Heatwaves and Emergency Departments in Italy (HEAT-ED IT)

Strategies to identify determinants of overload and mitigate impact

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Heatwaves And Emergency Departments in Italy (HEAT-ED IT): Strategies to Identify Determinants of Overload and Mitigate Impact

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Dedicated to Lara,

Compass and Sextant of my Journey

Declaration

I hereby declare that the contents and organization of this thesis, submitted in fulfillment of the requirements for completion of the International Doctoral Program in Global Health, Humanitarian Aid, and Disaster Medicine, jointly organized by Università del Piemonte Orientale (UPO) and Vrije Universiteit Brussel (VUB), constitute my own original work and does not compromise in any way the rights of third parties, including those relating to the security of personal data.

Matteo Paganini

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1. **Paganini M**, Valente M, Conti A, Ragazzoni L, Barone-Adesi F. Emergency medical care overload during heatwaves: a neglected topic. *Eur J Emerg Med*. 2023 Feb 1;30(1):5-6. doi: 10.1097/MEJ.0000000000000975.

2. **Paganini M**, Lamine H, Della Corte F, Hubloue I, Ragazzoni L, Barone-Adesi F. Factors causing emergency medical care overload during heatwaves: A Delphi study. *PLoS One*. 2023 Dec 20;18(12):e0295128. doi: 10.1371/journal.pone.0295128.

3. **Paganini M,** Markou-Pappas N, Della Corte F, Rosi P, Trillò G, Ferramosca M, Paoli A, Politi F, Valerio A, Favaro A, Hubloue I, Ragazzoni L, Barone-Adesi F, Lamine H. Heatwaves Impact on Prehospital Emergency Medicine: A Qualitative Study to Improve Sustainability and Disaster Preparedness in Veneto Region, Northern Italy. *Sustainability*. 2024; 16(16):6911. doi: 10.3390/su1616691

LIST OF ABBREVIATIONS

Authors'/Note (A/N)

Conference of the Parties 26 (COP26)

Conference of the Parties 28 (COP28)

Consolidated Criteria for Reporting Qualitative Research (COrEQ)

Emergency Department (ED)

Emergency Medical Service (EMS)

European Society for Emergency Medicine (EUSEM)

Extreme Weather Events (EWE)

General Practitioner (GP)

Hazard and Vulnerability Analysis (HVA)

Heat-Health Action Plan (HHAP)

Personal Protective Equipment (PPE)

Prehospital Emergency Medicine (PHEM)

Regional Agency for Environmental Protection and Prevention of Veneto (ARPAV)

Standard Deviation (SD)

World Association for Disaster and Emergency Medicine (WADEM)

World Health Organization (WHO)

INTRODUCTION

Global warming is a demonstrated phenomenon resulting in atmospheric and oceanic average temperatures rise. The prevailing scientific viewpoint attributes this phenomenon to various factors, with human (anthropogenic) activity being the most significant contributor [1].

The impact of human activities is connected to the accumulation of carbon dioxide and other pollutant gas emissions that mainly arise from the utilization of fossil fuels. As a consequence, these emissions are responsible for an additional greenhouse effect, which has led to an increase in the overall temperature of the troposphere. The connection between global warming and greenhouse gases emissions is further confirmed by data showing an exponential temperature rise from 1850, when the industrial revolution started [2].

Current situation reached an alarming threshold. Despite in 2015 in Paris countries have agreed to hold global warming well below 2°C over preindustrial levels by 2100, with efforts toward limiting warming to 1.5°C [3], greenhouse gases emissions are still above the recommended levels. By 2007, the mean surface temperature had already risen by 0.76°C [1], but more recent studies forecasted a rise of as high as 4.2°C by the end of the century [4,5]. After meeting again in the Conference of the Parties (COP26) in 2021, the Glasgow Climate Pact was signed, confirming the intentions of limiting planetary mean temperature increase, but without a detailed roadmap [6]. The last meeting (COP28) held in Dubai, introduced a new health declaration, signed by more than 140 countries, suggesting to intervene on the problem from two sides: adaptation to a changing climate and cutting GHGs emissions (mitigation) but, again, without a precise program [7].

Global warming, a primary driver of climate change [8], poses a severe risk to humankind. It has been described as “the biggest global health threat of the 21st century” [9]. Over the past six decades, climatologists have observed clear shifts in climate patterns, including sea level rise, glaciers retreat, and oceanic acidification – all occurring at unprecedented rates. The acceleration of Earth’s

Water Cycle through evaporation, caused by the average increase in temperatures, has been hypothesized as the mechanism underlying all these processes [10]. In a disaster medicine perspective, climate change can be interpreted as a complex and protracted hazard [11] primarily affecting the environment and – consequently – the human population [12]. In particular, a dramatic increase in Extreme Weather Events (EWEs), such as heatwaves, cyclones, droughts, rainfall, and floods has been registered[13,14]: as a risk multiplier and modifier, preparedness strategies against climate change are more than ever required.

Among EWEs, heatwaves are generally defined as periods of unusual heat or high temperatures. The term "generally" is here used since a unique definition, shared across researchers on the available literature, is currently lacking. Mirroring the increasing trends of global warming, there is clear evidence in literature that exposure to heatwaves has been worsening in the last decades [15,16] and projections are not comforting [17]. Apart from the clinical features of heat illness, which can be immediately known to healthcare personnel, the effects of heatwaves are contingent upon the readiness of the community and the health and welfare system. Therefore, successful implementation of preventive measures determines the balance between exposure and protection of individuals' vulnerabilities. In particular, the frailest strata of the population such the elderly, those socially or economically disadvantaged, and those with comorbidities are at risk of exacerbation of chronic diseases or suffering from heat illness [18]. In this view, heat-health action plans (HHAPs) have been implemented in several countries, but prospective studies confirming their positive impact on populations' outcomes are lacking. Moreover, HHAPs lack specific interventions aiming to preserve the resilience of emergency medical care – which is currently at the forefront of healthcare – during heatwaves [18,19].

ORGANIZATION OF THE THESIS

This doctoral thesis is organized as follows.

Chapter 1 provides a more detailed background regarding the impact of climate change on disaster patterns and, consequently, on healthcare.

Chapter 2 further explains the impact of heatwaves on emergency care, detailing issues in EDs and PHEM, limitations of current literature, and research needs, arising from a scoping review of the literature performed at the beginning of the doctoral project.

Chapter 3 describes the results obtained from a Delphi study aiming at investigating factors predisposing emergency medical care to overload during heatwaves.

Findings of a semi-structured interview study exploring PHEM aspects are explained in **Chapter 4**.

Finally, the overall achievements of this doctoral project are discussed in **Chapter 5**.

CHAPTER 1: IMPACT OF CLIMATE CHANGE AND HEATWAVES

As already explained in the introduction, EWEs accounts for 90% of all the disasters in the last 20 years and, more importantly, their frequency has increased by 46% from 2007 to 2016 (compared with the 1990-99 average) [8]. This pattern mirrors the increasing global temperatures in the same period, reinforcing the interconnections between climate change and disaster medicine.

The World Association for Disaster and Emergency Medicine (WADEM) recommends for the adoption of a risk-based approach by all disaster and emergency professionals and organizations [20]. This approach should aim to prepare for and enhance resilience to the effects of climate change. Additionally, WADEM recommends that this approach be linked to the implementation of the Sendai Framework for Disaster Risk Reduction (2015-2030) [21]. Also, considering the four disaster medicine cycle phases [22] – mitigation/prevention, preparedness, response, and recovery –, disaster risk reduction strategies are effective if applied during mitigation and preparedness [21], as every dollar spent in disaster mitigation results in a 6$ saving [23]. Developed countries, due to their technological, organizational, and financial capacities to cope with adverse effects of EWEs, are generally perceived as less vulnerable to climate change [24]. However, a recent study by Keim et al. suggests that the incidence of hydrological and meteorological EWEs is positively associated with world gross domestic product. Therefore, the risk of climate-related disasters is not reduced by an increase in societal capacity alone, but disaster-related hazards and exposures should also be targeted by disaster risk reduction strategies [25].

More broadly, by increasing and worsening disasters, climate change can deeply affect healthcare systems and populations in different ways.

Impact of climate change on healthcare systems

A significant effect exerted by climate change on global health include substantial financial losses due to both disrupted and lost lives, as well as increased healthcare expenses. Knowlton et al.

examined the health-related expenses associated with six climate change-related events potentially affecting human health – ozone pollution, heatwaves, hurricanes, infectious disease outbreaks, river flooding, and wildfires – finding that the estimated costs exceeded $14 billion (in 2008 U.S. dollars) [26]. This inevitably translates in a burden on different aspects of society and public health.

Moreover, EWEs threaten the sustainability of healthcare systems by causing direct damage to essential services and infrastructure networks, thereby diminishing their resilience and adaptability during periods of public health crisis [27]. The surge of individuals who have sustained injuries, or seeking care due to disruption in primary care networks, have a significant impact on hospitals and healthcare facilities, particularly in terms of managing patient flows presenting to Emergency Departments (EDs) [28].

Without significant mitigating measures, the increased incidence of EWEs pose a substantial threat to several components of current society, and especially the healthcare systems [9]. Quality of air, lack of drinking water, and food can be significantly affected by environmental and meteorological alterations, which can also cause significant changes in the prevalence of infectious diseases, forced population displacements, and migrations. All these stressors put a significant burden on healthcare systems critically threatening their resilience.

Climate change and population health

At an individual level, EWEs have a multitude of health implications. In the short term, these may encompass bodily harm, compromised nutritional status, heightened prevalence of communicable diseases, augmented susceptibility to water- and food-borne illnesses, worsening of chronic conditions, environmental diseases. In the long term, the protraction of severe weather phenomena may result in unfavorable effects on mental well-being associated with the disaster and prolonged states of precariousness, unpredictability, and social instability.

Interestingly, the association between climate and human health has been noted since at least the fifth century BC. In commenting on the good health of the Egyptians and Libyans, Herodotus (ca. 440 BC), attributed similar good health status to the stability of their climate, adding [29]:

> *"Diseases almost always attack men when they are exposed to a change, and never more than during changes of the weather"*

Hippocrates, who lived approximately between 460 and 377 BC, dedicated several chapters in his treatise "*On Airs, Waters, and Places*" describing the effects of the seasons of the year on the human body and associated diseases [30]. A concrete shift towards scientific demonstration of climate-health associations started in the late nineteenth century with meticulous meteorological data collection and systematic clinical registration. In 1885, Farr first presented evidence of an association between respiratory illness and low temperatures [31]. Later, West et al. reported a strong association between temperature and fatalities resulting from ischemic heart disease in England and Wales [32]. Over the past few decades, the subject of climate change and its effects has undergone rigorous scientific examination and has increasingly become a political issue since the mid-1990s, leading to better evidence demonstrating previously unnoticed effects due to this escalation in EWEs.

Heatwaves: definition

The inconsistency in heatwaves definition has already been highlighted by a number of authors in recent years, such as Perkins [33] and a systematic review of reviews performed by our research group [18]. The reason probably stems from the fact that no agreement exists on the best temperature measure to define a heatwave. Average mean temperatures and maximum daily temperatures are easy-to-find indicators commonly used by epidemiologists to describe the effects of heatwaves on large populations [15,34]. Humidex is another widely used temperature measure, created to describe temperature perception by an average person [35] and capture the increased heat-related physiological stress exerted on the body [36]. However, Barnett et al., after testing mean, minimum and maximum temperature with and without humidity, apparent temperature, and the Humidex, found that none was superior to the others in correlating with mortality, and several factors (such as age group, season, city) influenced the associations found. Moreover, the number of human heat stress indicators has grown exponentially in recent years [37], and in some cases, consider local meteorological conditions such as wind speed [36].

Time is another variable to be considered when discussing heatwaves definition. Literature again provides a broad number of days (and nights, so intending 24 hours) to define a heatwave, ranging from a minimum of two to six consecutive days [38,39], affecting the results, their interpretation, and therefore the implications for public health mitigating initiatives. Despite far from the aims of the present work, a future clear, operational definition of heatwaves is desirable, to help researchers compare studies from different areas and stakeholders attain disaster risk reduction [21], but with a comprehensive approach – thus considering meteorologic, epidemiological, and public health concerns with particular attention towards vulnerable groups [34].

Heatwaves: impact on populations and societies.

So far, the European-wide heatwave in 2003 is one of the most studied weather events in public health. With maximum temperatures of 35 to 40°C [40,41], this EWE left behind estimated agricultural damage of more than €13 billion [42] and caused more than 70,000 deaths [43]. In France, this heatwave was the most severe registered since 1873, with 15% of the 180 weather stations recording temperatures exceeding 40°C and two-thirds above 35°C [44]. Çulpan and colleagues identified a 7–31% rise in mortality risk during 20 heatwaves spanning 334 days in Istanbul, with 4281 excess deaths recorded [45]. A broader study encompassing 823 regions across 35 European countries–representing more than 543 million people, based on the Eurostat mortality database–estimated a total of 61,672 heat-related deaths having occurred in the hot season of 2022. The highest absolute toll was reported in Italy (18,010 deaths), Spain (11,324), and Germany (8,173); mortality rates were highest in Italy (295 deaths per million), Greece (280), Spain (237), and Portugal (211). Women experienced 56% more heat-related deaths than men, particularly those aged 80+ years, while higher rates were observed in men aged 0–64 (+41%) and 65–79 (+14%) years [46].

Other heatwaves in Europe [47] and other continents [48,49] have been described in literature and carried a similar burden. For example, between 2000 to 2009, occurrences of heatwaves led to approximate $5.4 billion in supplementary healthcare expenses in the United States. This amount constitutes 37% of the total healthcare costs amounting to $14 billion, which are linked to climate change-related incidents such as infectious disease outbreaks, hurricanes, wildfires, and floods [26]. Therefore, what is alarming is the growing trend of heatwaves in almost every region, in terms of frequency, intensity, and duration [50]. According to *EURO-Cordex*, the increase in average temperatures of all European regions is expected to be quicker than the rest of the planet [51]. For example, Rodrigues projects a 0.33% increase in temperature-related mortality in Lisbon by 2046–2065 under moderate cold and heat exposure thresholds, with vulnerable groups such as the elderly, children, and individuals with chronic illnesses disproportionately affected [52]. Martínez-Solanas and coworkers projected heat-related deaths in Europe to rise by 15.2% by mid-century under high-emission scenarios (based on Representative Concentration Pathways – RCP6.0, RCP8.5), with Mediterranean regions identified as the most vulnerable, experiencing the greatest impacts [53]. Exposure to heatwaves can have direct health consequences, including heat cramps, heat syncope, dehydration, up to heat exhaustion and heat stroke. The latter condition is a medical emergency, characterized by an increased central body temperature and varying levels of neurological dysfunction that may ultimately lead to death [54].

Also, heatwaves are known to increase mortality and morbidity in the general population, but are more associated with specific strata defined “vulnerable” or “frail” [18]. Specifically, vulnerable persons can be identified using a multifactorial framework that integrates the following characteristics: demographic factors (age); health conditions; social and economic status;

geographical/environmental factors. The most robust observations identify elderly individuals (aged 65 and above) and populations with a high prevalence of elderly as particularly vulnerable to heat-waves. Their heightened susceptibility is attributed to a confluence of factors, namely compromised physiological reactions to elevated temperatures and limited thermoregulation, which in conditions of combined high temperatures and humidity is physiologically achieved through perspiration, skin vasodilation and increase cardiac output but is impaired in the old. Pre-existing chronic health conditions affecting among the others the cardiovascular, respiratory, renal, or endocrine systems [55] significantly exacerbate susceptibility, as do certain medications, like diuretics or beta-blockers, that impair heat tolerance. Overall, a reduced cardiovascular fitness, a complex pharmacological therapy, and chronic under-hydration (due to decreased thirst response) heighten the susceptibility of old persons to environmental heat stressors. Moreover, heatwaves have profound effects on patients with mental health disease. Spikes in aggressions have been correlated with heatwaves, as well as stress, mood changes with increased anxiety, depression, suicidality, exacerbation of schizophrenia and psychosis; possible explanations are increased stress levels due to the intolerable heat, or sleep-patterns disruption, intensifying irritability, and straining coping mechanisms [56,57].

From the perspective of social network, vulnerable individuals often share reduced social interactions and connections, absence of family or caregivers, cognitive maladaptation to society, leading to isolation (in some cases voluntary, e.g., the homeless or those with psychiatric conditions). Lastly, economically disadvantaged persons have barriers to air conditioning installation or use, and live in substandard housing. Urban dwellers, particularly in densely populated areas, are further affected by the urban heat island effect: limited green spaces, high urban density, or poor air quality, can amplify the adverse effects of heatwaves, [58]. Finally, persons working outdoors or in non-cooled environments are exposed as well to harsh conditions, making them prone to develop heat-related illness.

In general, to improve preparedness, communities must reassess their level of acclimatization to their regional climate and consider whether they are still adequately equipped, capable, and resilient to confront this evolving threat. The ability of a community to effectively address and handle fluctuations in temperature is evidenced by the association between mortality and ambient temperatures, in which mortality rates tend to escalate beyond a certain temperature threshold. However, such associations exhibit variations across diverse urban areas, characterized by distinct optimal temperatures and temperature thresholds [59].

Collectively, these individuals are unable to cope with the adverse effects of heatwaves and specific interventions have been projected to prevent negative outcomes. First attempts can be tracked back in the 90s in Michigan [60], whilst in Europe the implementation of public health measures can be seen after the 2003 heatwave. At the beginning exclusively centered on heat warning systems [61], the 2003 heatwave catalyzed policy innovations aimed at addressing heatwave-related health risks through HHAPs. France implemented one of the most comprehensive HHAPs including early warning systems, real-time surveillance, and strengthened social care networks. Italy prioritized targeted support for vulnerable populations and public awareness campaigns, while Germany developed federal-level initiatives aimed at improving healthcare system preparedness. Over time, countries like Portugal and the United Kingdom began adopting more adaptive strategies, integrating predictive analytics and fostering localized health initiatives to enhance their preparedness. Despite this efforts, several authors confirmed the lack of uniformity [24,62], even after the publication of a European blueprint in 2008 [63] and persisting gaps [62]. From a research perspective, several attempts have been made to increase the understanding of public health initiatives against heatwaves [64,65]. However, results from literature are frequently inconsistent [66]. In a non-systematic review, Bassil and Cole concluded that evidence regarding the effectiveness of public health interventions in reducing morbidity and mortality during heatwaves is scarce [67].

Heatwaves: impact on healthcare systems.

Heatwaves impact all health systems' components by worsening population morbidity, interfering with essential infrastructure, or introducing collateral incidents such as wildfires and heightened air pollution. The immediate consequence is an escalation in healthcare-related expenses and a surge in patient volumes, overloading essential healthcare services, namely primary care and emergency care. For example, heat event days occurring each summer in USA are estimated to result in about 234,000 ED visits, more than 56,000 hospital admissions for heat-related or heat-adjacent illnesses, and approximately $1 billion in health care costs [68].

As one pillar of public health, primary care during EWEs must be prepared to handle a high number of patients. Vashishtha et al. did not found an association between heatwaves and ambulatorial visits for heat-related symptoms in San Diego (California, USA); this results is anyway moderated by the authors, admitting that patients could have directly accessed EDs for more serious symptoms [69]. Instead, the World Health Organization (WHO) clearly advised for General Practitioners (GPs) engagement in HHAPs to proactively identifying, advising, and monitoring patients susceptible to heat-related risks [63]. The suggested role of GPs before heatwaves is therefore to help in educating and counseling vulnerable patients, adjusting their individual behaviors, medications, and fluid intake. A recent survey among German population revealed that only 23% of the sample would consult their GP on how to protect their health during heatwaves, but such prevalence was higher in selected groups (women, elderly people, people with lower education level and lower incomes, people from urban or metropolitan areas, those living alone, people with a migration background) [70], thus highlighting the need of promoting proactive strategies in primary care. In the same vein, a 2013 qualitative study suggests that enhancing GPs' knowledge and awareness of heat health impacts and climate change is crucial [71].

The hospital system as well carry a similar burden. A higher pressure on hospitals has been observed during heat waves, with significant increases in mortality and emergency hospital admissions, mainly affecting the elderly and people with cardiovascular, renal, or diabetic diseases [72–74]. Such negative outcomes derive from a complex interplay between the already discussed exacerbation of chronic diseases and the efficiency preventive strategies adopted by primary care and public health. Hospitals are therefore another crucial target when predisposing HHAPs; if their resilience is properly strengthened before a heatwave, outcomes of a population can be improved. Unfortunately, specific literature about preparedness of hospitals to heatwaves currently lacks, but should be urgently explored. For example, hospitals experiencing lack of power – due to a power grid made overtaxed and instable by extensive use of air conditioning – and unprepared can easily develop unhealthy temperature inside their buildings [75].

CHAPTER 2: HEATWAVES: IMPACT ON EMERGENCY CARE

This chapter outlines the ideas put forth in the following publication:

Paganini M, Valente M, Conti A, Ragazzoni L, Barone-Adesi F. Emergency medical care overload during heatwaves: a neglected topic. Eur J Emerg Med. 2023 Feb 1;30(1):5-6.

In the context of Disaster Medicine, emergency medical care is deployed at the frontline, facing unique challenges and derangements from usual care. In the specific case of heatwaves, despite differences in the definitions used, strong epidemiological connections have been consistently described with the overload experienced by emergency care, and specifically by EDs and EMSs.

Several retrospective analyses confirmed a significant increase in ED accesses during heatwaves in different locations across the world [76–81], ranging from 2% [82,83] to 19.2% [84] for all-cause presentations. Calkins et al. identified an 8% and 14% rise in EMS dispatch during heatwaves respectively for basic life support and advanced life support ambulances [85], which is consistent with other authors who reported an overall increase in ambulance dispatch of 4.85% [82], 14% [83], and 18% [86] as due to heatwaves.

Prolonged increases in patient input often result in EMS overload and ED overload, which demonstrably affect patient care [87]. The Emergency Medicine's workflow peculiarly focuses not only on individual patients, but also groups, processes, and systems simultaneously: therefore, a constant monitoring of operational efficiency of the whole system – pre-hospital and in-hospital – is critical. A process breakdown of input, throughput, and output of patients can help to identify problems and develop solutions to improve efficiency in this context.

An example is the analysis of ED overcrowding, a global health issue leading to a considerable worsening in patient outcomes and clinical risk increase [87]. By applying this model, the constant growth of ED attendances experienced in the last decades by almost every healthcare system has led to an increased input of patients [88]; consequently, improvements in the primary care network (input), delivery of care (throughput) and hospital boarding or discharge through ambulances (output) are needed. Of note, Kelen et al. pointed out that the term “overcrowding” is misleading since it potentially attributes ED inefficiencies to localized management failures or blames patients themselves, obscuring the systemic issues such as high inpatient occupancy and inadequate discharge pathways [89]. As suggested in the manuscript presented at the beginning of this chapter [19], "overload" instead reflects the broader health system dysfunction that drives access block and resource bottlenecks. This terminology shifts accountability from the ED to the underlying structural and economic drivers, fostering a more comprehensive understanding essential for effective intervention. Therefore, “overload” was chosen to consistently identify this issue within this doctoral project’s framework.

Emergency care overload during heatwaves could be analyzed as well since some limited evidence highlights the same worsening trend in patient outcomes. For example, Toloo et al. detected an increased input due to heat-related illness during heatwaves between 2000 and 2012 in 11 EDs from the greater Brisbane area (Australia); among the secondary outcomes, a longer stay in the ED increased from 1 to 2 hours for these patients was detected [78]. Similarly, as secondary outcomes associated with heatwaves, higher death-in-ED mortality rates have been detected by Hess et al. [79] and increased in-hospital (ED) mortality rates by Oray et al. [84]. Unfortunately, the specific associations with ED overload were not investigated, but it is reasonable to think that the higher volumes, along with emergency medical care systems’ maladaptation leading to bottlenecks in throughput and output, might have contributed to the negatively measured outcomes.

Knowing the magnitude of heatwave-related overload in emergency medical care, a step towards better care should target its specific predisposing factors. To find these vulnerability elements, the authors performed a scoping review of the literature (according to the PRISMA-ScR checklist) on PubMed and Scopus. Any paper dealing with emergency care (EDs and EMSs) and heatwaves, in

English language and published after 2000 was included. Surprisingly, none of the retrieved full-texts analyzed or at least summarized the factors predisposing to emergency medical care overload during heatwaves. Similarly, literature regarding how to optimize emergency healthcare during heatwaves is lacking at the moment. These relevant gaps in the literature are the epiphenomenon of a not-in-depth studied field, as recently confirmed [18].

It is evident that this shortcoming should be urgently addressed before starting to plan effective solutions, and several possible methodologies are available. It is imperative that emergency medicine and disaster medicine assume an active role in the development of strategies aimed at mitigating and combating the emerging hazards associated with climate change.

Solutions already tested for other contexts could inspire preparedness interventions against heatwaves, such as those applied to reduce overcrowding [90]. By intersecting the input-throughput-output model and the staff-stuff-structure principles of surge science [28], plans to prepare EMSs and EDs to handle a higher-than-average request of urgent and emergent treatment during heatwaves could then be tested and the validity of the process verified.

In conclusion, the lack of literature addressing the factors predisposing emergency care to overload during HWs currently hampers any effective planning strategy. Only after such evidence is produced, focused interventions should be enacted, tested, and widely applied if proving to be successful after an evidence-based process.

CHAPTER 3: FACTORS CAUSING EMERGENCY MEDICAL CARE DURING HEATWAVES

This chapter outlines the ideas put forth in the following publication:

Paganini M, Lamine H, Della Corte F, Hubloue I, Ragazzoni L, Barone-Adesi F. Factors causing emergency medical care overload during heatwaves: A Delphi study. PLoS One. 2023 Dec 20;18(12):e0295128.

Introduction

As already described in the introduction, climate change and heatwaves are posing a great risk to the entire humankind, impacting healthcare systems and specifically emergency care. It is not clear whether this phenomenon impacts systems' efficiency or patient flow in EDs or EMSs [19]. In the era of the emergency medical care crisis and ED overcrowding [89], there is a need to identify the factors causing emergency medical care overload and provide stakeholders with valuable information to improve EMSs and EDs preparedness to face heatwaves-related surges of patients.

Given these premises, this study aimed at finding the factors causing an overload of emergency medical care – both pre-hospital (EMSs) or in-hospital (EDs) – during heatwaves, pursuing United Nations' Sustainable Development Goal No. 13th: Climate Action, and specifically aiming to "*strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries*".

Materials and Methods

This study was an expert opinion study based on the Delphi methodology, modified to be delivered and conducted online [91].

Participants

After obtaining formal authorization from the institutional ethics committee (No. 160 – 18/02/2022), the experts' recruiting phase started on July 20th, 2022. To be included, participants' expertise had to fall in one of the following fields: emergency medicine; disaster medicine; or public health. The number of experts was set to a minimum of 12, according to Delphi methodology literature [91]. Anonymity among panel members was ensured throughout the study; only two researchers handling recruitment and analysis accessed personal details.

Authors of literature dealing with both heatwaves and overload of healthcare or emergency medical care systems were identified using the same papers retrieved after recent reviews performed on Pubmed and Scopus –as internationally recognized indexing repositories [18,19]–, and then contacted via email. Two reminder emails were sent every 3 weeks if unresponsive. To ensure sufficient experts to conclude the study after possible drop-outs, a last recruitment round was held during the Disaster Medicine section's meeting at the European Society for Emergency Medicine (EUSEM) congress in October 2022. Recruitment was ended on October 31st, 2022.

Structure

The modified Delphi was structured in three rounds. After completing a review of the literature [18,19], the authors convened that the retrieved literature was insufficient to elaborate robust statements for the first round. Therefore, the following open-ended question was created to collect five to ten experts' answers: "What are the factors causing emergency medical care overload during heatwaves?". To ensure content and face validity, this question was pilot-tested with three Ph.D. students (with expertise in the field) and reviewed for accuracy by three senior faculty members from the Research Center in Emergency and Disaster Medicine (CRIMEDIM), Università del Piemonte Orientale, Novara, Italy. Age, country, and field of expertise were also tracked. Content analysis was then performed by one author and blindly reviewed by another author to ensure its validity. In the second round, experts were asked to rate each statement for importance on a 7-point linear scale, with 1 meaning "Not at All Important" and 7 meaning "Extremely Important". The consensus was defined as a standard deviation ≤ 1.0. Statements not achieving consensus were administered again in a third round between February 17th and March 9th, 2023; experts were shown the statement, their own answer in the second round, and the mean of the score assigned by all raters. Experts were able to confirm their previous rating or revise it on the same scale.

Data Analysis

Round administration and data analysis were performed using Stat59 (Stat59 Services Ltd, Edmonton, AB, Canada). Categorical data were described through their distribution frequency.

For each statement, answers were analyzed through mean, standard deviation, and frequency distribution. Statements not reaching consensus (SD > 1) after the third round were classified as "consensus not reached". The datasets are available from the corresponding author on reasonable request.

Results

Out of 95 authors contacted, 9 (9.5%) answered positively and were included after verifying their eligibility. Six eligible experts were recruited from the investigators' research network or referred by other contacted authors. Further 10 experts were recruited at the EUSEM 2022 congress, totaling 25 who consented to participate.

The first round was launched on October 22nd, 2022, and lasted one month, collecting 79 statements from 15 experts (Supplementary Table 1). The remaining ten experts dropped out of the study without participating, reporting a lack of time or generic difficulties. The 15 experts completed all the rounds. Their age ranged between 38 and 75 years; most of them came from Australia (n=4), Belgium (n=3), and Italy (n=2) and mainly were combined experts in emergency medicine and disaster medicine (n=10) (Supplementary Table 2).

After content analysis, the 79 responses from the first round were condensed to 31 statements. The second round was launched on January 6th, 2023, and lasted 40 days; 11 out of 31 statements reached immediate consensus. The remaining 20 statements were advanced to the third round between February 17th and March 9th, 2023. At this final stage, 7 statements reached consensus, while 13 did not. A response rate of 100% was obtained.

Table 1 lists the 18 statements reaching consensus ordered by strength of agreement; those not reaching consensus are instead available in Table 2. Statements reaching consensus ranged between a rating of 6.1 ("Important") and 5.1 ("Somewhat Important").

Table 1: Statements that attained consensus.

#	Statement	Round	Mean	SD	Processing Section (Intervention Target)
1	Availability of air conditioning at home or access to cooled spaces can reduce heat-related illnesses.	2	6.3	0.9	Input (Population)
2	Information campaigns about Heatwaves can help increase community awareness and educate on how to deal with extreme temperatures.	3	6.2	1.0	Input (Population)
3	During heatwaves, there is an increased number of presentations to the emergency department to be managed.	2	6.1	0.9	Input
4	Emergency planning and surge capacity development are important to prevent emergency medical care overload during heatwaves.	3	6.0	1.0	Throughput
5	Health systems already stretched by other coexisting medical conditions (e.g., COVID-19) could be more fragile if affected by heatwaves.	2	5.9	0.9	Input (Stakeholders)
6	Awareness of stakeholders and policymakers is important to mitigate heatwaves effects on emergency medical care overload.	2	5.9	0.6	Input (Stakeholders)
7	Training of healthcare personnel - working in primary care, emergency medical service, and emergency department - could improve heat-related illness diagnosis and treatment.	2	5.9	1.0	Throughput
8	Avoid planning of public events/mass gatherings during forecasted heatwaves.	2	5.8	1.0	Input (Stakeholders)
9	Primary care is responsible for identifying at-risk population strata and enacting interventions to prevent heat-related illnesses.	3	5.8	1.0	Input (Primary Care)

10	Prevention of chronic medical conditions exacerbations can reduce the burden on emergency medical care during heatwaves.	2	5.7	0.9	Input (Primary Care)
11	Interventions dedicated to emergency medical services and emergency departments into Heat Action Plans can improve the overall heatwaves response.	2	5.7	0.7	Throughput
12	Implementing telemedicine during heatwaves for fragile individuals in the community could improve patients' management through primary care.	2	5.6	0.7	Input (Primary Care)
13	During heatwaves there is an increased demand for emergency medical services (emergency calls, ambulance dispatches) to be managed.	3	5.6	1.0	Input
14	Investments are needed to minimize disparities between high- and middle/low-income countries regarding response to heatwaves.	3	5.5	1.0	-
15	The deployment of additional resources during heatwaves should be proportional to the prevalence of vulnerable/frail individuals found in the community.	2	5.3	1.0	Throughput
16	The reduction of hospital bed capacity during summer can worsen emergency medical care overload during heatwaves.	3	5.3	0.9	Output
17	Planning additional equipment in emergency medical service and emergency department is important when heatwaves are forecasted.	3	5.2	1.0	Throughput
18	Planning additional staff in emergency medical service and emergency department is important when heatwaves are forecasted.	2	5.1	1.0	Throughput

Table 2: Statements which did not attain consensus.

Round	Statement
3	Extended availability of primary care physicians during heatwaves could divert minor issues from the emergency medical care system.
3	Deploy additional primary care personnel to take care of frail persons and high-complexity cases (multiple diseases, high number of medications, social reasons), to avoid ambulance overuse and transport to the ED.
3	Systematic detection of patients' body temperature in primary care and emergency medical care during heatwaves could help diagnose heat-related illnesses.
3	Heatwave warning communications can educate the population on the appropriate use of primary care / emergency medical service / emergency department during heatwaves.
3	Heatwaves period coinciding with annual leaves/vacations of healthcare personnel can affect staff retrieval during heat-related surges.
3	Planning the repurposing of emergency medical service and emergency department is important when heatwaves are forecasted.
3	Digitalization and communication improvements between emergency medical care and emergency department can reduce emergency medical care overload during heatwaves.
3	Training about heatwaves specific features delivered to incident command systems' personnel can reduce emergency medical care overload during heatwaves.
3	Deploy dedicated personnel to deal with high-complexity patients (e.g., with comorbidities, high number of medications, limited family/social support) presenting to the Emergency Department during heatwaves to relieve the department's overload.
3	Emergency medical service personnel are at risk of suffering from acute heat-related illness when dispatched to the prehospital arena.
3	Daily variations in heat-related illnesses helps in resource adaptation.
3	Activation of dedicated beds to treat heat stroke patients in the Emergency Department during heatwaves is important.
3	Implementation of syndromic surveillance systems focused on diseases caused/exacerbated by heatwaves can be used to adapt resources.

Discussion

In terms of quality, the study achieved current literature recommendations on sample size including more than 12 experts, which worked in different countries worldwide as clinicians or researchers. Most had combined emergency and disaster medicine expertise, but also public health. The heterogeneity of backgrounds and countries suggests that multiple perspectives on the same problem could have been included.

The predominance of experts from high-income countries reflects the paucity of research on heatwave health impacts in developing nations [64]. Probably due to their background – overlapping with humanitarian medicine – the experts agreed that disparity between different income-level countries is a factor causing emergency care overload (#14). Given the lack of literature in the field from low-income countries, and therefore no demonstrated association between the country's income level and the degree of emergency care demand during heatwaves, this statement seems not to identify an issue to be addressed to increase the resilience of emergency medical care systems. On the other hand, statement #14 offers the opportunity to reflect on the vulnerabilities of resource-poor countries in facing heatwaves [92]. Also, it raises the attention on future threats deriving from climate change, such as massive migrations due to regions becoming uninhabitable, that should be included in hazard and vulnerability analyses (HVAs) as phenomena potentially destabilizing emergency care systems in middle- and high-income countries.

The overload experienced by emergency care during heatwaves mirrors the broader term of ED overcrowding, which affects acute care also in normal times. Several authors tried to analyze and find solutions to ED overcrowding by adopting different conceptual models. The most diffused model of input-throughput-output proposed by Asplin et al. applies operations management concepts to patient flow [93], and can be used to classify the findings of the present Delphi study.

Input section

Most of the statements achieving consensus and the only three statements attaining a mean score > 6 (Important) seemed to deal specifically with the input part of patient processing, probably in the search for solutions to prevent the surge rather than trying to expand the capacity of an emergency system – almost exhausted already in non-crisis times. In fact, the Delphi experts reiterated the importance of the surge of patients requesting care during heatwaves in causing overload (input) – in terms of increased demand to EMSs (#13) and presentations to the EDs (#3) – as already demonstrated by several authors [19]. Such a tendency of the panel could be interpreted as that the excessive demand and burden on EDs and EMSs could be tackled by enacting public health initiatives or preventive healthcare measures delivered to the most vulnerable before acute care. Within the statements attaining consensus, experts therefore identified three main targets: stakeholders / policymakers, the population itself, and primary care.

The role of stakeholders and policymakers

The experts confirmed the importance of improving the awareness of stakeholders and policymakers (#6) since they have the responsibility of creating HHAPs or revising those already existing to prepare all the sectors of healthcare [75]. Of note, experts highlighted the need to reshape healthcare systems already stretched by other coexisting medical conditions (e.g., COVID-19) as being more fragile if affected by heatwaves (#5). In light of the future recurrence of heatwaves and their possible overlap with other concurrent disasters amplifying detrimental effects [94], HHAPs should be flexible, dynamic, and based on frequent, periodic HVAs.

An interesting statement that obtained consensus targeted public events and mass gatherings during forecasted heatwaves (#8) as a potential source of overload for emergency care. Particular attention should be paid to which healthcare resources prediction model is used since only some tools include variables such as temperature and humidity [95]. Also, given the potential short notice of weather forecasts, local authorities should consider postponing events coinciding with heatwaves to avoid multiple casualties and an unpredicted strain on the emergency care system.

The role of the population

As HHAPs contain several interventions triggered by warning systems to preserve population health during heatwaves [61,63], the experts agreed on some as potentially important to relieve the burden on emergency medical care. Heatwaves-awareness campaigns and alerts are a critical element in documents providing guidance on HHAPs [63,96]. Standardized messages can be effectively delivered through different media but campaigns have to consider factors hampering information access, such as higher age, unemployment, or low education [97]. The experts, in fact, considered information campaigns important for raising community awareness and educate the population (#2). Despite limited evidence, awareness campaigns and structured heat warnings seem to contribute to reducing mortality [98] and could help in preventing heat illness or the worsening of chronic diseases, which represent the majority of emergent presentations during heatwaves. On the other hand, the experts did not agree on the potential of warning communications in educating the population on the appropriate use of primary care, EMSs, and EDs during heatwaves (Table 2), probably because this aspect is already difficult to establish in non-heatwaves times [99] and has still to be studied. Anyway, it could be reasonable to update HHAPs with statements raising the awareness of the population on the burden posed by heatwaves on the healthcare system and promoting both prevention and a more appropriate use of healthcare.

Availability of air conditioning at home or access to cooled spaces can reduce heat-related illnesses, especially among vulnerable populations. The experts agreed that air conditioning could translate into a reduced burden on emergency care (#1), probably by preventing heat illness development. Unfortunately, a reduced access to air conditioning has been associated with lower socio-economic status and poorer quality of housing [100]. Electric fans are cheaper, but current literature is insufficient to recommend such devices as a valid method to reduce heat during heatwaves [101]. Cooling centers can be another alternative, but prejudices hampering their attendance have been reported [102]. Therefore, access to air conditioning could be considered a factor improving population health during heatwaves, but not the main solution.

The role of primary care

Discrepancies in risk perception and self-protecting behaviors during heatwaves have been noted in the literature, especially in the elderly and subjects with comorbidities being not aware of their frailty [18,102]. Also, chronic diseases undoubtedly contribute to ED overload during ordinary times [89] and constitute a significant part of patients seeking care during heatwaves [18,86]. Experts agreed that primary care should identify these vulnerable strata and enact interventions to prevent heat-related illnesses (#9) and that preventing chronic medical conditions exacerbations during heat-waves could reduce the burden on emergency medical care (#10). These two statements are in line with current recommendations, suggesting that the at-risk population should be identified before heat-waves occur [103], which could make warning systems more efficient from the earliest phases. Interestingly, experts also deemed telemedicine implementation important to improve fragile individuals' management during heatwaves by primary care in the community (#12). Such innovative technology could not be available in every setting, but improving at least telephone contact through a dedicated heat-help line could allow the management of mild cases at home and deliver tailored counseling, especially for the elderly. Experts did not agree on the usefulness of extending the availability of primary care physicians or deploying more primary care personnel (Table 2), in contrast with current literature, suggesting that ED visits could be reduced by addressing barriers inherent to a timely access to primary care [104]. The experts probably interpreted these statements as two isolated and one-sided factors/interventions during the Delphi process, thus disagreeing. Wider integrated interventions, with population and stakeholders' engagement, could instead be more effective in improving access to primary care. In general, the contribution of primary care during heatwaves can be fundamental [105]. Its role in preserving emergency medical care from overload and failure should be therefore addressed explicitly in HHAPs and measured by future studies.

Throughput section

Knowing from previous analyses that HHAPs lack uniformity [62], it can be expected that not every plan specifically entails emergency medical care-tailored interventions to improve patient flow, which instead were deemed important by the experts to improve ED and EMS response to heatwaves (#11). By following disaster medicine principles, HHAPs should contain measures to develop surge capacity (#4) in different ways so to improve patient throughput [89]. Experts agreed also on planning additional equipment (#17) and staff (#18) in both EMSs and EDs when heatwaves are forecasted, consistently with the "staff, stuff, and structure" surge science framework [28], and proportionally to the prevalence of vulnerable/frail individuals in that community (#15). Of note, experts did not agree on deploying dedicated personnel to care for high-complexity, comorbid patients in the ED or to create "heat stroke" beds in the ED (Table 2), probably because they were more concerned by the volumes of all-comers (more predictable) rather than by specific cases (less predictable). Along with more resources, adequate training across primary and emergency medical care has been identified as important by the panel (#7). Dedicated training proved to increase heat illness recognition and treatment in the ED [106], but could easily be exported to other healthcare contexts. Experts did not agree on systematically measuring body temperature (Table 2), probably because skin temperature is not accurate in heat illness detection, and core body temperature (rectal), despite being the most accurate [54], is unfeasible as a screening tool. Therefore, the effects of mandatory training for primary and emergency care practitioners with a refresher provided once a year (e.g., before the hot season), or adjunctive triage questions triggered by HHAPs activations could be studied.

Output section

Regarding output in patient processing, the reduction of hospital bed capacity during summer has been identified as potentially worsening emergency medical care overload during heatwaves (#16). Seasonal hospital adaptations meet fluctuations in diseases throughout the year, usually by expanding bed capacity and reducing elective procedures during winter to admit respiratory illnesses [107]. Since one of the most critical factors causing ED overcrowding is hospital boarding [89], healthcare systems with a reduced bed capacity during the warm season and coinciding with heatwaves could register significant delays in patient output from the ED. Hospital boarding also delays throughput since personnel is diverted to care for patients while waiting to be admitted to the wards, and stretchers are unavailable to receive new patients from EMS – automatically reducing ambulance availability. A reasonable approach could therefore consider dynamically adapting bed capacity when HHAPs are activated, similar to hospital repurposing during the COVID-19 pandemic, mitigating the boarding bottleneck.

Final recommendations

Overall, a list of recommendations can be summarized from the consensus reached among experts:

- HHAPs should be flexible, dynamic, and based on frequent, periodic HVAs to meet climate change consequences
- HHAPs should contain interventions raising the awareness of the population on heatwave-related risks and preventing heat illnesses towards a more appropriate use of healthcare system's resources
- Develop telemedicine dedicated to the frail strata of the population (e.g., a telephone helpline for counseling or at-home management)
- HHAPs should contain interventions dedicated to primary care, which has a fundamental role in preserving emergency medical care from overload
- Local authorities should consider postponing events coinciding with heatwaves to avoid multiple casualties and an unpredicted strain on the emergency care system.
- Training on heat illnesses for primary and emergency care practitioners before every hot season
- Adapt hospital bed capacity when HHAPs are activated

Limitations

The results derived from this Delphi study are specific to the panel of experts who participated and could be invalid for other contexts. For example, there was no expert from Southern America or Africa, and 14 out of 15 were from high-income countries. In line with both UN Sustainable Development Goals #1, "No Poverty", and #13, "Climate Action" – low- and middle-income countries should be given the possibility to improve research and find more specific strategies against heatwaves, so a dedicated Delphi process could help filling this gap.

Conclusions

Heatwaves, as a consequence of climate change, are affecting population health and healthcare systems worldwide. In particular, emergency medical care suffers from an overload of patients to be processed during heatwaves, but studies testing solutions to mitigate such burden are lacking. Since Delphi studies are performed to gather information in fields with poor or conflicting knowledge, this methodology identified factors causing emergency care overload during heatwaves thus providing ground for future interventions. The Delphi process provided 18 statements, mostly focused on the input section of patient processing, identifying stakeholders, the population, and primary care as targets of future discussion and interventions such as the implementation of HHAPs, training of healthcare personnel, or education and awareness campaigns. Additional dedicated resources and bed capacity were deemed important as per throughput and output sections, respectively.

The next steps in relieving emergency care strain during heatwaves should entail the evaluation of these statements by national and international scientific societies to be implemented and tested in EDs and EMSs.

CHAPTER 4: PREHOSPITAL EMERGENCY MEDICINE PROFESSIONALS' PERCEPTION OF HEATWAVES IMPACT

This chapter outlines the ideas put forth in the following publication:

Paganini M, Markou-Pappas N, Della Corte F, Rosi P, Trillò G, Ferramosca M, Paoli A, Politi F, Valerio A, Favaro A, Hubloue I, Ragazzoni L, Barone-Adesi F, Lamine H. Heatwaves Impact on Prehospital Emergency Medicine: A Qualitative Study to Improve Sustainability and Disaster Preparedness in Veneto Region, Northern Italy.
Sustainability. 2024; 16(16):6911. doi: 10.3390/su1616691

Introduction

With the similar premises already depicted in the introduction and Chapter 1, the need for better evidence in the field of heatwaves' impact on emergency care, pursuing the United Nations' Sustainable Development Goal No. 13th: Climate Action ("*strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries*") guided this qualitative study. In fact, the results of the Delphi study depicted in Chapter 3 provided limited insight in PHEM, so the aim was to clarify the interactions of heatwaves with PHEM systems. By interviewing EMS personnel, potential vulnerability factors predisposing EMS to overload or dysfunction during heatwaves were identified to help stakeholders and policymakers improve EMS preparedness and resilience during these events.

Materials and Methods

The Veneto Region, located in Northeastern Italy, has a population of about 4.9 million residents. The regional healthcare system provides universal coverage to all those in need. PHEM is coordinated by 7 dispatch centers, one per province, and is a physician-based, three-tiered EMS. The Veneto Region is particularly vulnerable to geological hazards, namely landslides and floods, resulting from an intense human manipulation of the landscape [108]. Climate change will worsen this trend, as seen with rainfall [109]. Also, temperatures showed an increasing trend of about 0.5 °C per decade between 1993 and 2019, as registered by the Regional Agency for Environmental Protection and Prevention of Veneto (ARPAV), making the whole region more prone to experience heatwaves.

These vulnerabilities, coupled with the gaps in heatwaves-related literature, identified the Veneto region as a case study within this PhD's framework. Since measures applied to EMSs can reduce inappropriate input pressure on EDs, a multicentric qualitative study employing semi-structured interviews was conducted to collect the thoughts and perspectives of PHEM professionals working in this region. This qualitative design was chosen because it can reliably document opinions on a specific subject and because of the exploratory nature of the study [110]. The study methods have been reported in accordance with the Consolidated Criteria for Reporting Qualitative Research (COrEQ) (see Supplementary Materials 3) [111].

Participants were recruited through email and personal contact among PHEM physicians or nurses. A target of two participants per dispatch center was set, preferably 1 nurse and 1 physician each, to be representative of the regional EMS. Current literature suggests different strategies for determining the adequate sample size in qualitative studies, but nonprobabilistic methods are widely diffused and rely on the predictability of data saturation. Guest et al. found that data saturation usually occurs at twelve interviews, especially when the scope of the research is narrow and the target audience is similar [112]. In their review, Sim et al. confirmed the appropriateness of 12 as the minimum number of interviewees for studies similar to the present [113].

The inclusion criteria were a full-time employment in the regional PHEM system and having at least 5 years of work experience. One of the authors contacted those interested and carefully provided information on the study objective, ethical implications, anonymity, and interview methodology. Upon confirmation and after signing the informed consent, the researcher scheduled and conducted interviews with each participant (in Italian).

Data Collection

An interview guide, consisting of leading and probing questions, was elaborated based on the available literature and related research work previously conducted by the authors (see Supplementary Materials 4 – Interview Guide) [18,19]. The guide was internally reviewed by experts in emergency medicine and disaster medicine for further adjustments, then pilot-tested on a pool of research fellows before making final modifications guided by their feedback. The same guide was used to carry out all the interviews, with minimal linguistic adaptations when needed. Interviews were conducted in October 2023, and each lasted approximately 30 – 40 min, with the interviewer and the participants alone. Each interview was audio-recorded after double checking the participant's permission, and manual notes were taken.

Data Analysis and Reporting

Interviews were manually transcribed and read multiple times for accuracy. Two researchers (MP, NMP) prepared two lists of potential codes, using inductive reasoning, after reading all the transcripts and extracting the most important topics addressed by the participants. The lists were then compared, and a unified codebook was devised to analyze interviews. The unified codebook was used to code each transcript deductively, extracting significant quotes related to the generated codes by two authors (MP, NMP) to ensure consistency and reliability.

Data analysis was carried out with the Atlas.ti software (ver. 23.1.2; ATLAS.ti Scientific Software Development GmbH, Berlin, Germany) and using an inductive approach based on the thematic analysis methodology proposed by Braun and Clarke [114]. The answers dealing with factors affecting EMS performance during heatwaves and potential solutions were also classified according to the surge science principles of staff, stuff, structure, and system [28,115]. The "4-S approach" has been previously used to provide both experts and non-experts in disaster medicine with a schematic and intuitive framework to plan their interventions and guide surge capability expansion [115,116] Since the aim of the present study was to identify factors leading to EMS disfunction and concrete solutions, such a framework – widely recognized and used in disaster medicine planning – was deemed appropriate to organize this section's results discussion. In the other identified themes, such framework was not adopted since answers dealt with heatwaves' definition or focused on the effects on the population during heatwave. The analysis was conducted in Italian language over three weeks, and approximately one hour was allocated to analyze each interview. After analysis, the results were translated into English to be integrated into the manuscript.

Ethical Considerations

The study was conducted according to the principles of the Helsinki Declaration. All participants signed a written informed consent after a precise explanation of the study's aims and procedures and before their inclusion. Data collected from the interviews were anonymized, and access to the data was restricted to the co-authors of this paper only; only the principal investigator knew the identity of the participants. This study was approved by the Veneto Regional Ethics Committee, South-West Territorial Area section (No. 54564).

Results

Sixteen participants were recruited across the Regional EMS network, and 14 (7 nurses and 7 doctors) consented to participate in the study – randomly re-named S1-S14. The last subject dropped from the study due to personal reasons, thus bringing the final number of included to 13. Data saturation was reached at 10 interviews. As depicted in Table 3, four themes emerged during data analysis: perception of heatwaves; clinical impact of heatwaves; social factors and heatwaves; heatwaves and EMS.

Table 3: list of themes (with operational definitions), subthemes, and topics emerging from the semi-structured interviews involving Emergency Medical Service (EMS) personnel.

Themes	Subthemes	Specific Topics (number of participants)
Perception of Heatwaves (***how did the interviewees define heatwaves***)	Heatwave definition	High temperatures (13) Humidity (9) Time factor (7) Location-specific effects (4) Urban Heat Island Effect (1)
Clinical Impact of Heatwaves (***health consequences of heatwaves on vulnerable groups and the general population***)	Concerns about vulnerable/ frail groups and population at risk	Children, elderly, homeless (vulnerable/frail); and those working outside (exposed to risk) (6)
	Different case epidemiology	Acute on chronic illness (4) Syncope (4) + due to unmodified antihypertensive chronic therapy (2) Heat stroke: more frequent (2), or a rare event (2) More aggressive behaviors (3) Worsening psychiatric disease (2)
Social Factors and Heatwaves (***factors involving education and behaviors of population during heatwaves, or support of social and family networks***)	Culture	Lack of behavioral adaptations (4) Elderly not aware of their frailty (1) Elderly not relocating to better climate locations (2) Air conditioning not used (2) Air conditioning not installed or not working due to economic concerns (6)
	Social network	Lack or disruption of social connections (2)
	Family network	Lack or failure of family support (3)
Heatwaves and EMS (***factors influencing EMS performance during heatwaves – analyzed through the Staff, Stuff, Structure,***	Gaps and Vulnerabilities	Staff - Concerns for safety and performance (3) Staff - Need for more personnel (2) Stuff - Need for more equipment (10) Structure - Need for places with higher capability (2)

***and System framework derived from surge science*)**		System – Information to the public needed (1) System - Information to the personnel needed (2) System - Inadequate availability of general practitioners (2) System - Population increase in touristic areas during holydays (2)
	Strengths	Staff - Training on heat illness dispatch, recognition, and treatment adequate (3) Staff and Stuff – Capability of recruiting additional EMS vehicles or personnel (1) System – Awareness of alert systems and reminders to personnel (3) System – Flexible and adaptable to heatwaves (4) System – Adaptation to summer season (3)
	Potential solutions to mitigate the impact	Staff – progressive personnel implementation (3) Staff – screening personnel for physical efficiency (1) Staff – reduce working hours (2) Staff – remind proper hydration (1) Stuff – implementation with specific materials (4) Stuff – increase the number of EMS means (4) Stuff – improve EMS means air conditioning (2) Structure – create triage points in the district (1) Structure – divert vulnerable individuals to shopping centers with air conditioning (2) System – Training and information to personnel (4) System – Training and information to the population (3) System – Strengthening primary care (8) System – Granular activation of civil protection (2)

	System – improvement of hospital resilience (1)
	System – improvement of heat alert systems (2)
	System – create a dedicated number for calls (1)

Perception of Heatwaves

When asked to define the term "heatwave", all interviewees identified the temperature increase as the main characteristic. Nine participants mentioned "*humidity*" as a factor affecting temperature perception when increased, "*amplifying a bit the problem of temperature rise*" (S2); S8 and S12 explained higher humidity as potentially due to lower wind speeds in the area hit by a heatwave.

Some participants added a time factor to their definition of heatwaves. Two referred to the event onset by using the terms "*sharp, fast […] and not gradual*" (S6) and "*sudden, abrupt*" (S10). Five focused instead on the duration of the temperature anomaly, defining it a "*period*" (S3, S8), "*prolonged*" (S6), "*protracted*" (S4, S5), exerting its effects on "*many consecutive days*" (S8).

Four participants described the relationship between geography and peculiar climatic conditions of different locations in configuring a heatwave that can hit "*a specific region*" (S2). Temperatures can be "*higher in absolute terms, but also relatively higher than the normal of that geographical area, if compared with its historical average values*" (S3). According to S1, "*the concept* [of a heatwave, Authors'/Note (A/N)] *is also connected to where it happens*", and "*for example, a heatwave happening in Kenya is different from a heatwave happening in Italy, not only for the different humidity but also for how the population endures the heatwave*". S5 instead highlighted the influence of the urban heat island effect on heat perception: "*For sure*, [higher temperature and humidity, A/N] *are more perceived in areas, let's say, more urbanized than in others*".

Clinical Impact of Heatwaves

Part of the answers focused on clinical aspects, with the participants expressing different perspectives about the problem. The most recurrent subtheme concerned those strata of the population defined as “*vulnerable*” or “*frailer*” – such as children, elderly, homeless individuals – and those working outside (6 participants). Heatwaves seemed to cause “*a different epidemiology of presentations*” than usual (S3), characterized mainly by acute on chronic illness (4 participants) or syncope (4 participants), potentially due to unmodified antihypertensive chronic therapy despite high temperatures (2 participants). Heat stroke was deemed frequent among frailer subjects (S7), and exertional heat stroke in “*athletes running under the sun*” (S13); however, S2 and S11 perceived heat stroke as a paradoxically rare event during heatwaves, compared to other diseases (S2: “*talking about real emergencies, namely heat stroke, I’ve only seen two cases in my 23 years-long career*”).

Three participants underlined that, during heatwaves, those calling the emergency number have “*less patience*” (S3); “*From a psychological point of view, there is an alteration. There is a behavioral modification, less tolerance to specific things, and people become impatient.*” (S6), or “*people are more nervous, and many times it’s more difficult to interact with them when they call the emergency number*” (S5). S3 and S5 were concerned regarding patients suffering from psychiatric illness, “*calling you because they are feeling hot; and they call you because they are decompensated and don’t know how to manage themselves*” (S5) and potentially more “*episodes of aggressiveness or violence*” (S3).

Other conditions pointed out by the participants pertained to the following conditions: dehydration (n=2), predisposing to urinary infections or exacerbated by acute gastroenterological diseases (n=1); fatigue (n=2); respiratory (n=1); and cardiovascular (n=1).

None of the interviewees spontaneously mentioned an increase in mortality, and when probed, only two referred again to older people or comorbid individuals.

Social Factors and Heatwaves

Particular attention was dedicated to social factors, with four subthemes emerging from the interviews: culture; economic factors; social network; family network.

Issues dealing with population culture and education concerned most of the participants. Four highlighted a lack of behavior modifications during heatwaves, with people "*continuing to travel or work although temperatures are higher*" (S4), mainly "*workers in the healthcare and construction sectors*" (S8), but in general "*not following common recommendations to stay hydrated or avoiding going outside during hottest hours*" (S7), such as "*athletes training in very hot conditions*" or "*kids excessively dressed*" (S13). Moreover, the elderly could "*underestimate or be unaware of their vulnerability to extreme heat*" (S4), thus not considering relocating to areas with better climate conditions during summer (S2, S10). According to three participants, such factors could determine more inappropriate care demands on both EMSs and EDs.

Particular attention was dedicated by the participants to the misuse of air conditioning during heatwaves. In particular, S13 mentioned that elderly could "*refuse to install conditioning systems for cultural factors*" preferring to live in houses "*not suitable*" for hot temperatures, while S2 highlighted that this subgroup of the population could "*easily use air conditioning*". Other six interviewees identified an overlap with economic factors – namely costs of installing or running conditioning systems – as a barrier hampering the use of air conditioning to mitigate elevated temperatures. Paradoxically, low-income individuals and families with a conditioning system could "*avoid operating them because of the skyrocketing high costs of electricity in these times*" (S7), forcing PHEM personnel to work in "*top floor apartments with prohibitively high temperature"* (S1), while "*as usual, rich people… have all the possibilities to keep cool, and who isn't [*rich, A/N*] gets sick*" (S8).

Both social and family network failures were perceived as significant in causing an overload during heatwaves, such as disruption of connections with "*their community*" (S11), "*elderly living alone, without anyone reaching out to them*" (S13), and lacking "*family or support*" (S2, S9) or because family and caregivers "*want to go away for the summer leave, and don't know how to manage the old person: so, they call the emergency number to hospitalize them*" (S4).

Heatwaves and EMS

This topic included most of the themes captured by the interviews, divided into three sub-themes related to the interactions between heatwaves and EMS: gaps and vulnerability factors; strengths; and potential solutions to mitigate the impact. Overall, the interviewees identified different vulnerabilities and solutions in the four domains of surge science principles defined as stuff, stuff, structure, and system but expressed conflicting perspectives regarding PHEM system preparedness against heatwaves or information and communication between stakeholders and care providers.

Gaps and Vulnerability Factors

Regarding "staff", the interviewees were concerned by the influence of heatwaves on EMS personnel safety and performance, especially when delivering emergency care "*under the sun on the streets or inside houses without air conditioning at the top floor*" (S5), "*performing cardiopulmonary resuscitation*" (S3), or attending a "*complex and prolonged extrication from a car accident, on the asphalt*" (S4). Lack of available EMS personnel was reported by two interviewees, from both the perspectives of acute response "*to answer a higher number of emergency calls*" and fatigue due to "*increased calls protracted for days*" (S5), and also poor heatwave awareness or training on "*materials used*", "*multiple casualty management*", "*triage*", were deemed significant.

Scarcity of resources was highlighted by most of the participants, especially regarding the following "*stuff*": the number of EMS vehicles insufficient "*to meet surges during heatwaves*"; inconsistent availability of instant ice on vehicles; no water availability for personnel; inadequate climatization of vehicles; clothes and personal protective equipment not comfortable at high temperatures; potential malfunctioning of medical devices.

Structures, namely places "*to accommodate multiple patients together during heatwaves*" (S1) because "*EDs are overcrowded*" or to "*gather persons to repair from heat*" (S5), were perceived as absent.

Most observations dealt with system preparedness and organizational factors. Initiatives and outreach efforts to inform and educate the public were deemed insufficient, as were structured prevention measures and, specifically, alerts and heat plans – which, for some interviewees, "*scarcely translate into concrete actions*" (S4). In particular, "*information to the personnel*" was "*the most vulnerable part*" (S7), configuring a gap between the governmental level and end users of plans. The interviewees described the rise in calls to the emergency number and the high rate of emergency care requests in general as inappropriate. The participants explained this as caused by inadequate availability of primary care services, usually "*filtering non-urgent cases, easily manageable at home*" (S9) because the population attempting to reach their GP "*can't find anyone*" (S8). Notably, a vulnerability factor was identified in the marked population increase in touristic areas during holidays, thus requiring more resources (S6, S11).

Strengths

Four interviewees perceived that their PHEM system is overall well prepared because it "*is flexible and adaptable*" to heatwaves (S8). Moreover, the EMS system can "*quite rapidly increase the number of rescue vehicles and personnel*" (S8) in case of surges. Three participants admitted being aware of the national and the regional heat-response plans and advice to the population; also, periodic reminders before the hot season were noted by three. According to three interviewees, the dispatchers "*know well heat-related illness*" (S12), and "*a dedicated dispatch protocol has been introduced to specifically detect heat illness*" (S13), periodically reminded to dispatchers (S7); personnel is also trained and capable of managing heat illness emergencies. Of note, S11 reported "*improvements in climatization inside retirement homes*", S7 an "*increased capability proportional to the higher number of the population*" (tourists, A/N), and S8 "*the luck of having healthcare* workers (doctors or nurses, A/N) *on every ambulance, and not volunteers, prepared to manage correctly heat illness*" – factors potentially reducing heat-related morbidity in the population and the consequent overload of PHEM system.

Potential Solutions to Mitigate the Impact

Three participants suggested "*implementing personnel during these difficult periods*" (S13) by "*identifying best triggers*" (S11) or "*by local government levy*" (S1). To mitigate adverse effects of heat on PHEM personnel, screening for "*physical efficiency*" (S3) was advised beforehand. Directors should contemplate "*improving personnel turnover*" (S11) by "*cutting down to the half active working hours*" (S8) and by reminding "*proper hydration during shifts*" through "*periodic emails*" (S4).

Suggested implementations to materials and equipment included: ice (S3); cold crystalloids for intravenous infusion (S12); water for personnel hydration (S4, S8); and clothes and personal protective equipment more suitable to high temperatures (S4). Four participants confirmed the need to increase the number of EMS vehicles during heatwaves, and two suggested improving their air conditioning system.

Regarding structures, the interviewees suggested creating "*triage points in the districts, made available by local administrations, for example inside gyms*" (S1) and directing the frail population to shopping centers "*where air conditioning is easily available*" (S7), if necessary, by "*establishing a public-private partnership*" (S3).

System modifications included most perspectives captured by the interviews in this subtheme. The interviewees mentioned training and information campaigns for PHEM personnel (n=4) and the population (n=3) as needed to improve the system. Particular attention was dedicated to primary care, with 8 participants suggesting the improvement of integrated care at home, delivered by nurses, or trained volunteers, and coordinated by local governments' social services. Individuals deserving particular attention were suggested to be identified through "*new frailty scales and, therefore, preventively assisted if above a certain threshold*" (S9) to receive support from their social network or through "*economic incentives*" (S8). Two participants suggested strengthening the healthcare system with a more granular activation of civil protection (S3), while S7 suggested improving hospitals' resilience. Heat alert communication, or how the alert is communicated to both PHEM personnel and the population was perceived by two interviewees as to be improved: for communication to the population S11 suggested the participation of mass media; for the interface between agencies and EMS, a standardized communication from the regional forecasts, followed by actions depicted and delineated on a paper to guide dispatchers' actions, was suggested as fundamental. Finally, a dedicated number to answer heat-related health questions was cited but deemed unimportant "*until a predefined threshold is exceeded*" (S12).

Discussion

Although several attempts have been made to increase the understanding of public health initiatives against heatwaves, results from the literature are frequently inconsistent [18,64]. For example, after the heatwave of 2003 in Europe, public health measures were implemented but almost exclusively centered on health warning systems [61]. Progressively, HHAPs were introduced throughout Europe, but several authors confirmed the lack of uniformity [24,62], even after the publication of a European blueprint in 2008 [63]. Therefore, high-quality evidence is more than ever needed to improve current heat-action plans. This study specifically investigates underlying factors causing overload and disfunction to EMS systems during heatwaves, as perceived by PHEM workers of a high-income, European region. Overall, the participants expressed concern during the interview, describing this study as "*innovative*" or "*important*". S2 felt "*emotionally involved*" and supported the project due to her "*climate change awareness*". S8 was positively impressed because "*no one is investigating this important issue*". These are positive signals of involvement of interviewees, which could in future positively affect implementation of interventions.

As in a previous study on heatwave perception among German GPs, all the participants mentioned "temperature" increase as the main characteristic of a heatwave, and 9 out of 13 also added "humidity" to better characterize their answer; other features regarded the time of onset, duration, geographic/location-specific features, and the urban heat island effect. This inconsistency among the described characteristics of a heatwave mirrors the lack of a shared definition [18]. In particular, no agreement exists on the best temperature indicator to define a heatwave. Average mean temperatures and maximum daily temperatures are easy-to-find indicators commonly used by epidemiologists to describe the effects of heatwaves on large populations [34]. Humidex is another widely used temperature indicator, created to describe temperature perception by an average person [35] and capture the increased heat-related physiological stress exerted on the body [36]. However, Barnett et al., after testing mean, minimum and maximum temperature with and without humidity, apparent temperature, and the Humidex, found that none was superior to the others in correlating with mortality, and several factors (such as age group, season, city) influenced the associations found [117]. Moreover, the number of human heat stress indicators has grown exponentially in recent years [37], and in some cases, consider local meteorological conditions such as wind speed [36] (mentioned by two interviewees in the present study). A future clear, operational definition of heatwaves could help stakeholders attain disaster risk reduction [21], but with a comprehensive approach – considering meteorologic, epidemiological, and public health concerns with particular attention towards vulnerable groups [34] – and trigger specific interventions also for EMS.

When asked about heatwaves' impact on the population, the participants narrowed their attention to clinical aspects and social factors. The complexity of the topic is further confirmed by the multifaceted answers given, which, for the first time, are gathered from the perspective of PHEM.

EMS personnel seemed to be aware of the vulnerability of some population strata to heatwaves by referring to those at the extremes of age. In particular, the elderly were cited multiple times, probably due to an increasingly aging population, with a high number of coexisting illnesses and complex pharmacologic therapy encountered during prehospital emergency care. Homelessness was cited by only one participant, consistent with literature and policy neglect concerns expressed by English et al. for this group [118]. The participants expressed concerns regarding "*those working outside*" (S10), as already known from two systematic reviews denoting an association between heatwaves and workers in general [119] and specifically in the agricultural and construction sectors [120]. "*... we rescued* *several times people working in construction sites, or inside factories… or, for example, those working on highways*" (S8).

The interviewees confirmed the complex spectrum of illnesses caused or exacerbated by heatwaves and described in the literature [18]. Surprisingly, only two participants mentioned heat illness or exertional heat stroke in athletes, and another pointed out that, luckily, this is a rare event, with two possible explanations: an actual epidemiologic modification in the clinical presentation during heatwaves in the investigated region, or a poor awareness of the disease. Heat stroke and exertional heat stroke are two medical emergencies whose prompt recognition and treatment have tremendous impacts on patients' outcomes [54,121–123]. It is reasonable to think that the included participants were aware of these emergencies and manifested instead their disappointment (emerging by field notes of the interviewer) by describing a series of preventable diseases, such as acute on chronic illness or syncope due to dehydration, "*abruptly exiting from a cold to a very hot environment*" (S1, S11), or related to a relatively excessive antihypertensive therapy not meeting known seasonal fluctuations in blood pressure [124]. Other diseases pertaining, for example, with cardiovascular, pulmonary, and renal systems were rarely mentioned by the participants; and none of them expressed concerns regarding mortality or morbidity, which instead are well-known to be significantly associated with heatwaves. A possible explanation could be the limited time of contact between patients and EMS personnel in the prehospital arena: PHEM workers could not grasp the definitive diagnosis (usually reached after evaluations in ED or during hospital admissions) and only see acute signs and symptoms or could not perceive mortality as due to other causes than a heat-related or -exacerbated disease. Also, it is reasonable to think that the participants were not experts of heatwave literature, despite this aspect not being among the aims of the present study.

Overall, the issues described above can be associated with a need for more awareness and behavioral change in the vulnerable population. In their scoping review, Mayrhuber et al. summarized that behavioral factors, awareness, and attitude towards heatwaves were protective or risk factors [102]; in particular, individuals unaware of their vulnerability were less prone to enact behavioral changes or defensive measures against heatwaves. Also, the tendency to go *against common sense* reported by the interviewees, such as avoiding walking or exercising during a hot summer day or continuing work despite prohibitive environmental conditions, was consistently present in the literature [102,125].

Three participants confirmed the literature trend regarding the exacerbation of psychiatric illnesses during heatwaves and, more interestingly, highlighted a tendency of people calling the emergency number to be more nervous. While the former aspect is already but limitedly described in the literature [18,126], the latter is a new finding. Further research focused on this behavioral change in the population caused by excessive heat could help deploy measures to prevent verbal and physical aggression, unfortunately, more and more described against healthcare workers in current times.

Among other factors potentially causing overload and inappropriate use of EMS are social isolation due to reduced interaction and separation from family. Depicted in the interviews as a problem predisposing vulnerable individuals to exacerbation of their diseases, unnoticed dehydration, or precluding prevention strategies during heatwaves, such problem has been previously demonstrated [127] and suggested as an essential target of public health interventions [128]. Also, the participants raised a point on the interconnected fields of economic restrictions, inequities, and air conditioning, confirming this as another specific target of policies such as public cooling centers [129,130].

Overall, the "heatwaves and EMS" section offered the highest number of perspectives, probably because it was the most pertinent to the everyday working life of the interviewees. By classifying content through the surge science framework of staff, stuff, structure, and system, the latter was the most mentioned, with aspects focusing on strategic planning and how to effectively prepare to forecasted heatwaves.

Despite some participants expressed confidence in staff preparation to recognize (on the phone or in person) a potential heat-related illness – whose prompt diagnosis and treatment is widely recognized to positively affect patient outcomes [54] – others expressed conflicting opinions regarding training and information needs for both the personnel and the population. To the authors' knowledge, in the literature, there is no study specifically examining the knowledge of healthcare personnel about heatwaves and the associated HHAPs at local, regional, and national levels, while a consistent number of studies has been published on the same parameters within the general population [131]; given these interviews, is reasonable to think that the involved EMS personnel is not well or fully aware of currently established heatwave planning, which is meritorious of future investigation and consequent intervention.

Primary care has also been mentioned as unable to meet patients' needs during heatwaves and in need of precise interventions. Interestingly, two interviewees manifested frustration regarding a reduced availability of GPs, causing "*patients to use the emergency number, ambulances, or access the ED for problems of minor entity*" (S8). Failure of primary care to meet patients' needs has already been demonstrated to significantly contribute to ED overload [132], which mirrors a similar burden placed on EMSs. On the other side, primary care as well is subjected to higher pressure during heatwaves [133]. As suggested by the interviewees, current examples of primary care improvement during heatwaves include dedicated numbers or helplines – offering non-urgent telephone consultation to the overall population and providing active telemonitoring planned for identified vulnerable individuals [134]. A more granular activation of civil protection in every district could also help in scheduling periodical home visits by volunteers to check proper room temperature, adequate hydration, and providing support for out-of-home activities during hottest hours, such as grocery procurement. In general, interventions aiming at modifying population behavior and supporting primary care could easily translate in a reduced input to the EMS, alleviating its burden, and the consequent ED overload during heatwaves.

Staff and structures concepts expressed in the interviews focused on safety concerns, EMS means features, and proper equipment. In particular, personnel were deemed vulnerable as subjected to harsh working conditions, with heat posing a risk to both their health and their performance. Interestingly, literature has explored the impact of heat on workers wearing personal protective equipment (PPE) against COVID-19 but not during heatwaves, finding a precepted worsening of performance [135], and that cooling strategies can improve comfort of workers but seems not impacting cognitive performance [136]. Given the lack of robust data, suggestions of the participants could be used to mitigate heat strain, such as reducing working hours, maintain proper hydration by using reminders and ensuring access to water, adopting more comfortable working clothes during summer, and screening for personnel physical efficiency. Also, high-performance air conditioning in both air and ground vehicles was deemed important to deliver better care to patients, improve personnel comfort, and preserve medical equipment from malfunctioning due to overheating.

Among other positive points captured by the interviews, four highlighted the capacity to adapt to a sudden increase in emergency care demand during heatwaves, thanks to a flexible system capable of recruiting further EMS means and personnel in the same district or by requesting support to a bordering district. The adaptation and response of EMS to a disaster involve in fact a coordinated effort to provide timely and effective medical care to those affected but can be erroneously limited to mass casualty incidents and not to protracted, extreme weather events such as heatwaves. Anyway, interviewees perceived a lack of staff and EMS means during heatwaves and suggested its progressive implementation and to be included in HHAPs. Useful noted adaptations to summer, for example, included the planned increase in staff and means during summer anticipating a growing population in touristic locations, in order to adequately respond to a higher number of care requests. Lastly, the participants suggested implementing structures mainly to divert patients from the EDs or to manage a sudden influx of ambulances. While these aspects may not directly involve EMS, any dysfunction or disruption in their operation could potentially result in a delay in the overall patient processing within the hospital system, ultimately affecting the efficiency of EMS. In fact, ambulances handover in ED is known to significantly impact EMS missions processing times, and derives from a bottleneck in patient acceptance (input) to the ED [137]. Such a mismatch between ED capacity and the number of patients arriving during heatwaves could therefore be addressed inside an integrated approach aiming at improving hospital resilience against disasters, as highlighted by the Sendai Framework for Disaster Risk Reduction [21].

Limitations

This study has two main limitations. First, participants were recruited from a single region. Therefore, the findings could not be applicable to other contexts. Second, the small sample size (13) could have limited the results; however, data saturation was already reached after 10 interviews and comprehensively answered the research questions. The scientifically sound methodology based on the COrEQ guidelines increases the validity of this study.

Conclusions

This study provides valuable insights into the perspectives of PHEM personnel from a high-income European region regarding EMS's vulnerabilities to heatwaves and potential solutions. The findings underscore the importance of addressing these vulnerabilities to mitigate the risk of health system dysfunction during such extreme weather events.

Concrete interventions should improve current HHAPs through strategic planning, resource allocation, training and awareness campaigns, enhancing patient care and personnel safety during heatwaves. This approach, integrating other healthcare sectors, will enable PHEM to effectively adapt to a changing climate, resulting in a more streamlined service.

CHAPTER 5: DISCUSSION

The constant increase in temperatures and the resultant change in climate patterns will cause modifications in the prevalence of chronic and acute diseases, globally affecting the quality of healthcare provided to the populations [18]. Due to already existing vulnerabilities and lack of evidence in this limitedly investigated field, healthcare systems are ubiquitously unprepared to face the threats posed by such a rapidly changing climate [72,75,138,139].

Unfortunately, climate change can't be stopped. The hope is to find a way to limit the forecasted degree of temperature rise through globally shared strategies. Meetings are periodically held among governments in an attempt to limit greenhouse gas emissions, but are constantly shadowed by the interests of private companies and fossil fuels-based economies; these aspects emerged at the last COP28 hosted by the United Arab Emirates in Dubai [7], so there are still no concrete solutions.

Healthcare systems worldwide already start from an overstretched situation. Factors such as the growing and aging population, increasing demand for higher-quality care requiring more economic resources, and the lack of personnel have requested profound adaptations through the years. Within each health system, emergency care is carrying the heaviest burden since it responds not only to urgent and emergent cases (which is its mission) but also to the unmet health and social needs of the population [89]. Therefore, hospitals and EDs must anticipate a rise in the number of visits and admissions and potential quality deterioration of delivered care due to already existing strain on the healthcare system and the consequences of climate change.

In particular, this project focuses on specific climate change-related EWEs: heatwaves. As already depicted in Chapter 1 and 2, an increasing frequency and intensity of heatwaves will pose a particular risk to population health and consequently worsen the already present overload of emergency care. This PhD project identified a gap in the literature and produced two deliverables aiming to improve knowledge in emergency care preparedness against heatwaves.

The Delphi study and semi-structured interviews were selected for their complementary strengths in addressing the research objectives on underexplored topics, where direct empirical data may be complex to obtain. Specifically, the Delphi method was selected for its structured, iterative approach to gather consensus among multidisciplinary experts globally while refining diverse perspectives. Moreover, semi-structured interview methodology was chosen for its ability to capture context-specific experiences, offering grounded insights, with a grade of flexibility allowing exploration of emergent themes and addressing gaps that quantitative or strictly structured methods might miss. Alternative methods, while promising in some aspects, were less suitable for this study's objectives. For example, focus groups could foster collaborative dialogue but risk dominance by vocal participants introducing an important bias which is instead mitigated in Delphi studies; the logistical challenges of gathering geographically distant participants also makes focus groups difficult to organize. Other methods such as content analysis and open-ended surveys, while efficient and scalable, fall short in capturing the depth of lived experiences emerging from interviews, or providing the iterative refinement achieved by Delphi studies [140].

The Delphi study described in Chapter 3 provided a consensus on 18 statements, to be implemented by emergency medicine practitioners in the frontlines of EDs and EMSs. By classifying such items according to the input-throughput-output framework of the ED patient processing, it is somewhat interesting to consider that 10 out of 18 statements specifically deal with the input section. The participating experts probably believed that most of the work to improve resilience should be performed before emergency care, namely primary and community care, as confirmed by recent analyses [141]. Other items dealt with emergency planning and surge capacity development, such as structural modifications within the ED, staff training, and more personnel and equipment in ED or EMS during heatwaves as already noted in the literature [89,106].

The results provided by the Delphi study were acknowledged by the research team as mostly dealing with the in-hospital side of emergency medicine (EDs): only three out of 18 statements mentioned PHEM. For that reason, another qualitative study was performed to better analyze the perspective of PHEM personnel, find their priority needs, and fill another gap in heatwaves-related literature. The results from semi-structured interviews described in Chapter 4 are more granular than the Delphi study, highlighting the need for interventions targeting the population before the encounter with PHEM. For the interviewees, most of the work carried out by EMSs during heatwaves did not qualify as an emergency, and could have been managed by primary and community care, mirroring again what emerged during the Delphi study [103–105]. The interviewees also provided interesting insights on social factors triggering an increase in care demand during heatwaves, sometimes defined as inappropriate, such as failure of social and caregiver/family networks, lack of air conditioning, and poverty [100–102,129,142]. Also, improvements in staff training and adequate equipment during the hot season were expressed as useful.

The overall recommendation stemming from this project targets HHAPs to include interventions targeting the whole emergency care, directly or indirectly, outside and inside hospitals–meaning PHEM or EDs, respectively– and dealing with different domains of a structured response to heatwaves, as expressed by Table 4

Table 4: Summary of the recommendations emerging from the project. The Input – Throughput – Output framework serves as a common denominator for the analysis of both Prehospital Emergency Medicine / Emergency Medical Service (EMS) and Emergency Departments (EDs).

Theme	Delphi Study Insights	Interview study insights	Recommendations
Input			
Vulnerable Populations	Elderly, children, outdoor workers, and socioeconomically disadvantaged individuals are most at risk.	Vulnerabilities include frailty, lack of awareness, mental health issues, and social isolation.	Tailored awareness campaigns, mapping vulnerabilities, improving social and healthcare networks; targeted, inclusive campaigns to reduce stigma and provide economic incentives for air conditioning and against poor housing.
Community Awareness	Public information campaigns can reduce heat-related health risks.	Behavioral adaptation is limited by cultural and socioeconomic factors.	Develop targeted, accessible public messaging and outreach, and leverage local leaders to promote community actions.

Health Impacts	Chronic diseases, heat-related pathologies, and exacerbated comorbidities are prominent.	Cases include syncope, dehydration, aggressive behavior, and psychiatric conditions.	Integrate heat-health services into HHAPs, focusing on physical and mental health.
Throughput			
Staff and Resources (Stuff)	Insufficient personnel and equipment hinder response during heatwaves.	Staff safety, hydration, fatigue, and need for training were major concerns in EMS.	Expand training, increase resources, and ensure staff support during high-demand periods.
Infrastructure (Structure)	Lack of designated cooling areas and summer hospital bed reductions cause bottlenecks.	Inadequate triage spaces exacerbate patient processing delays.	Establish temporary triage centers and pre-designated cooling zones for critical cases.
Systemic Preparedness	HHAPs lack integration of emergency care-specific measures like surge capacity planning.	Poor intersectoral communication impacts effectiveness.	Incorporate EMS/ED-specific measures into HHAPs, improve cross-sector coordination, and integrate telemedicine.
Output			
Boarding	Summer bed reductions worsen ED bottlenecks during heatwaves.	Patient handover and discharge delays can strain emergency care systems.	Enhance hospital surge capacity and expedite discharge processes during heatwaves.

For example, through widespread awareness and education campaigns, the population could learn how to prepare against heatwaves and which service should be contacted—diverting some calls or clinical cases from the emergency care stream towards primary care and reducing the emergency medicine overload already present during non-heatwave times [63,96,98]. Policies supporting the economically disadvantaged individuals should not be limited to economic incentives to implement air conditioning in their homes: more widely, integrated strategies of urban planning, enhancing green architecture and tree canopy effect, and a better social network supporting those in need removing the social stigma should be among priorities for local and district stakeholders. Primary care should also be provided with adequate training and personnel and then act as the filter for potentially inappropriate demand for emergency services, implementing, for example, telemedicine to monitor the frailest patients at home. Telemedicine is widely known for its potential in helping primary care physicians in better managing patients and efforts in this direction should be enacted [143], mirroring what have been done during the COVID-19 pandemic and, more generally, during healthcare crises due to different causes [144]. Telemedicine could also be used to provide on-demand psychological support services during heat events, as the activation of centers for psychological support, potentially reducing unnecessary accesses to EDs for consultations.

Finally, modifications to EMSs and EDs should be part of a wide preparedness strategy against heat-waves, targeting the essential components of staff, stuff, structure and system, but divided in two steps. First, stakeholders should acknowledge that – at the beginning of the hotter season – awareness campaigns and focused training should be delivered to personnel regarding how to protect themselves against excessive hot and how to recognize heat-related diseases. Specific resources, protocols, or – informally writing – "solutions" should be available to emergency care providers treating patients with social problems, in order to filter such cases at the input by diverting them again to primary care or social services, or facilitating throughput and output processes once in charge to emergency care. Second, early warning systems should trigger already prepared contingency plans, renewed each year through a systematic process of de-briefing and lessons-learned analysis.

A general limitation of the project relies in the context of the semi-structured interviews, performed in a specific region and a single country (Northern Italy). Italy's climate varies significantly across its regions. In the Alpine and sub-Alpine areas in the north, the climate is largely continental, with cold winters and hot, humid summers. In contrast, central Italy is characterized by a Mediterranean climate, where coastal regions enjoy mild, wet winters and warm, dry summers. The inland areas, particularly those along the Apennine Mountain range, tend to be cooler due to higher altitudes, creating pockets of climatic diversity even within the region. Southern Italy, including the islands of Sicily and Sardinia, is dominated by a Mediterranean and semi-arid climate, marked by hot, dry summers and mild, rainy winters. Veneto Region summarizes both the cool mountain, the lowland and coastal humid climates. Whilst the latter could experience more frequent heatwaves during the hot season, its population could be acclimatized to such events thus mitigating morbidity and mortality, while it is the opposite in the mountain area. This climatic variability is anyway comparable to other countries worldwide, thus highlighting the need to understand climate differences to tailor region-specific interventions and enhancing the effectiveness of each HHAP.

While addressing the acute challenges of heatwaves remains crucial, the long-term resilience of healthcare systems in facing evolving climate patterns should be considered. Since heatwaves can be forecasted, future challenges lie at the intersection of predictive analytics and adaptive resilience strategies, in which healthcare systems should prepare rather than simply react.

Artificial Intelligence (AI) showed promising results in supporting heatwaves forecasting [145,146]. Thus, AI could be used to produce climate-responsive algorithms: AI could forecast a heatwave and its magnitude, then estimate patient influxes by analyzing microclimate data coupled with urban design metrics, local demographic vulnerabilities, disaster risk profiles, and previous events epidemiology. Real-time vulnerability mapping could also help primary care in proactively identifying individuals in need of an increased social or health safety network during heatwaves. Also, behavioral nudges could be tailored to each event by targeting specific geographical areas and to counteract framing effect developing during summer.

Such examples of forward-looking perspective can ensure adaptation and sustainability against future crises.

CONCLUSION

This PhD project used two qualitative research techniques – Delphi and semi-structured interviews – to establish a basis to grow further knowledge regarding how emergency care can prepare and improve its resilience against heatwaves.

The project's results covered two branches of emergency medicine, one in the hospital (EDs) and the other in the prehospital arena (EMSs). Both are subject to increased pressure during heatwaves and could benefit from the following recommendations.

First, stakeholders and policymakers should improve HHAPs with actions raising the awareness of the population, supporting frailer strata with social interventions, and strengthening primary care. This will probably lead to a reduced input and pressure on emergency care by avoiding preventable and inappropriate calls to emergency numbers, emergency vehicles dispatches, and ED presentations / admissions. If successful, these measures will reduce the number of patients requesting emergency care during heatwaves, but will not eliminate this burden. Therefore, HHAPs should be revised to include dedicated sections to improve the resilience of emergency care. Briefly: staff training (on heat illness recognition and heat-harm prevention) and recruitment; adequate resources (emergency vehicles; dedicated treating areas in ED or spaces in the community; equipment to treat heat illness); infrastructural adjustment (preventing power grid failures). Ultimately, boarding should be specifically targeted during heatwaves to avoid bottlenecks and expedite patient processing, along with strategies to improve hospital surge capability.

The overall findings shall also be used as the basis for future work by scientific societies and governmental or non-governmental organizations. By gathering the results from this project, formal recommendations could precede protocols to be applied in local, regional, or national contexts. Finally, these actions should be scientifically tested and validated to produce high-quality evidence and achieve the overarching aim of reducing the burden of climate change as the most worrisome challenge of the next decades.

EXECUTIVE SUMMARY (ENGLISH)

Due to global warming and climate change, periods of unusual heat called heatwaves are increasing in frequency and intensity. Heatwaves pose an important risk for population health and are associated with an increased demand for emergency care. This overload on prehospital emergency medicine (PHEM) and emergency departments (EDs) during heatwaves has been retrospectively confirmed, but evidence on how to mitigate this effect still needs to be provided. This PhD project aimed at finding the factors causing PHEM and ED overload during heatwaves using qualitative methods.

First, an online Delphi study included 15 experts in emergency medicine, disaster medicine, or public health. Thirty-one statements were obtained after content analysis. The experts agreed on 18 statements, mostly focusing on the input section of patient processing and identifying stakeholders, the population, and primary care as targets of potential interventions. Additional dedicated resources and bed capacity were deemed important as per throughput and output sections, respectively. Since the results of the Delphi study mainly dealt with the ED, a multicentric study using semi-structured interviews was performed to shed light on PHEM systems. Thirteen PHEM doctors and nurses working in Veneto region, Northern Italy, were interviewed. After content analysis, their perspectives were categorized into four themes: perception of heatwaves; clinical impact of heatwaves; social factors and heatwaves; heatwaves and emergency medical service (EMS). According to the interviewees, the strain on EMS during heatwaves may be partially reduced by interventions targeting vulnerable populations, primary care, social networks, and education and information. Specific actions could follow the surge science principles of staff, stuff, structure, and system to help policymakers improve EMS surge capacity planning, preparedness, and response against heatwaves.

Overall, these findings could be used in the future to implement heat-health action plans and test solutions to increase emergency healthcare resilience during heatwaves, reduce dysfunction due to overload, and mitigate disaster risk due to climatic change.

EXECUTIVE SUMMARY (DUTCH)

Door de opwarming van de aarde en de klimaatverandering komen periodes van ongewone hitte, ook wel hittegolven genoemd, steeds vaker en intenser voor. Hittegolven vormen een belangrijk risico voor de volksgezondheid en worden geassocieerd met een toegenomen vraag naar urgente zorg. Deze overbelasting van de pre-hospitaal middelen en spoedgevallediensten tijdens hittegolven werd reeds aangetoond, maar er moet nog bewijs worden geleverd over hoe men deze overbelasting kan verminderen. Dit doctoraatsonderzoek heeft als doel de factoren te vinden die de overbelasting van de pre-hospitaal middelen en spoedgevallendiensten tijdens hittegolven veroorzaken en dit via een kwalitatief onderzoek.

In een eerste stap werd een Delphi-studie uitgevoerd met 15 experts in het gebied van de urgentiegeneeskunde, de rampengeneeskunde en experten in "public health". Consensus werd bekomen over eenendertig stellingen. De experts waren het eens over achttien uitspraken, die voornamelijk gericht waren op de inputsectie van patiënten gegevensverwerking, het identificeren van belanghebbenden binnen de bevolking en tenslotte de eerstelijnszorg als voornaamste terrein voor mogelijke interventies. Extra toegewezen hulpmiddelen en de beschikbare bedcapaciteit voor hospitalisatie waren bijkomende belangrijke parameters. Aangezien de resultaten van de Delphi-studie voornamelijk betrekking hadden op de spoedgevallendiensten, werd er een multicentrische studie uitgevoerd met semi-gestructureerde interviews om de pre-hospitale hulpverlening te evalueren. Dertien artsen en verpleegkundigen werkzaam in de pre-hospitale organisatie uit de regio Veneto, Noord-Italië, werden geïnterviewd. De analyse van de interviews kon ondergebracht worden in 4 categorieën: de perceptie van de hittegolven, het klinische impact van de hittegolven, de sociale factoren en hittegolven, de invloed van hittegolven op de pre-hospitale organisatie. Volgens de geïnterviewden kan de druk op pre-hospitaal systeem tijdens hittegolven gedeeltelijk worden verminderd door specifieke interventies gericht op kwetsbare bevolkingsgroepen, de eerstelijnszorg, de sociale netwerken, en educatie en informatie. Specifieke acties zouden de principes van "surge capacity" kunnen volgen om beleidsmakers te helpen bij het verbeteren van de planningscapaciteit, de voorbereiding en de respons van de pre-hospitaal organisatie bij hittegolven.

De bevindingen uit dit proefschrift kunnen in de toekomst worden gebruikt om hitte-gezondheidsactieplannen te implementeren en ook oplossingen te testen die de veerkracht van de urgente zorg tijdens hittegolven verhogen, de disfunctie door overbelasting verminderen alsook en het risico op rampenscenario's door klimaatverandering te beperken.

TABLES AND FIGURES

ANNEXES

Supplementary Table 1

First Round: 79 statements proposed by the 15 included experts to the question:
"*What are the factors causing emergency medical care overload during heatwaves?*"

lack of adeguate emergency plans (prehospital emergency medicine, emergency department, hospital)
reduction of hospital beds due to staff summer holidays (hospital)
reduced hydration capacity by the elderly (public health) (primary care)
lack of an adequate home care network for the elderly and vulnerable groups (Primary care)
lack of adeguate information. Public health messages about the potentially significant health risks need to be dissemitaed to the entire population. Everyone is at risk and everyone must be able to understand if a person is in danger (public health)
Increased heat related pathology influenced by Community based factors including social, economic, behavioural, environmental and health literacy factors
variable immediate access to primary care
Increases in health risk factors such as chronic disease potentially amenable by enhanced public health strategies and enhanced primary care
Limited alternatives available to prehospital paramedics. Transfer to hospital is often the quickest approach when organising social support and primary care may be more efficient and effective form a whole of system perspective
Emergency medical system planning often does not allow for the impact of heatwaves as it would for other disasters. Thus sudden (and largely predictable increases in demand) are often not met with additional resources. Indeed, resources are often constrained as heat related illness and carer responsibilities reduce resource availability.
Public risk management strategies and public awareness raising by public health authorities and community leaders is often not effective.
no communications plan: national, regional and local governments need to plan the response in terms of communications tools (sms, chats, mails) and media involvement. When there're no plans, not appropriate accesses and mass flows can create critical impacts into the emergency services.
not diffused telemedicine networks for fragile categories: health services and primary care could improve these aspects
medical cultural aspects: temperature (high or low) is a vital parameter but not often considered as a main parameter by primary care, emergency medical service / prehospital emergency medicine, emergency department, public health department, hospital
family doctors: they can educate their own patients and can suggest right lifestyles before and during heatwaves
health services : must be able to educate about right lifestyles during heatwaves
Does working in the Middle East make one more susceptible to heat stroke
What is leading cause of heat related illnesses in the world
Whats the treatment difference in different types of heat related pathologies
Is there a set algorithm for managing heat-related pathologies
WHat the rate of morbidity and mortality in heat-related illness and does it depend on geography
Should Emergency Departments build specialized heat stroke rooms? These need highly efficient cooling air conditioning, refrigerators stocked with iced saline and crushed ice machines, and possibly ice water bathtubs.
Should nations mandate reporting of heat illness, given the medical importance of the condition for national preparedness and also monitoring of climate change effects?

Assuming that the prevalence of heat stroke and other acute heat-related illnesses is likely higher in poorer countries, should rich countries and/or the UN determine a minimum capability that they will strive to help poor countries achieve?
Should the WHO determine a global information dataset regarding heat-related health effects, both chronic and acute, and invest in monitoring this information in most nations on earth?
Should rich nations spend very large sums of money on transformational technologies to protect people, especially in poor nations, from the direct health effects of increasing temperatures?
What is THE most important technological challenge to be addressed re item 5 above? Examples may include: 1. Low energy-consumption air conditioning? 2. Low energy-consumption refrigeration? 3. Low-tech, cheap, mild-moderate cooling systems for dwellings and food storage systems? 4. Quick proliferation of distributed modes of ecologically efficient electricity generation?
Increased demand for prehospital and retrieval medical services during extreme heat.
Lack of access to air conditioning in homes
Failure of health disaster management units to communicate risk to the community
Exacerbation of chronic medical conditions
No surge capacity in prehospital or emergency department services
Heat illness affecting prehospital EMS clinicians
Lack of screening/interventions for at risk populations during primary care encounters {Primary Care]
Lack of social support to vulnerable populations [Public Health]
Increased EMS Call Volume [EMS]
ED Overcrowding [Emergency Medicine]
Staffing shortages [Public health, Primary Care, EMS, Emergency Medicine, Hospital, Social Services agencies]
Poverty. (Pre-hospital), The number of people requiring emergency medical care at the time. (Emergency medical service)
Very young and very old. (Pre-hospital)
Number of healthcare staff in hospital emergency department (Emergency medical service)
Treatment facilities and equipment available (Emergency medical service)
Expertise of healthcare professionals (Emergency medical service)
Individuals with chronic or mental health conditions are more susceptible to extreme heat.
Heat waves were associated with increased overall admissions in emergency department
Heat waves have a greater health impact among the elderly and young children
Access to space cooling (build environment)
An acute increase in visits to the Emergency Department is caused by heat effects on adults and children for a range of causes, including respiratory illness, renal disease, heat injury and accidents. The causes of these diseases which are exacerbated are complex and outside the Emergency Department remit.
Reducing greenhouse gas emissions will be reduce future heatwaves
An acute increase in visits to the ED could be managed better by heatwave warnings to inform staffing and other measures by the ED. [Emergency Department]
Better case management in primary care of chronic diseases and frailty could avoid some emergency admissions
Hospital: incident command system not trained to scenario heatwave specific on long period
ED lack of communication inside chain of care and digitalisation(IT overview tools)
ED : high complexity of diseases and treatment on heatwave ED have not good organisation, Stuff, Staff, for clinical decisions units and response protocols
Poor primary care and poor private health preparedness at home , focus on vulnerable groups like elderly, children , not mobile patients at home (dehydration, medication) . Preclinic treatment insufficient for response after 16:00 and organised treatment at home

EMS dispatch Center initial Actions goals mostly to transportation to ED No physician inside dispatch Center
ED : no protocols not enough space or stuff for short term treatment in heatwave situations
limited resilience of. the elderly (pre end in)
limited preparedness in organization of sports events (pre , disaster)
higher risk of drowning (pre)
unawareness of risks of physical activity (pre and in - hospital)
heat stroke (pre hospital)
dehydration (pre and in hospital)
Inadequate identification of high risk groups and preparations to minimise the effects of a heat wave in these groups.
Inadequate public health messaging of the risks of heatwaves
Insufficient preparedness by the community for heatwave events, with impacts at the ED.
Inadequate training of GPs and ED staff on signs, symptoms and management of heat stress
Inappropriate public events planning that occurs in peak periods for heat stress
Limited community knowledge of the signs and symptoms of heat illness from general practitioner and public health sources
preventive measures are better than treating a patient with hyperthermia
A social network prevents to become a victim of a heat wave
Heat waves have a severe influence in the afternoon
Heat waves have no influence on hospitalized patients.
Heatwaves coincide with vacation periods, when medical staff is taking annual leave - complete healthcare sector
Insufficient means and attention for heatwaves - political level
Understaffing of healthcare sector due to long-term sick leave after COVID-19 crisis - complete healthcare sector
Overburdened healthcare sector with patients experiencing other morbidities (e.g. COVID-19) - complete healthcare sector
Insufficient preventive measures before and during heatwaves - population and public health level
Increasing number of vulnerable (elderly and comorbid) people in the population - population level

Supplementary Table 2: Included Experts' Characteristics

Country

Australia	4
Belgium	3
Italy	2
India	1
Israel	1
Greece	1
UK	1
USA	1
United Arab Emirates	1

Area(s) of expertise

Public Health alone	3
Emergency Medicine + Disaster Medicine	10
Emergency Medicine + Public Health	1
Disaster Medicine + Public Health	1

Supplementary Material 3

COREQ (COnsolidated criteria for REporting Qualitative research) Checklist

A checklist of items that should be included in reports of qualitative research. You must report the page number in your manuscript where you consider each of the items listed in this checklist. If you have not included this information, either revise your manuscript accordingly before submitting or note N/A.

Topic	Item No.	Guide Questions/Description	Reported on Page No.
Domain 1: Research team and reflexivity			
Personal characteristics			
Interviewer/facilitator	1	Which author/s conducted the interview or focus group?	35
Credentials	2	What were the researcher's credentials? E.g. PhD, MD	35
Occupation	3	What was their occupation at the time of the study?	N/A
Gender	4	Was the researcher male or female?	34
Experience and training	5	What experience or training did the researcher have?	35
Relationship with participants			
Relationship established	6	Was a relationship established prior to study commencement?	35
Participant knowledge of the interviewer	7	What did the participants know about the researcher? e.g. personal goals, reasons for doing the research	35
Interviewer characteristics	8	What characteristics were reported about the inter viewer/facilitator? e.g. Bias, assumptions, reasons and interests in the research topic	35
Domain 2: Study design			
Theoretical framework			
Methodological orientation and Theory	9	What methodological orientation was stated to underpin the study? e.g. grounded theory, discourse analysis, ethnography, phenomenology, content analysis	35-36
Participant selection			
Sampling	10	How were participants selected? e.g. purposive, convenience, consecutive, snowball	35
Method of approach	11	How were participants approached? e.g. face-to-face, telephone, mail, email	35
Sample size	12	How many participants were in the study?	35
Non-participation	13	How many people refused to participate or dropped out? Reasons?	35
Setting			

Setting of data collection	14	Where was the data collected? e.g. home, clinic, workplace	35
Presence of nonparticipants	15	Was anyone else present besides the participants and researchers?	35
Description of sample	16	What are the important characteristics of the sample? e.g. demographic data, date	36
Data collection			
Interview guide	17	Were questions, prompts, guides provided by the authors? Was it pilot tested?	35
Repeat interviews	18	Were repeat inter views carried out? If yes, how many?	N/A
Audio/visual recording	19	Did the research use audio or visual recording to collect the data?	35
Field notes	20	Were field notes made during and/or after the inter view or focus group?	35
Duration	21	What was the duration of the inter views or focus group?	35
Data saturation	22	Was data saturation discussed?	35
Transcripts returned	23	Were transcripts returned to participants for comment and/or correction?	N/A
Topic	**Item No.**	**Guide Questions/Description**	**Reported on Page No.**
Domain 3: analysis and findings			
Data analysis			
Number of data coders	24	How many data coders coded the data?	36
Description of the coding tree	25	Did authors provide a description of the coding tree?	36
Derivation of themes	26	Were themes identified in advance or derived from the data?	36
Software	27	What software, if applicable, was used to manage the data?	36
Participant checking	28	Did participants provide feedback on the findings?	N/A
Reporting			
Quotations presented	29	Were participant quotations presented to illustrate the themes/findings? Was each quotation identified? e.g. participant number	36-41
Data and findings consistent	30	Was there consistency between the data presented and the findings?	N/A
Clarity of major themes	31	Were major themes clearly presented in the findings?	36-41
Clarity of minor themes	32	Is there a description of diverse cases or discussion of minor themes?	36-41

Developed from: Tong A, Sainsbury P, Craig J. Consolidated criteria for reporting qualitative research (COREQ): a 32-item checklist for interviews and focus groups. *International Journal for Quality in Health Care*. 2007. Volume 19, Number 6: pp. 349 – 357

Supplementary Materials 4: Semi-structured Interview Guide

Theme	Subject	Question
Introduction and confirmation of consent	Welcome greetings. Introduction: refresh on purpose of the study; criteria for participants selection; how the interview is carried out (open questions, any clarifications / insights requested by the interviewer). Confirmation of consent. Reminder that audio is recorded and anonymity is ensured.	
Introductory question	General – *icebreaker*	*This project aims to investigate the preparedness of pre-hospital emergency care systems against heatwaves and, as an ultimate goal, contribute to its improvement. What was your first thought when you heard about this project?*
The "Heatwaves" Problem	Definition of Heatwave Risk to the population	*According to you: what is a heatwave?* *What could be the impact of heatwaves on the population?* [Probing: mortality and morbidity? Exacerbation of chronic diseases? Economic impact? Social impact on vulnerable strata?]
"Heatwaves" and the Pre-hospital Health Emergency System	Impact on the Pre-hospital Health Emergency System. Heat wave preparedness	*How could heatwaves impact the Prehospital Health Emergency system?* *What do you think of your district's Pre-Hospital Emergency Health System preparedness against heatwaves?* *What do you think about response plans to heat waves in your district, region, or country?*
Vulnerability of the Pre-hospital Health Emergency System	Weaknesses	*What are the factors of vulnerability that can make the pre-hospital emergency system inefficient during heat waves?* [Probing: System, Staff, Stuff (equipment / Means of transport), Structure]
Quality improvement	Potential solutions	*What solutions could be enacted to prevent overload and/or inefficiency of the pre-hospital emergency care system during heatwaves?* Probing: - System; Staff (staff); Stuff (equipment / Means of transport); Structure
Conclusion	Concluding greetings	*Do you have any other suggestions or thoughts you'd like to share?* *Thank you for your participation.*

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