://www.universityofgalway.ie/cdp-cdp/cdp-cdptraining/mentorship/	Collaborative Doctoral Programme in Chronic Disease Prevention (CDP-CDP)	June 2022	Burton E. Carvalho M. Dunne P. Gibson I. Haseldine C. Kenna E.
Review of the process of exporting a medication list from a reliable source and importing it into the “current medication” of the electronic patient care record (ePCR)	National Ambulance Service Clinical Directorate	March 2022	Burton E. Willis D.

Professional Magazine Articles

Title	Publication	Date	Author(s)
Stroke and TIA Stroke and Transient Ischaemic Attack (TIA) - IPU	IPU Review	March 2024	Burton E.
A Pharmacist Among Paramedics: My Experience with the National Ambulance Service Clinical Directorate	Hospital Professional News	August 2022	Burton E.
Taking the Road Less Travelled – My Journey to Becoming a PhD Student	Hospital Professional News	November 2020	Burton E.
Taking the Road Less Travelled – My Journey to Becoming a PhD Student	Irish Pharmacy News	October 2020	Burton E.

Title	**Blog site**	**Date**	**Author(s)**

Blogs

A Pharmacist Amongst Paramedics An account of a SPHeRE national placement in the National Ambulance Service Clinical Directorate	Structured Population and Health services research education (SPHeRE) Blog series	June 2022	Burton E. Willis D.
Taking the Road Less Travelled – My Journey to Becoming a PhD Student	Structured Population and Health services research education (SPHeRE) Blog series	October 2020	Burton E.

Conferences

Title	Conference	Date	Type	Authors
Ambulance duration at hospital for stroke calls before and during the covid-19 pandemic in Ireland	European Stroke Organisation	May 2024	Poster presentation	E. McCarthy, E. Burton, R. Quinn, K. Crosbie-Staunton, C. Deasy, Á. Merwick, P.M., Kearney, V.J.C. McCarthy, C.M. Buckley, D. Willis, S. Masterson, C. O'Donnell
Heterogeneity in the pre-hospital terminology for "call volume" through the lens of stroke: a review of the international literature	Prehospital Emergency Care Council	November 2023	Poster presentation	E. Burton, S. Masterson, C. O'Donnell
Heterogeneity in the prehospital terminology for "call volume" through the lens of stroke: a review of the international literature	Irish Association of Emergency Medicine	October 2023	Poster presentation	Burton E, Masterson S, O'Donnell C
Title	**Conference**	**Date**	**Type**	**Authors**
Temporal trends of duration of	Irish	October	Poster	E. McCarthy,

resource at hospital time for suspected stroke/transient ischaemic attack (TIA) before and during the COVID-19 pandemic in Ireland: a quasi-experimental study	Association of Emergency Medicine	2023	presentation	E. Burton, R. Quinn, K. Crosbie-Staunton, C. Deasy, Á. Merwick, P.M., Kearney, V.J.C. McCarthy, C.M. Buckley, D. Willis, S. Masterson, C. O'Donnell
Temporal trends of duration of resource at hospital time for suspected stroke/transient ischaemic attack (TIA) before and during the COVID-19 pandemic in Ireland: a quasi-experimental study	UCC College of Medicine and Health Futures Conference	Sept 2023	Poster presentation	E. McCarthy, E. Burton, R. Quinn, K. Crosbie-Staunton, C. Deasy, Á. Merwick, P.M., Kearney, V.J.C. McCarthy, C.M. Buckley, D. Willis, S. Masterson, C. O'Donnell
Title	**Conference**	**Date**	**Type**	**Authors**
Temporal trends of duration of	Safe Patient	June 2023	Poster	E. McCarthy, E.

resource at hospital time for suspected stroke/transient ischaemic attack (TIA) before and during the COVID-19 pandemic in Ireland: a quasi-experimental study	Care Conference		presentation	Burton, R. Quinn, K. Crosbie-Staunton, C. Deasy, Á. Merwick, P.M., Kearney, V.J.C. McCarthy, C.M. Buckley, D. Willis, S. Masterson, C. O'Donnell

Other Presentations

Title	Location	Presentation type	Date	Authors
Stroke and TIA	Irish Pharmacy Union Academu	Webinars	February and March 2024	Burton E.
Prehospital emergency care of stroke	Munster Integrated Stroke Research Catalyst, UCC	Oral	September 2023	Burton E.
Medication management after stroke	Regional Stroke Conference, Tipperary	Oral	June 2023	Burton E.
The impact of the COVID-19 pandemic on prehospital emergency care for stroke/transient ischaemic attacks and implications for future policy and service delivery	University of Galway – CDP-CDP Summer School	Oral	May 2023	Burton E. McCarthy V. Kearney PM. Buckley C

Title	Location	Presentation type	Date	Authors
Temporal trends of duration of resource at hospital time for suspected stroke/TIA before and during the COVID-19 pandemic in Ireland: a quasi-experimental study	Irish Paramedicine Education and Research Network (IPERN) EMS week symposium	Oral	May 2023	E. McCarthy, E. Burton, R. Quinn, K. Crosbie-Staunton, C. Deasy, Á. Merwick, P.M. Kearney, V.J.C. McCarthy, C.M. Buckley, D. Willis, S. Masterson, C. O'Donnell
The impact of the COVID-19 pandemic on prehospital emergency care for stroke/transient ischaemic attacks and implications for future policy and service delivery	Online – CDP-CDP Executive Programme Advisory Board	Oral	February 2023	Burton E. McCarthy V. Kearney PM. Buckley C.

Title	Location	Presentation type	Date	Authors
The impact of the COVID-19 pandemic on prehospital emergency care for stroke/transient ischaemic attacks and implications for future policy and service delivery	Online Collaborative Doctoral Programme in Chronic Disease Prevention Exeucitve Board Meeting	Oral	October 2022	Burton E. McCarthy V. Kearney PM. Buckley C.
The impact of the COVID-19 pandemic on prehospital emergency care for stroke/transient ischaemic attacks and implications for future policy and service delivery	Bons Secours Hospital Cork Journal Club	Oral	September 2022	Burton E. McCarthy V. Kearney PM. Buckley C.
The impact of the COVID-19 pandemic on prehospital emergency care for stroke/transient ischaemic attacks and implications for future policy and service delivery	National University of Ireland Galway	Oral	June 2022	Burton E. McCarthy V. Kearney PM. Buckley C.

Title	Location	Presentation type	Date	Authors
A Pharmacist Amongst Paramedics – My Experience of National Placement	Trinity College Dublin – SpheRE Peer Learning Day	Oral	June 2022	Burton E.
When shock strikes twice – stroke/TIA ambulance times in COVID - 19	Pint of Science Festival "Our Society" Section	Oral	May 2022	Burton E.
My PhD Knowledge Translation Strategy	University College Cork, HRB CDP-CDP Training Event	Oral	May 2022	Burton E.
Mentorship in my PhD studies	University College Cork, HRB CDP-CDP Training Event	Oral	March 2022	Burton E.
Overview of stakeholder involvement, international collaborations, and placement in my PhD	HRB Collaborative Doctoral Award in Chronic Disease Prevention Executive Programme Advisory Board Meeting	Oral	October 2021	Burton E. McCarthy V. Kearney PM. Buckley C.
Doing a PhD – Tips and Tricks	Online UCC Postgraduate Research Orientation	Oral Presentation	October 2021	Burton E. Thomas S.

Title	Location	Presentation type	Date	Authors
Medication Management After Stroke	Cork Stroke Support Group, Blackrock, Cork	Oral presentation	September 2021	Burton E.
Overview of PhD research	HRB Collaborative Doctoral Programme on Chronic Disease Prevention Summer School	Oral presentation	June 2021	Burton E. McCarthy V. Kearney PM. Buckley C.

Other outputs during the PhD

Publications

Title	Journal	Date of Publication	Authors
Adherence to Antihypertensive Prescription Guidelines in Older Adults: A Cross-Sectional Study Using Data from The Mitchelstown Cohort Re-Screen Study	BMC Proceedings (Abstract)	October 2024	T. Das, E. Burton, M. Bermingham, P.M. Kearney
Prescriber Adherence to Antihypertensive Prescription Guidelines and the Impact of Patient Socioeconomic Factors: A Cross-Sectional Study Using Data from The Irish Longitudinal Study on Ageing	Journal of Pharmacoepidemiology and Drug Safety (Paper)	September 2024	Akhtar A, Burton E, Bermingham M, Kearney PM
The effects of removing the requirement for prior reimbursement approval on anticoagulant use in Ireland: A cross - sectional study	Journal of Pharmacoepidemiology and Drug Safety (Paper)	September 2024	Scannell M, Burton E, Kearney PM
Impact of sociodemographic characteristics on Prescriber Adherence to Antihypertensive Prescription Guidelines: A Cross-Sectional Study Using Data from The Irish Longitudinal Study on Ageing	International Journal of Pharmacy Practice (Abstract)	September 2024	Akhtar A, Burton E, Bermingham M, Kearney PM
Impact Of Pharmacovigilance Concerns on Dispensing of Angiotensin-Converting Enzyme Inhibitors and Angiotensin Receptor Blockers During (Abstract)	Pharmacoepidemiology and Drug Safety	August 2024	E. Burton, Éilis O'Reilly, Meadhbh Cosgrove, Mark Coughlan, Lorna English, Prajakta Meshram, Margaret Bermingham

Title	Journal	Date of Publication	Authors
Alcohol per capita and prevalence of alcohol exposed pregnancies: systematic review and meta-analysis (Abstract)	European Journal of Public Health	July 2024	E Burton, S Kelly, PM Kearney, M Moffat, J Morris, J Rankin, M O'Mahony
Identifying Research Priorities for Infection Prevention and Control. A mixed methods study with a convergent design.	Journal of Infection Prevention	February 2024	M Smiddy, E Burton, L. Kingston, T Thomas, M Moyo, A Flores
Development of the Irish Paramedicine Education and Research Network (IPERN): Overview of Activity 2021-2022 **(Abstract)**	Prehospital and Disaster Medicine	June 2023	Niamh Cummins, Ann-Marie Bright, Edel Burton, Brian Doyle, Damien Gaumont, Michelle O'Toole
The effects of removing the requirement for prior reimbursement approval on anticoagulant use in Ireland: A cross-sectional study **(Abstract)**	International Journal of Pharmacy Practice	September 2023	Scannell M. Burton E. Kearney P.M.
The protected antimicrobial process in a University Teaching Hospital: a qualitative interview study exploring the knowledge, attitudes, and experiences of healthcare professionals	International Journal of Clinical Pharmacy	February 2022	Burton E. O'Driscoll M. Fleming A.

Title	Journal	Date of Publication	Authors
Appropriate Prescribing in Hospitalized Older Adults with Renal Impairment: A Retrospective Audit from The Senator Trial **(Abstract)**	Journal of Pharmacoepidemiology and Drug Safety	August 2021	Burton E. Byrne S. O'Mahony D. Dalton K.
The Protected Antimicrobial Process: Knowledge, Attitudes and Experiences of Healthcare Professionals in An Irish Hospital **(Abstract)**	Journal of Pharmacoepidemiology and Drug Safety	august 2021	Burton E. O'Driscoll M. O'Riordan F. O'Brien D. Halleran C. Fleming A.

Conference Presentations

Title	Conference	Date	Type	Authors
Factors Influencing Medication Adherence Among People with Anxiety or Depression: A Cross-Sectional Study Using Data from The Mitchelstown Cohort Rescreen Study 2015	Psychology Health and Medicine Conference	May 2024	Oral	Hearne L, Burton E, Bermingham M
Impact Of Pharmacovigilance Concerns on Dispensing of Angiotensin-Converting Enzyme Inhibitors and Angiotensin Receptor Blockers During Covid-19 In Ireland and The United Kingdom	Prescribing Research in Medicines Management (PRIMM)	May 2024	Poster	E. Burton, Éilis O'Reilly, Meadhbh Cosgrove, Mark Coughlan, Lorna English, Prajakta Meshram, Margaret Bermingham
Impact of sociodemographic characteristics on Prescriber Adherence to Antihypertensive Prescription Guidelines: A Cross-Sectional Study Using Data from The Irish Longitudinal Study on Ageing	Health Services Research and Pharmacy Practice Conference	April 2024	Oral	Akhtar A, Burton E, Bermingham M, Kearney PM
Impact of sociodemographic characteristics on Prescriber Adherence to Antihypertensive Prescription Guidelines: A Cross-Sectional Study Using Data from The Irish Longitudinal Study on Ageing	Health Services Research and Pharmacy Practice Conference	April 2024	Poster	Akhtar A, Burton E, Bermingham M, Kearney PM

Title	Conference	Date	Type	Authors
Factors associated with non-attendance among older adults in the national diabetic retinal screening programme: A cross-sectional study	Structured Population Health and Health Services Research Education Conference	Poster	February 2024	Ryan A, Kearney PM, Burton E, McHugh S, O'Keeffe L, Stamenic D, Buckley CM
Impact of pharmacovigilance concerns on dispensing of angiotensin-converting enzyme inhibitors and angiotensin receptor blockers during COVID-19 in Ireland and the United Kingdom	Structured Population and Health Services Research Education (SPHeRE) Conference	Poster	February 2024	E. Burton, Éilis O'Reilly, Meadhbh Cosgrove, Mark Coughlan, Lorna English, Prajakta Meshram, Margaret Bermingham
Adherence to Antihypertensive Prescription Guidelines in Older Adults: A Cross-Sectional Study Using Data from The Mitchelstown Cohort Re-Screen Study	International Conference for Healthcare and Medical Students	Poster	February 2024	T. Das, E. Burton, M. Bermingham. P.M. Kearney
Title	**Conference**	**Date**	**Type**	**Authors**

Title	Conference	Date	Type	Authors
Alcohol per capita and prevalence of alcohol exposed pregnancies: systematic review and meta-analysis	Royal College of Physicians Ireland Faculty of Public Health Medicine Winter Scientific Meeting	Oral	December 2023	E Burton, PM Kearney, S Kelly, M Moffat, J Morris, J Rankin, M O'Mahony
The effects of suspected pharmacovigilance concerns related to angiotensin receptor blockers (ARBs) and angiotensin-converting-enzyme inhibitors (ACEIs) during the COVID-19 pandemic on their prescription frequencies in Ireland and the United Kingdom - an interrupted time series analysis	The National Patient Safety Office Conference	Poster	October 2023	E. Burton, Éilis O'Reilly, Meadhbh Cosgrove, Mark Coughlan, Lorna English, Prajakta Meshram, Margaret Bermingham
Alcohol per capita and prevalence of alcohol exposed pregnancies: systematic review and meta-analysis	Health Research Board Advancing alcohol research in Ireland	Poster	September 2023	E Burton, PM, Kearney, S Kelly, M Moffat, J Morris, J Rankin, M O'Mahony

Identifying Research Priorities for Infection Prevention and Control. A mixed methods approach.	Infection Prevention Society	Oral	October 2023	Smiddy M, Burton E, L. Kingston, Moyo M, Thomas T, Flores A
Alcohol per capita and prevalence of alcohol exposed pregnancies: systematic review and meta-analysis	European Public Health Conference	Poster	November 2023	E Burton, S Kelly, PM Kearney, M Moffat, J Morris, J Rankin, M O'Mahony
Adherence to Antihypertensive Prescription Guidelines in Older Adults: A Cross-Sectional Study Using Data from The Mitchelstown Cohort Re-Screen Study	College of Medicine and Health Futures Conference	Oral	Sept 2023	T. Das, E. Burton, M. Bermingham, P.M. Kearney
Impact of sociodemographic characteristics on Prescriber Adherence to Antihypertensive Prescription Guidelines: A Cross-Sectional Study Using Data from The Irish Longitudinal Study on Ageing	College of Medicine and Health Futures Conference	Poster	Sept 2023	Akhtar A, Burton E, Bermingham M, Kearney PM
Title	**Conference**	**Date**	**Type**	**Authors**
Development of the Irish Paramedicine	World	Oral	May 2023	Niamh

Education and Research Network (IPERN): Overview of Activity 2021-2022	Association for Disaster and Emergency Medicine	(tabletop)		Cummins, Ann-Marie Bright, Edel Burton, Brian Doyle, Damien Gaumont, Michelle O'Toole
Adherence to Antihypertensive Prescription Guidelines in Older Adults: A Cross-Sectional Study Using Data from The Mitchelstown Cohort Re-Screen Study	SPHeRE Conference	Oral	March 2023	Akhtar A, Burton E, Bermingham M, Kearney PM
The effects of removing the requirement for prior reimbursement approval on anticoagulant use in Ireland: A cross-sectional study	SPHeRE Conference	Oral	March 2023	Scannell M, Burton E, Kearney PM
Prescriber Adherence to Antihypertensive Prescription Guidelines and the impact of patient socio-economic factors: A Cross-Sectional Study Using Data from The Irish Longitudinal Study on Ageing (TILDA)	SPHeRE Conference	Oral	March 2023	Akhtar A. Burton E. Bermingham M. Kearney P.K.
Adherence to Antihypertensive Prescription Guidelines in Older Adults: A Cross-Sectional Study Using Data from The Mitchelstown Cohort Re-Screen Study	SPHeRE Conference	Poster	March 2023	Tarun D. Burton E. Bermingham M Kearney PM
Title	**Conference**	**Date**	**Type**	**Authors**
The effects of removing the	Health	Oral	April 2023	Scannell M.

requirement for prior reimbursement approval on anticoagulant use in Ireland: A cross-sectional study	Services Research and Pharmacy Practice Conference			Burton E. Kearney P.M.
Experiences, attitudes, and wellbeing of university students of a period of restricted movement and self-testing during COVID-19 iSWAB study	Structured Population Health and Health Services Research Education	Poster	March 2022	McGovern M. Burton E. Fanning L. Killeen G. O'Sullivan K. O'Mullane J Fitzgerald T Byrne M Kearney PM
Experiences, attitudes, and wellbeing of university students of a period of restricted movement and self-testing during COVID-19 iSWAB study	European Public Health Conference	Oral	November 2021	McGovern M. Burton E. Fanning L. Killeen G. O'Sullivan K. O'Mullane J Fitzgerald T Byrne M Kearney PM
Appropriate Prescribing in Hospitalised Older Adults with Renal Impairment: A Retrospective Audit from the Senator Trial	Prescribing and Research in Medicines Management Conference	Oral	June 2021	Burton E. Byrne S. O'Mahony D. Dalton K.
Title	**Conference**	**Date**	**Type**	**Authors**
The Protected Antimicrobial Process:	Prescribing	Poster	June 2021	Burton E.

Knowledge, Attitudes and Experiences of Healthcare Professionals in An Irish Hospital	and Research in Medicines Management Conference			O'Driscoll M. O'Riordan F. O'Brien D. Halleran C. Fleming A.
The Protected Antimicrobial Process: Knowledge, Attitudes and Experiences of Healthcare Professionals in An Irish Hospital	Structured Population and Health Services Research Education Conference	Poster	February 2021	Burton E. O'Driscoll M. O'Riordan F. O'Brien D. Halleran C. Fleming A.
Appropriate Diagnosis and Treatment of Community Acquired Pneumonia Requiring Hospitalisation – A Retrospective Audit in an Acute Irish Hospital	Structured Population and Health Services Research Education Conference	Poster	February 2021	Burton E. Finch K. Nugent F. Carey B. Fitzmaurice K.
The Protected Antimicrobial Process: Knowledge, Attitudes and Experiences of Healthcare Professionals in An Irish Hospital	University College Cork's New Horizon Conference	Poster	December 2020	Burton E. O'Driscoll M. O'Riordan F. O'Brien D. Halleran C. Fleming A.

Other Presentations

Title	Location	Presentation type	Date	Authors
Medicine used in self-harm in Ireland – an overview	National Suicide Research Foundation	Oral	October 2023	E Burton
The effects of suspected pharmacovigilance concerns related to Angiotensin receptor blockers (ARBs) and Angiotensin-converting-enzyme inhibitors (ACEi) on their prescription frequencies during the COVID-19 pandemic in Ireland – an interrupted time series analysis	Bons Secours Hospital – Learn at lunch	Oral	6th September 2023	Edel Burton, Éilis O'Reilly, Meadhbh Cosgrove, Mark Coughlan, Lorna English, Prajakta Meshram, Margaret Bermingham
Association of alcohol per capita (APC) with national, regional, and global prevalence of alcohol use during pregnancy and fetal alcohol	EU Joint Research Centre (JRC) – EUROCAT Registry Leaders Meeting (RLM)	Oral	28th June 2023	Burton E., Kelly S., Kearney P.M., Moffat M., Morris J., Rankin J., O'Mahony M.

syndrome: a systematic review and meta-analysis				
My journey to becoming a pharmacist – Course and Career Talk	Mount Mercy College, Cork.	Oral Presentation	November 2021	Burton E.
COVID-19 Vaccine Centres and common questions by clients	Online Town Hall meeting for UCC School of Public Health staff and students	Oral Presentation	September 2021	Burton E.

Teaching contributions and student supervision

1. Students supervised during PhD

Academic Year	Student	Course	Project
2023/2024	Sheesa Joseph	Pharmacy	Pharmacist roles in delivering cardiac rehabilitation: A Scoping Review of the Literature
2023/2024	Sonia Akthar	Pharmacy	Pharmacist roles in delivering cardiac rehabilitation: A Scoping Review of the Literature
2023/2024	Emma Crowley	Master of Pharmacy	An evaluation of self-management support education in the mpharm curriculum, University College Cork – the views of students
2023/2024	Maeve Smith	Master of Pharmacy	A cross-sectional survey of community pharmacists' views on the provision of regular hormonal contraception in community pharmacy practice

Academic Year	Student	Course	Project
2023/2024	Gráinne Barrett	Master of Pharmacy	An evaluation of self-management support education in the mpharm curriculum, University College Cork – the views of students
2023/2024	Kate Fitzgibbon	Master of Public Health	Temporal trends in the dispensing patterns of semaglutide and dulaglutide in ireland from 2018-2023
2023/2024	Mujtaba Mohammed	Master of Public Health	Demographic and clinical characteristics associated with the prescription of beta-blockers in older adults: a cross-sectional study using data from the English Longitudinal Study of Ageing (ELSA).

Academic Year	Student	Course	Project
2023/2024	Ashwin Basavaraj	Master of Public Health	Demographic and clinical characteristics associated with the prescription of beta-blockers in older adults: a cross-sectional study using data from the Northern Ireland Cohort for the Longitudinal Study of Ageing
2023/2024	Aoife Doody and Róisín mcauliffee	Bsc Public Health placement students	Ethnic disparities in pre-hospital stroke outcomes in New Zealand.
2022/2023	Lorna English	Postgraduate Diploma in Pharmaceutical Regulatory Sciences	Impact of COVID-19 pandemic on prescribing trends of ACEis and ARBS in the UK
2022/2023	Maeve Cosgrove	Postgraduate Diploma in Pharmaceutical Regulatory Sciences	Impact of COVID-19 pandemic on prescribing trends of ACEis and ARBS in Ireland
2022/2023	Prajakta Meshram	Master of Public Health	Impact of COVID-19 pandemic on prescribing trends of ACEis and ARBS in the UK

Academic Year	Student	Course	Project
2022/2023	Mark Coughlan	Master of Public Health	Impact of COVID-19 pandemic on prescribing trends of ACEis and ARBS in Ireland
2022/2023	Govind Rajesh Kartha	Master of Public Health	Systematic Review of Covid-19 Outcomes in People Using ACEis/ARBs
2023/2024	Alizeh Akthar	Medicine	Effects of Management of Depression in Cardiovascular Disease Risk in Older Adults: A Cross-Sectional Study Using Data from The Irish Longitudinal Study on Ageing
2022/2023	Emma McCarthy	BSc Public Health placement student	Temporal trends of duration of resource at hospital time for suspected stroke/transient ischaemic attack (TIA) before and during the COVID-19 pandemic in Ireland: a quasi-experimental study

Academic Year	Student	Course	Project
2021-2024	Ailish Ryan	Medicine HRB Summer Studentship 2023	The factors associated with non-attendance in the Irish National Diabetic Retinal screening programme by older Irish adults
2021/2022	Mary Scannell	Master of Public Health	The effects of removing the requirement for prior reimbursement approval on anticoagulant use in Ireland: A cross-sectional study.
2021/2022	Alizeh Athar	Master of Public Health	Prescriber Adherence to Antihypertensive Prescription Guidelines and the Impact of Patient Socioeconomic Factors: A Cross-Sectional Study Using Data from The Irish Longitudinal Study on Ageing

Academic Year	Student	Course	Project
2021/2022	Tarun Das	Medicine HRB Summer Studentship	Adherence to Antihypertensive Prescription Guidelines in Older Adults: A Cross-Sectional Study Using Data from The Mitchelstown Cohort Re-Screen Study
2020/2021	Maeve McGovern	BSc Public Health SURE, Summer Scholarship	Experiences, attitudes and wellbeing of university students of a period of restricted movement and self-testing during COVID-19 the iSWAB (Student Wellbeing and the Acceptability and Benefits of serial COVID-19 testing) study

2. Modules taught during PhD

Academic Year	Module title	Module code
2023/2024	University College Cork Pilot Patient and Public Involvement postgraduate course	Pilot course - NA
2023/2024	Central Nervous System	PF4014
2023/2024	Respiratory, Musculoskeletal and Dermatology Systems	PF3012
2023/2024	Professional Practice 11	PF3011
2023/2024	Supply of Medicines and Organisation and management Skills	PF6414
2023/2024	Professional Practice and Public Health	PF6416
2023/2024		PF2017
2023/2024	Pharmacy Research Project	PF4016
2023/2024	Research Dissertation in Pharmacy	PF6421
2021 – present	Research for Medicine and Health 11	MX4091
2023/2024	Population Health	EH3013
2023/2024	Principles and Practices of Public Health	EH6025
2023/2024	Epidemiology for Evidence Based Healthcare	HC3008
2021 - 2023	Data Analysis for Public Health Research	EH3004

Academic Year	Module title	Module code
2022-present	Pharmacovigilance	EH6137
2022/2023	Pharmacoepidemiology	EH6136
2021 - present	Health Protection	EH4003
2021 - present	The Principles and Practice of Multi-disciplinary Health Protection	EH6019
2021 - present	Master of Public Health Dissertation	EH6115
2021 – present	The Principles and Clinical Practices of Infection Prevention and Control	EH6146
2021 – present	Advanced Health Protection	EH6151
2021 – present	Clinical Practice 1	PF 4013
2021 – present	Clinical Practice 11	PF6400
2020/2021	Principles and Practice of Systems Development	IS2205
2020 - 2023	Advanced Epidemiology	EH6031
2020 - present	Public Health in Practice	EH3016