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Literature review

A mixed methods descriptive literature review assessing the affects of chemical, biological, radiological and nuclear personal protective equipment on human factors and clinical skills

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Abstract

Background Aum Shinrikyo pioneered the first impactful domestic mass-application of a nerve-agent since its inception in warfare. Approximately 10% of responders and 23% of hospital staff reported symptoms of secondary exposure, fuelling concerns about the United Kingdom response. Secondary exposure risks in chemical incidents continues across developed countries in lesser circumstances.

Legislation and guidance for emergency responders in specialist situations further compounds complexity of responding in challenging environments. The Human Rights Act alongside modern western medico-legal philosophy encourages everything possible to preserve life. Conversely, this must be balanced against the risks to rescuers.

Specialist units have been established ensuring pre-hospital responders are protected while delivering care. In England and Wales, this is through Hazardous Area Response Teams (HART).

These teams deliver Advanced Life Support (ALS) in challenging environments. However, the extent to which Personal Protective Equipment (PPE) affects the ability to deliver clinical interventions is not truly tested alongside human factors.

Methods An electronic database search for articles was undertaken, using a PRISMA framework for reporting, individual articles were then assessed using Critical Appraisal Skills Program (CASP) checklists before common themes were extrapolated using mixed methods to analyse the impact of PPE on clinical skills and human factors.

Results 14 articles were found for full review, being a mix of systematic reviews (n=2), simulative studies (n=11) and a masters thesis (n=1). Data was heterogenous with articles measuring specific skills including intubation, cannulation and chest compression quality with others taking a qualitative approach to impedance of skills i.e. effects on dexterity. Major flaws were identified in most of the literature.

Conclusion Findings from this review reveal PPE delays and affects clinical care — impacting human factors and exacerbating the standard of care delivered failing below normal standards. This needs full assessment and further research to inform guidance for operatives in this environment.

Introduction

The Hazardous Area Response Team (HART) has formed part of the multi-agency operational model for the last 10 years.[1] Prior to this, 'hot zone' working was led solely by fire rescue services with no clinical intervention in this area. Development of legislation has continued to put an onus on 'responsible bodies' to deliver the highest standard of care for people in environments that pose hazards to rescuers and the public alike. Coupling case law, informing the tort of medical negligence and modern medical ethics of non-maleficence,[2] there is a heavy responsibility for prehospital providers to deliver care in these environments regardless of challenges they may pose.

With chemical incidents in civilian practice being rare,[3,4] it is assumed there will be little evidence and literature available that assesses the impact of Personal Protective Equipment (PPE)

on patient care. However, the use of simulative pedagogy, in modern medical practice, allows the safe testing of equipment and procedures subsequently supplementing the available literature.

This review aims to probe the literature beyond the confines of medical research to establish the facts surrounding the use of PPE (Specifically Chemical, Biological, Radiological and Nuclear protective PPE: CBRN) and how this affects emergency service personnel. It is essential we understand how PPE impacts emergency service personnel in the course of their duties. If it is shown that PPE negatively impacts clinical skills such as intubation or cannulation then prior planning, training, standard operating procedures, and guidance is required to counter this to uphold the rights of patients, with an evidence base to underpin this. The review follows the PRISMA structure for reporting of systematic reviews.

Methods

The patient/population, intervention, comparison and outcomes (PICO) format was used to construct the research question:

> *'In the adult population injured in hazardous circumstances, is the standard of clinical care affected when compared between PPE and non-PPE wearing clinicians?'*

Eligibility was based on articles measuring the effect PPE has against a control group of no PPE published since the year 2000. Groups outside of healthcare were included due to the relative youth of HART and this style of working within healthcare. Studies were not limited to any specific skill or task to allow broader inclusion and build an overall understanding of how PPE effects emergency personnel to allow consideration of human factors.[5] Only open access articles were reviewed, allowing a full review of the articles. Non-English studies were excluded to ensure key messages are not lost in translations. Publications older than the year 2000 were excluded to ensure current practice is used. Otherwise, if upon review of title, abstract or article, they were found to not make the aforementioned comparisons, they were eliminated from this review.

Articles were critically assessed using the Critical Appraisal Skills Program (CASP) checklists[6] for systematic reviews and cohort studies relative to the shortlisted articles facilitating a consistent approach to assessing each article and to reduce bias from researchers. Findings were reported using the PRISMA framework.[7]

Databases were searched in June 2022 by both researchers and results can be seen in Figure 1.

These databases gave access to literature both inside and outside of medical research to allow inclusion from other emergency services and military databases which include more historical exposure to the use of PPE. Search criteria was: "CBRN" AND "PPE" AND "Performance" within the title fields only with a years filter of 2000-current.

Duplicate titles were not removed at the initial stage as a method of self-checking. The exclusion of titles and abstracts was completed manually by two researchers. A third impartial reviewer was available to settle disagreements; however no disagreements arose. Titles and abstracts were eliminated from each database, based on a manual check, against the search and eligibility criteria on review. Inconsistencies in the method could be detected if a title or abstract was to be eliminated in one database but not another; no such inconsistencies were detected ensuring a consistent method. Identified duplicate titles were removed in the last stage.

Shortlisted articles seen in Tables 1 and 2 below, were then grouped into homogenous cohorts to extrapolate comparable quantitative values and can be seen in Table 2. Qualitative themes were extrapolated by a single researcher in a reflexive thematic analysis style[8] and identified themes are discussed below. These themes were retrospectively discussed with the second researcher, who agreed on the themes.

Results

Of the shortlisted articles, eleven are primary research simulation studies, two are systematic reviews and one was a research masters thesis. These studies are predominantly in the medical field (n=11) with the remainder coming from policing (n=2) and the military (n=1). No studies were identified from fire services. The primary research spanned North America (n=3), Europe (n=5), Asia (n=3) and Africa (n=1) demonstrating a heterogenous spread of healthcare systems and economies. However heterogenous the geography of data sources, consistent approaches to PPE allow comparison across the research articles. PPE classifications seen in table 3 can either be graded as per the National Fire Protection Association Standards (NFPA), class 1 to 4, or by the American Environmental Protection Agency (EPA) class A to D. NHS HART often refers to PPE classifications in line with EPA standards and this is reflected in the majority of the articles.

Table 1 uses Dougherty and Conway' s system of translational research[10] to compare articles as a simple way to demonstrate the power of each article in a numerical scale from 1 (lowest) to 3 (highest). This tool allows a comparison of the shortlisted articles and demonstrates how they either impact current clinical practice (translational level) or the likelihood these simulations would influence practice.

Simulations studies involved in the review are at low translational levels. However, with little incidence of patient illness requiring Levels A, B and C PPE,[9] it is unlikely there would be articles assessing simulative training impacts above the lower translational levels.

Figure 2 shows a summary of the data from Table 2.

Qualitative data was also collected in several studies.[12,16–18,20,22,24] Common themes were:

Dexterity: PPE reduced dexterity particularly the hands and wrists making tasks such as intubation or cannulation difficult.[17,22] Kou *et al*[18] noted it is obvious participants were finding it more difficult to move while wearing PPE.

Vision: Participants identified vision was reduced especially in respirators with limited visual fields.[17,22]

Higher exertion and increased fatigue: Participants felt fatigued whilst wearing PPE.[12,16,24] Two studies stopped participants from completing the full study due to rising body temperatures.[12,24] Rising temperatures inside the PPE was observed in one other study.[20]

Communication: A single study discussed how communication was impaired through voice muffling and noise from powered respirators creating obvious limitations when compared to no PPE.[20]

Kou *et al*[18] measured perceptions of PPE before and after their PPE simulation showing improvement in how severely the perceived impact would be. They noted that training boosted participants' confidence.

Wang *et al*[22] showed how the above themes were prevalent among their participants. However, half or less of the participants felt PPE affected vision and dexterity while performing tasks compared to no PPE. This suggests that even though it is a reported issue, it was not for a significant portion of participants, contrary to other studies.

Critical appraisal of included studies

The CASP tool[6] was used to assess articles. Significant flaws were found throughout the simulations which commonly referenced each other or their own work, reinforcing the risk of bias.[11–18,20,22,24] The two included systematic reviews[19,23] that also reference these key flawed studies in their evidence. These themes are discussed below.

Study designs: Three of the articles [13–15] shortlisted in this review were by research teams led by Nicholas Castle. A futher four shortlisted articles[17,18,19,23] referenced the three Castle et al articles. Of the remaining four, three were focussed on law enforcement[12,24] or military personnel[21], and as such, were unlikely to reference this 'healthcare-focused' work. This means articles from this

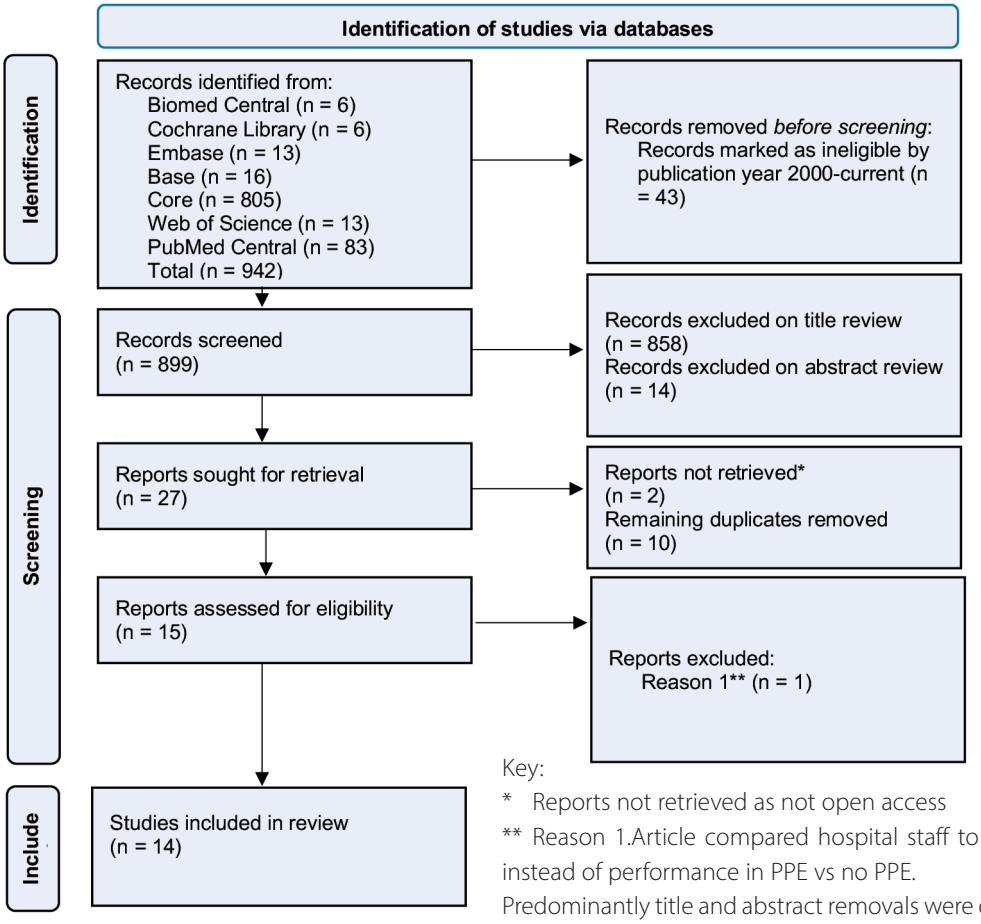


Figure 1. PRISMA Flow Diagram adapted from Page et al[7].

Key:

* Reports not retrieved as not open access

** Reason 1.Article compared hospital staff to prehospital staff instead of performance in PPE vs no PPE.

Predominantly title and abstract removals were due to the search terms not being in the title or the abstract demonstrating the article was not suitable for the review.

single author[13–15] makes up or impacts approximately 75% of the evidence. But the design of one of the studies[14] is flawed, which should invalidate the applicability of the results to practice. Furthermore, when this work is referenced in systematic review, subsequent researchers claim to have only included articles where 'users have experience of wearing PPE'[19] or studies that 'mimicked realistic situations'[23]; bringing into doubt the authors understanding of this equipment use or its application. The issue is that the problematic article[14] used students as participants, but they're referred to as 'experienced and this article employs PPE not in line with current guidance'. Additionally, when referring to studies that only mimicked realistic scenarios the majority of simulations studying time-affect, laid equipment out prior to starting and ran simulations in a hospital environment.[13–15,18,20,22] Meanwhile other studies measuring resuscitation involved solo rescuers or doing compressions on the floor, which is contrary to current standard procedures.[16–18] This remains exceptionally pertinent as to sit, kneel or lay on the floor to deliver these skills or interventions would compromise the integrity of the PPE and so would not be done in practice, so testing the effect of PPE on compressions while kneeling would not be applicable to practice.

'Experience': Several studies compare levels of experience.[15,18,19,21,22] However, only one study considers experience of wearing PPE,[18] while the remaining articles considers experience based on years served or clinical seniority.[15,18,19,21,22] Often these comparisons are between anaesthetists, especially when referring to intubation. However, these authors do not consider the need for experience of operating in PPE and how this impacts performance. 'Experience' was shown to reduce error,[15,20,22] however there is philosophical debate around what defines experience in this environment.

Results: Some articles state they were unable to finish their study as participants breached safety cut-offs and had to stop,[12] this

Table 1. Shortlisted literature review articles

	Authors	Year	Title	Research type	Translational level10	Sample size
1	Ansari et al[11]	2020	The effects of personal protective equipment on airway management: An in-situ simulation	Simulation	1	36 intubation teams
2	Blacker et al[12]	2013	Physiological responses of police officers during job simulations wearing chemical, biological, radiological and nuclear personal protective equipment	Simulation	1	17
3	Castle et al[13]	2009	Impact of Chemical, Biological, Radiation, and Nuclear Personal Protective Equipment on the performance of low- and high-dexterity airway and vascular access skills	Simulation	1	64
4	Castle et al[14]	2011	What is the optimal position of an intubator wearing CBRN-PPE when intubating on the floor: A manikin study	Simulation	1	48
5	Castle et al[15]	2015	Does CBRN-PPE increase right bronchus intubation	Simulation	1	112
6	Chen et al[16]	2016	Chest compression with personal protective equipment during cardiopulmonary resuscitation	Simulation	1	40
7	Kim et al[17]	2016	Influence of personal protective equipment on the performance of life-saving interventions by emergency medical service personnel	Simulation	1	20
8	Kou et al[18]	2022	Impact of personal protective equipment on the performance of emergency paediatric procedures by prehospital providers	Simulation	1	59
9	Sanfilippo et al[19]	2022	Tracheal intubation while wearing personal protective equipment in simulation studies: a systematic review and meta-analysis with trial-sequential analysis	Systematic review	1	1306
10	Schumacher et al[20]	2021	Influence of respiratory protective equipment on simulated advanced airway skills by specialist tracheal intubation teams during the COVID-19 pandemic	Simulation	1	14
11	Simon[21]	2010	The effects of personal protective equipment Level A suits on human task performance	Masters	1	7
12	Wang et al[22]	2016	The effect of personal protective equipment on emergency airway management by emergency physicians	Simulation	1	40
13	Wiyor et al[23]	2020	Impact of clinician personal protective equipment on medical device use during public health emergency: a review	Systematic Review	1	92 articles
14	Yokota M et al[24]	2014	Thermal-work strain in law enforcement personnel during chemical, biological, radiological, and nuclear (CBRN) training	Simulation	1	30

Table 2. Homogenous results

Endo-Tracheal intubation (ETT)									
Authors	**Control group***	**SD**	**PPE group***		**SD**	**Difference***	**P value**	**95% confidence interval**	**Note**
Kou et al[18]	*37*		43			+4.5	0.0117		Compared no PPE to Level B PPE.
Schumacher et al[20]	*8.1*	3.5	*6.5*	*8*	*5.6* (powered hood) *4.4* (FFP3)	*-3*	0.09		No direct measure of difference between groups. First value in PPE group for wearing powered hood FFP3 Second value in is FFP3 mask
Castle et al[14]	*30.4*	7.18	39.42		9.44	+9.38		(Control group, 27.95–32.12) (PPE group, 36.68–42.16)	PPE Level C. Figures from 'intubating on a trolley' arm, so figures are comparable to other studies.
	47		48			+ 1			
Castle et al[13]	*36.1*		67.5			+31.4		(control group, 34.2–38) (PPE group, 63.3–71.7)	PPE Level C
	64		57			-7			2 abandoned and 5 oesophageal
Wang et al[22]	*17.83*	11.13	17.86		6.38	+0.03	0.99		PPE Level C
	39		38			-1			
Kim et al[17]	*49.8*	+/- 23.1	*64.6*		+/- 30.9	*+14.8*		0–29.6 (confidence interval of difference)	PPE Level C
	20		17			-3	0.231		
Sanfillippo et al[19]	*25.67*		36.77			+11.1			All PPEs included with mix of video laryngoscope and direct laryngoscope
	587		558			-29			
Chest compressions: % effective compressions									
Chen et al[16]	67.50	+/- 15.6	41.30		+/- 17.1	-26.2	<0.001		Level C PPE
Kim et al[17]	55.50	+/-40.1	57.10		+/- 43.6	+1.60		-7.4–42.7	PPE Level C Proportion of adequate depth
	49.60	+/-37.6	62.40		+/-34.7	+12.90		0.5–24.2	Proportion of adequate rate
IV Access									
Castle et al[13]	*40.8*		*129.6*			*+88.8*		(Control group, 38.9–42.7) (PPE group, 119.7–139.6)	PPE Level C. PPE Group had 9 abandoned attempts
	64		55			-9			
Kim et al[17]	*54.1*	+/- 21.1	*89.9*		*+/- 22*	*+35.8*	34.8	26.7–44.9	PPE Level C
	19		17			-2	0.605		
Wiyor et al[23]						1.2–2.5 times longer			Difference in success time
						12% difference			Difference in failure rate

**Timings measured in seconds (seen in italics)*

Second row shows successful at first attempts of noted skill.

Table 3. PPE Classifications and descriptions[9]

NFPA Level	Class 1	Class 2	Class 3	Class 4
EPA Level	Level A PPE Equivalent	Level B PPE Equivalent	Level C PPE Equivalent	Level D PPE Equivalent
Brief description	Completely encapsulated suit and self-contained breathing apparatus (SCBA)	Encapsulating suit or junction seams sealed, supplied air respirator or SCBA.	Splash suit and air-purifying respirator	Work clothes, including standard precautions for health care workers (eg, gloves, splash protection)
NHS HART equivalent	Gas Tight Suit (GTS)	GTS	Powered Respirator Protective Suit (PRPS) Level 4 High Consequence Infectious Disease protection.	Level 3 or universal precautions

could have impacted the result. Small participant numbers also reduce reliability.[12,17,20,21] Otherwise, wide standard deviations seen above in Figure 2 suggest the need for larger sample sizes.[17]

Generalisability to prehospital practice: Often studies focused on a hospital environment.[13–15,18,20,22] With only one study employing a pre-hospital approach to their study design,[16] it is unfortunate that participants were doing resuscitation while on the floor in PPE.[16]

Discussion

CBRN-PPE has negative effects on clinical skills, predominantly intubation and skills requiring finer dexterity, such as cannulation.[11,13–15,17–23] Regarding resuscitation,[25] it is shown that PPE negatively impacts compressions.[16,17] This is compounded by the impact on fatigue.[12,24] However, this evidence is brought into doubt by multiple flaws,[15,18,19,21,22] and misunderstandings of correct application of PPE.[14,19]

Industrial accidents or acts of chemical-based terrorism may require high levels of PPE and clinical care, justifying the need to maintain this capability and protect rescuers.[3,4,26] Especially in cases with deteriorating patients, delays in definitive care during lengthy decontamination processes (that are required to prevent secondary contamination of rescuers and forms an essential part of patient treatment) must be considered as part of ongoing care.[1,27]

Legislation balances the rights of rescuers and victims while placing a duty to deliver prompt care[25,28,29]; given this, it is not as simple as removing the capability/duty on the basis it is difficult to deliver, frequency of use or concepts of expertise. Therefore, while guidance[25] built on evidence of survivability supports delivery of ALS with toxic causes, consideration needs to be granted to the impact of PPE on specialist paramedics' ability to deliver these specific skills.

Common reference to experience, based on clinical seniority or number of years served shows little consideration towards how experience of operating in PPE[18] is a key confounder, especially in the light of human factors being a leading risk to patient safety.[30,31] Experience is far more complex than 'years served'.[5]

Operating in these PPE must always be done in a team further compounding the difficulties therein.[5] Teamwork and human factors elements are under-assessed in the review and this shows a significant absence in the literature. Simulative methods[32] should be applied in the future to looking at how this level of PPE impacts team factors.

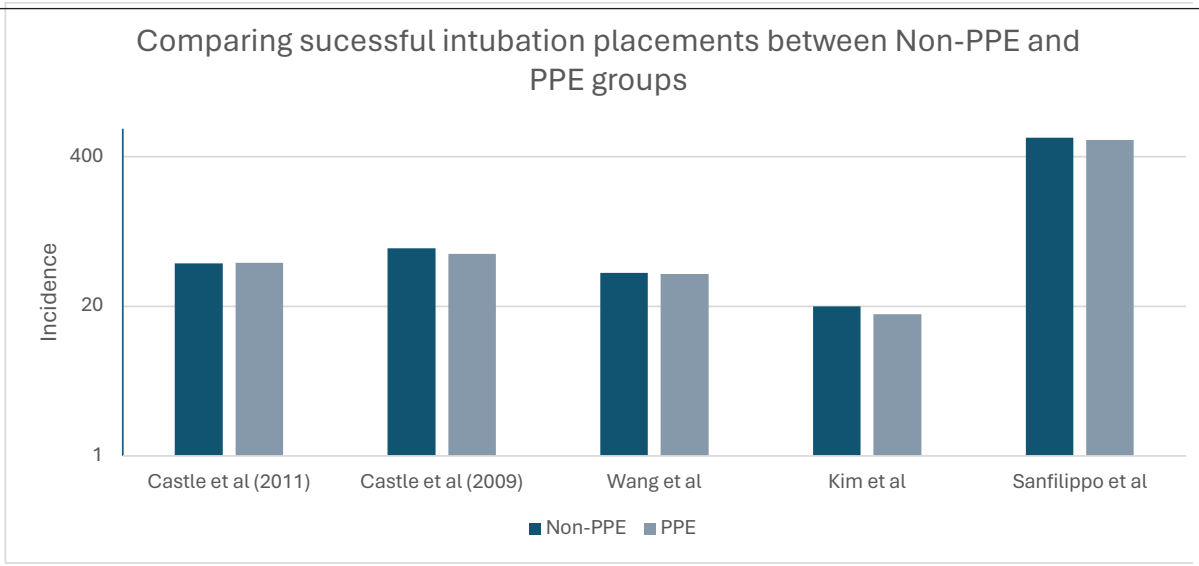
The literature carries little applicability to prehospital practice. The simulations operated in hospital environments or laid equipment out prior to starting.[13–15,18,20,22] Further to this, study designs either led to compressions being done on the floor [16–18] or in positions that simply would not be employed due to the limitations of PPE.[13–15] This highlights an area that needs further investigation through teams that are experienced in the use of PPE.[33] These teams need to pioneer the research into this specialty field, giving credibility behind the results and employ studies that are realistic within the confines of the PPE. Consideration should be given towards human factors to increase patient safety[30,31] and how the PPE limits these elements, alongside impacts on specific clinical tasks. Guidance on care in these environments can be generated with consideration towards impacts of PPE on clinical care balancing the protection of wearers[29] with the rights of victims.[28]

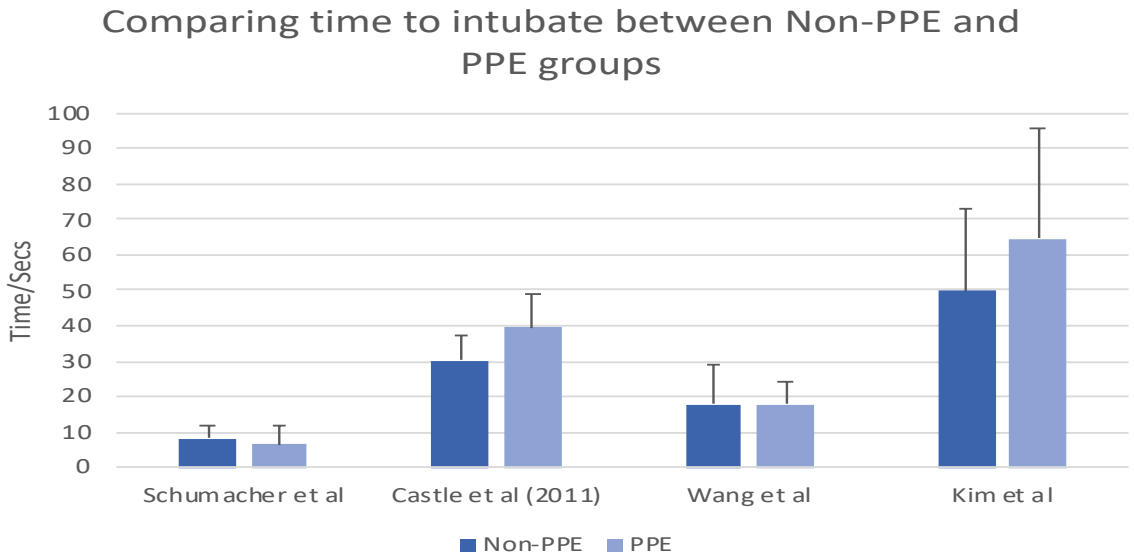
Limitations

Searches were limited to articles only written in English which would eliminate research in other languages that may investigate more recent wide scale chemical weapons use.[34,35] 'Years' filters removed any research from incidents of historic use where research could be found outside of simulation.[27,36,37] The articles had a heterogenous pool of data which limited the ability to perform a statistical meta-analysis and establish statistical significance. Lastly, because of the variety in PPEs within the found literature and limited comparisons between similar PPEs it is not possible to draw conclusions as to whether there is a correlation between level of PPE and level of impedance of each skill set.

Conclusion

This review searched seven databases looking for evidence outside of and including the medical literature to establish


Comparing sucessful intubation placements between Non-PPE and PPE groups
Incidence
400
20
1
Castle et al (2011)
Castle et al (2009)
Wang et al
Kim et al
Sanfilippo et al
Non-PPE
PPE


Comparing time to intubate between Non-PPE and PPE groups
Time/Secs
100
90
80
70
60
50
40
30
20
10
0
Schumacher et al
Castle et al (2011)
Wang et al
Kim et al
Non-PPE
PPE

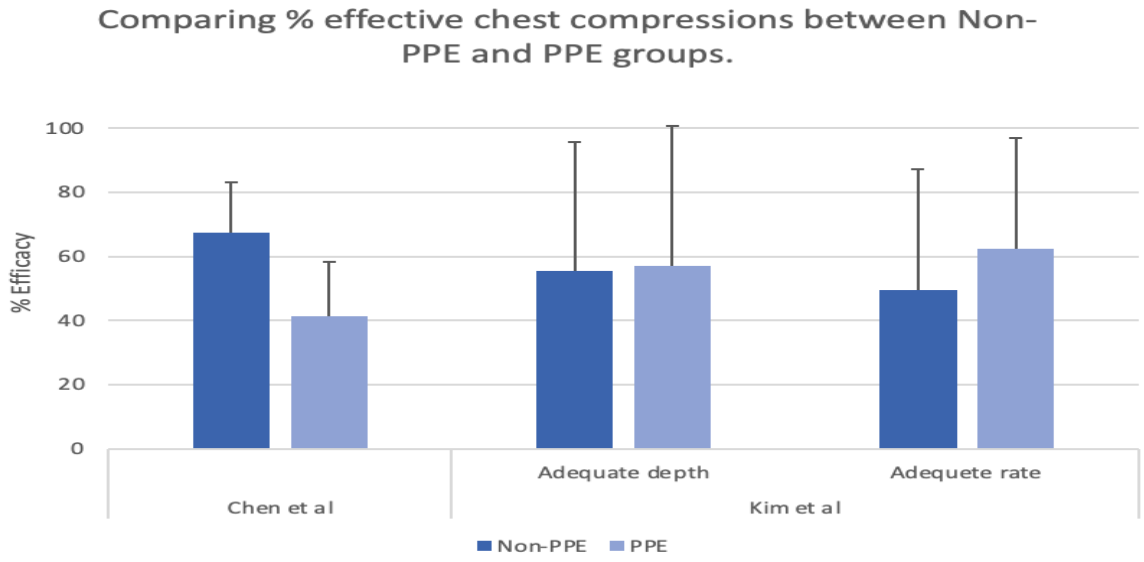

Comparing % effective chest compressions between Non-PPE and PPE groups.
% Efficacy
100
80
60
40
20
0
Chen et al
Adequate depth
Adequete rate
Kim et al
Non-PPE
PPE

Figure 2

the effect PPE has on wearers in the delivery of tasks. Most evidence is simulation-based which would align with the low incidence of work requiring this level of protection. PPE had negative impacts on wearers' ability to deliver key clinical skills associated with advanced life support and increases fatigue. This is demonstrated through PPE having a negative effect on specific skills (such as intubation, IV cannulation and chest compressions), when compared to non-PPE groups. However, the evidence has significant flaws affecting its credibility and applicability to the prehospital environment. There is an established gap evidenced from this review on how PPE can affect the delivery of ALS in the prehospital environment and further assessment of human factors is required.

Conflicts of interest

Author is a UK HART Paramedic

Ethics

Ethics were approved as part of Queen Mary University ethics approval process reference QMERC22.264.

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References

1. JESIP. Responding to a CBRN(e) event [Internet]. Joint Operating Principles For The Emergency Services. 2016 [cited 2022 May 23]. Available from: https://www.jesip.org.uk/uploads/media/pdf/CBRN JOPs/JESIP_CBRN_E_JOPS_Document_On.pdf
2. Laurie G, Harmon S, Dove E. Mason and McCall Smith's Law and Medical Ethics. 11th ed. Oxford: Oxford University Press; 2019.
3. HSE. Health and safety at work Summary statistics for Great Britain [Internet]. 2016 [cited 2022 Jun 29]. Available from: https://www.hse.gov.uk/statistics/overall/hssh1516.pdf
4. PHE. Chemical Hazards and Poisons Report Issue 26 [Internet]. 2016 [cited 2022 Jun 29]. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/522065/CHaP_Report_26_V2.pdf
5. College of Paramedics. Human Factors in Paramedic Practice. Rutherford G, editor. Bridgwater: Class Professional Publishing; 2020.
6. CASP. CASP Checklists. 2022 [cited 2022 Jul 2]. Available from: https://casp-uk.net/casp-tools-checklists/
7. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021 Mar 29;n71. doi: https://doi.org/10.1136/bmj.n71
8. Byrne D. A worked example of Braun and Clarke's approach to reflexive thematic analysis. Quality and Quantity [Internet]. 2022 Jun 26;56(3):1391–1412. doi: https://doi.org/10.1007/s11135-021-01182-y
9. US Dept. Health and Human Services. Personal Protective Equipment (PPE) Classification Systems [Internet]. Radiation Emergency Medical Management. 2022 [cited 2022 Jun 30]. Available from: https://remm.hhs.gov/ppe_classification.htm
10. Dougherty D, Conway PH. The "3T's" Road Map to Transform US Health Care. JAMA. 2008 May 21;299(19):2319–2321. doi:10.1001/jama.299.19.2319
11. Ansari U, Mendonca C, Danha R, Robley R, Davies T. The effects of personal protective equipment on airway management: An in-situ simulation. Trends in Anaesthesia and Critical Care 2020 Oct;34:23–27. doi: https://doi.org/10.1016/j.tacc.2020.07.003
12. Blacker SD, Carter JM, Wilkinson DM, Richmond VL, Rayson MP, Peattie M. Physiological responses of police officers during job simulations wearing chemical, biological, radiological and nuclear personal protective equipment. Ergonomics. 2013 Jan 12;56(1):137–147. doi: https://doi.org/10.1080/00140139.2012.734335
13. Castle N, Owen R, Hann M, Clark S, Reeves D, Gurney I. Impact of Chemical, Biological, Radiation, and Nuclear Personal Protective Equipment on the performance of low- and high-dexterity airway and vascular access skills. Resuscitation. 2009 Nov;80(11):1290–1295. doi: https://doi.org/10.1016/j.resuscitation.2009.08.001
14. Castle N, Pillay Y, Spencer N. What is the optimal position of an intubator wearing CBRN-PPE when intubating on the floor: A manikin study. Resuscitation. 2011 May;82(5):588–92. doi: https://doi.org/10.1016/j.resuscitation.2011.01.005
15. Castle N, Pillay Y, Spencer N. Does CBRN-PPE increases right bronchus intubation. Resuscitation. 2015;96:152. doi: https://doi.org/10.1016/j.resuscitation.2015.09.364
16. Chen J, Lu KZ, Yi B, Chen Y. Chest compression with personal protective equipment during cardiopulmonary resuscitation. Medicine. 2016 Apr;95(14):e3262. doi: 10.1097/MD.0000000000003262
17. Kim TH, Kim CH, Shin S do, Haam S. Influence of personal protective equipment on the performance of life-saving interventions by emergency medical service personnel. Simulation. 2016 Oct 20;92(10):893–898. doi: https://doi.org/10.1177/0037549716662322
18. Kou M, Donoghue AJ, Stacks H, Kochman A, Semião M, Nash M, et al. Impact of personal protective equipment on the performance of emergency pediatric procedures by prehospital providers. Disaster Medicine and Public Health Preparedness. 2022;16(1):86–93. doi:10.1017/dmp.2020.128
19. Sanfilippo F, Tigano S, la Rosa V, Morgana A, Murabito P, Oliveri F, et al. Tracheal intubation while wearing personal protective equipment in simulation studies: a systematic review and meta-analysis with trial-sequential analysis. Brazilian Journal of Anesthesiology (English Edition). 2022 Mar;72(2):291–301. doi: https://doi.org/10.1016/j.bjane.2021.08.017
20. Schumacher J, Carvalho C, Greig P, Ragbourne S, Ahmad I. Influence of respiratory protective equipment on simulated advanced airway skills by specialist tracheal intubation teams during the COVID-19 pandemic. Trends in Anaesthesia and Critical Care. 2021 Aug;39:21–27. doi: https://doi.org/10.1016/j.tacc.2021.05.001
21. Simon Y. The effects of personal protective equipment Level A suits on human task performance. Missouri University Of Science And Technology; 2010. Available from: https://scholarsmine.mst.edu/masters_theses/4994
22. Wang CC, Chaou CH, Tseng CY, Lin CC. The effect of personal protective equipment on emergency airway management by emergency physicians. European Journal of Emergency Medicine. 2016;23(2):124–129. doi: 10.1097/MEJ.0000000000000157
23. Wiyor HD, Coburn JC, Siegel KL. Impact of clinician personal protective equipment on medical device use during public health emergency: a review. Disaster Medicine and Public Health Preparedness. 2020 Apr 9;14(2):273–283. doi: 10.1017/dmp.2019.52
24. Yokota M, Karis AJ, Tharion WJ. Thermal-work strain in law enforcement personnel during chemical, biological, radiological, and nuclear (CBRN) training. International Journal of Occupational and Environmental Health. 2014;20(2):126–133. doi: https://doi.org/10.1179/2049396714Y.0000000056

25. Soar J, Böttiger BW, Carli P, Couper K, Deakin CD, Djärv T, et al. European Resuscitation Council Guidelines 2021: Adult advanced life support. Resuscitation [Internet]. 2021 Apr;161:115–151. doi: https://doi.org/10.1016/j.resuscitation.2021.02.010

26. Okumura S, Okumura T, Ishimatsu S, Miura K, Maekawa H, Naito T. Clinical review: Tokyo — protecting the health care workers during a chemical mass casualty event: an important issue of continuing relevance. Critical Care (London, England). 2005 Aug;9(4):397–400. doi: https://doi.org/10.1186/cc3062

27. Marrs T, Maynard R, Sidell F, editors. Chemical Warfare Agents Toxicology and Treatment. 2nd ed. Wiley-Blackwell; 2007.

28. Human Rights Act. London: UK; 1998. Available from: https://www.legislation.gov.uk/ukpga/1998/42/contents

29. Health and Safety at Work etc. Act. 1974. Available from: https://www.legislation.gov.uk/ukpga/1974/37/contents

30. Institute of Medicine. To Err Is Human. Kohn L, Corrigan J, Donaldson M, editors. Washington, D.C.: National Academies Press; 2000.

31. Department of Health. An Organisation with a Memory [Internet]. United Kingdom: Stationary Office Books; 2000 [cited 2021 Feb 19]. Available from: https://webarchive.nationalarchives.gov.uk/20130105105027/http://www.dh.gov.uk/en/Publicationsandstatistics/Publications/PublicationsPolicyAndGuidance/DH_4065083

32. Levine A, DeMaria S, Schwartz A, Sim A. The Comprehensive Textbook of Healthcare Simulation [Internet]. Levine AI, DeMaria S, Schwartz AD, Sim AJ, editors. New York, NY: Springer New York; 2013. Available from: http://link.springer.com/10.1007/978-1-4614-5993-4

33. NARU. HART. 2021 [cited 2021 Jul 3]. Available from: https://naru.org.uk/what-we-do/hart/

34. Guardian. Russia names gas used to end siege. The Guardian. 2002 [cited 2022 Jul 3]. Available from: https://www.theguardian.com/world/2002/oct/30/russia

35. Chulov M. Syrian regime blamed for sarin gas attacks in landmark report. The Guardian. 2020 [cited 2022 Jul 3]. Available from: https://www.theguardian.com/world/2020/apr/08/syrian-regime-blamed-for-using-sarin-gas-in-landmark-opcw-report

36. Nakajima T, Sato S, Morita H, Yanagisawa N. Sarin poisoning of a rescue team in the Matsumoto sarin incident in Japan. Occupational & Environmental Medicine. 1997;54(10):697–701. doi: https://doi.org/10.1136/oem.54.10.697

37. Broughton E. The Bhopal disaster and its aftermath: a review. Environmental Health. 2005;4(1):6. doi: https://doi.org/10.1186/1476-069X-4-6