Journal of High Threat & Austere Medicine

Original research

A controlled multi-arm simulation study to assess the effect of CBRN PPE on advanced life support

Tim Anderson

Hazardous area response team, UK
Institute of Health Sciences Education, Faculty of Medicine and Dentistry, Queen Mary University of London, London, UK

Corresponding author email tim.anderson@eastamb.nhs.uk

Keywords prehospital, CBRN, advanced life support, cardiac arrest, personal protective equipment

For referencing. Anderson T. A controlled multi-arm simulation study to assess the effect of CBRN PPE on advanced life support. JHTAM. 2024;6(2):11-20.

DOI https://doi.org/10.33235/JHTAM.6.2.11-20

Submitted 28 September 2023, Accepted 7 May 2024

Abstract

Background UK medical teams who respond to chemical attacks and industrial accidents require higher levels of Personal Protective Equipment (PPE) to deliver care, including Advanced Life Support (ALS). However, there is limited research exploring the impact of PPE on the ability of responders to provide cardio-pulmonary resuscitation (CPR) and there is no guidance on changes to algorithms in these high consequence environments.

Methods A standardised simulation was repeated across five groups: control (plain uniform), gas tight suit, powered respirator protective suit, level 3 and level 4 PPE. Time to compressions and pauses between CPR sets were measured with a Corpuls-3 defibrillator. Additionally, participant physiology, fatigue and human factors were measured using the Anaesthetists Non-Technical-Skills Framework and Likert scaled feedback forms. This allowed holistic assessment of the impact of PPE on ALS.

Results As the level of PPE increased, a downwards trend in 'good compressions' from the control group to Gas Tight Suits (GTS) (50% and 12% respectively) with a mean absolute difference in GTS comparison to control of 38% (95% CI 19.90 – 55.47], p<0.01). This aligned with a reduction in participants' confidence in performance and survivability using Likert scales. Basic physiology was measured to make an assessment on increasing fatigue with increasing level of PPE being shown.

Discussion PPE delays care and affects the quality of resuscitation. 'Good compressions' deteriorate as the level of PPE increases, suggesting participants' ability to deliver ALS in higher levels of PPE is impaired. As such, further guidance is required in these specialised circumstances.

Introduction

Background

Terror attacks create risks to rescuers[1] necessitating high levels of Personal Protective Equipment (PPE); this is replicated in industry where regular chemical incidents have created casualties and posed additional risks to emergency services[2,3]. As such, in England and Wales specialised teams called Hazardous Area Response Teams (HART) have been formed to be trained and equipped for these specialised circumstances. Advanced Life Support (ALS) is difficult in this environment due to the restrictions of PPE. The removal of toxins is crucial but decontamination is a lengthy process[4,5]. Clinicians therefore need to operate in PPE to ensure ALS is maintained during decontamination of casualties. However, the evidence-base behind ALS in hazardous environments is flawed[6–19] and difficult to apply to current pre-hospital practice.[5,20]

Good clinical practice requires evidence to reduce the risks to patients and challenge the dogma of what is thought to be best practice.[21] As such, in absentia of applicable evidence, it is essential that an understanding of how modern PPE affects clinician's delivering lifesaving skills is made.[22–25] This should influence policymakers in the production of guidelines for working in these environments with consideration towards maintaining standards and best practice, balanced against risks to rescuers and patient outcomes.

Aims

It is hypothesised that PPE negatively impacts ALS performance. Simulative techniques[26,27] demonstrate how PPE affects evidence-based metrics of ALS, such as time to starting compressions,[28–30] while simultaneously considering how human factors[31] are influenced alongside fatigue[19]. Each element contributes towards the standard of care in ALS. The use of simulation to deliver this

assessment will keep the risks to participants low and produce no risk to the public.

Simulations will be delivered in line with current procedures[30,32] and manufacturers' recommendations[22,23,25] to conform with legislation.[33,34] As such, this is a pioneering assessment of the impact of PPE on ALS while conforming to current procedures.

This standardised simulation was repeated across a control (plain uniform), gas tight suit, powered respirator protective suit, level 3 and level 4 PPE. It measured time to compressions and pauses between sets of CPR with a Corpuls-3 defibrillator, alongside participant physiology-based-fatigue and human factors using Anaesthetists Non-Technical-Skills Framework and Likert scaled feedback to form a holistic assessment of the impact of PPE on ALS.

Materials and methods

Participant selection and setting

Between September and December 2022, 33 HART paramedics from a single base took part in a standardised simulation repeated across five study arms of different PPEs (gas tight suit, powered respirator protective Suit, level 3 and level 4 PPE) and a control group (plain uniform). Table 1 demonstrates participant distribution.

Participants were HART paramedics who have demonstrated competence in each PPE as part of their regular training routine.

Table 1. Participant demographics

Demographic	n
Male	29
Female	4
Age	
26-30	5
31-35	6
36-40	4
41-45	10
46-50	4
51≤	4
Years of ambulance service experience	
0-5	14
6-10	3
11-15	9
16-20	6
21≤	1
Number of years in HART	
Unanswered	1
0-5	18
6-10	7
11≤	7

Participants consented and volunteered, while available, to train as part of their work routine. Participant selection was based on who was available at the time of the simulation. Selection bias of participants was reduced by block convenience sampling of groups. This was done by random availability of participants, available on operational duties, alongside the availability of the researcher to set up and run simulations.

Sample size

Similar studies [6–19] utilised a mean average of participants of just over 30, so this was the target minimum sample size of participants in this study. A set of 40 simulations (eight simulations per study arm) were scheduled with the aim of producing enough data to generate comparable averages within practical and financial limitations. Once eight simulations of each study arm were delivered no more data was collected.

Method

Simulations were run by a single researcher ensuring consistency in delivery. Simulations were set up with all appropriately sized PPE out and checked prior to donning, each study arm was a standardised simulation repeated in different levels of PPE as described in Table 2. A Laerdal SimMan ALS mannequin with SimPad and shocklink device[35] was used for generation of shockable/non-shockable rhythms for trial blinding, preventing pre-planning of performance by particpants. A Corpuls-3 defibrillator and Puc feedback[36] device measured all elements of compressions. Participants had a response bag with training equipment they were all familiar with. This bag only gave access to equipment allowing focus on evidence-based metrics of ALS[30]. Where required, a fairteck stretcher, ferno basket and scoop were accessible, facilitating lifting the mannequin from the floor to expedite compressions while standing, in compliance with standard operating procedures (SOPs) for PPEs preventing kneeling.[22–25] PPE descriptions and classifications can be seen in Table 2.

Figure 1 shows the simulation layout in an air-conditioned room ensuring a standardised environment. Safety staff, peers observing for human factors and simulation directors stood clear of the simulation as highlighted by the dotted line. Participants took observations before/after the simulation for comparison. A standardised brief was presented re-asserting the simulation objective and established the rules, safety elements and what was required. Each brief contained information advocating for the required PPE. This was the only variation between briefings. Simulations ran with teams of three participants.

Upon finishing the brief, a Corpuls-3 monitor was turned on, commencing a timer to starting compressions. Participants donned relevant PPE (or none for the control group), following SOPs [5,22–25] before advancing to the mannequin to deliver ALS.[30] After 10 minutes of compressions the simulation was stopped,

and the carotid pulse was enabled on the SimMan mannequin. Participants then each assessed whether they could identify a pulse and its rate (Figure 5). A post-CPR report from the Corpuls-3 provided data on compressions (Figure 2). At the end participants removed their PPE and immediately provided a second set of observations for comparison to depict fatigue (Figure 4). Lastly, participants filled in post-simulation experience forms assessing attitudes and perceptions on Likert scales relating to confidence in performance and survivability (Figure 3).

Peers were provided with the Anaesthetist's Non-Technical Skills (ANTS) Framework[31] with no prior training to assess intra-simulation human factors. This framework is commonly used in the assessment of human factors for anaesthetists to provide feedback on performance and identify areas of improvement. Peers noted appropriate comments against each line of the framework to highlight common areas between groups of participants in each PPE arm. Common themes were retrospectively assessed by a single researcher to identify and extract commonalities under each of the framework sub-headings: task management, team working, situational awareness and decision making. These common themes are reported below.

Overall, time-based measures of 'time to start compressions', 'length of pauses between compression' were recorded

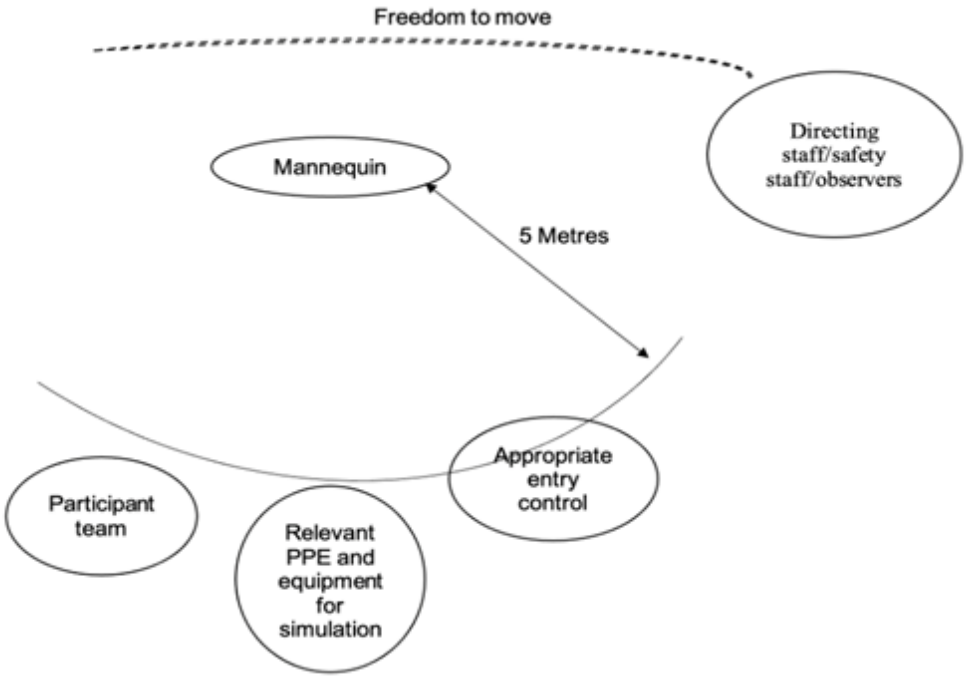


Figure 1. Diagrammatical layout of standardised simulation showing consideration of potential confounders

Table 2. PPE Classifications and descriptions[37]

National Fire Protection Association (NFPA) level	Class 1	Class 2	Class 3	Class 4
Environmental Protection Agency (EPA) Level	Level A	Level B	Level C	Level D
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[20]	Gas Tight Suit (GTS)[22]	GTS [22]	Powered Respirator Protective Suit (PRPS)[23] NXGen PPE with FM-53 respirator[25] Level 4 High Consequence Infectious Disease protection[24]	Level 3 or universal precautions[38]

alongisde '% good compressions', '% good compressions/rate', '% good compressions/depth' (as reported by the Corpuls-3) as well as participants' physiology before and after the simulations (including heart rate, respiratory rate, blood pressures and oxygen saturates). Also recorded were Likert scale feedback from post-simulation questionnaires and qualitative observations on human factors from peers using the ANTS tool, Lastly, the number of participants able to identify the pulse on the mannequin and its rate after the simulation was recorded. All information was submitted through Microsoft forms with QR codes and analysed in Microsoft Excel.

IBM SPSS Version 28 was used to analyse the difference between the means of '% good compressions' only with a simple 2-sided independent samples T test. This was the most succinct way to test for statistical significance of any differences.

The original study design planned for each participant to partake in all study arms. However, difficulty recruiting participants meant some had full participation whereas others were partial, only taking part in one or two study arms instead of all arms. CPR performance data was grouped in teams of three participants which was not controlled. This is a significant confounder of the data.

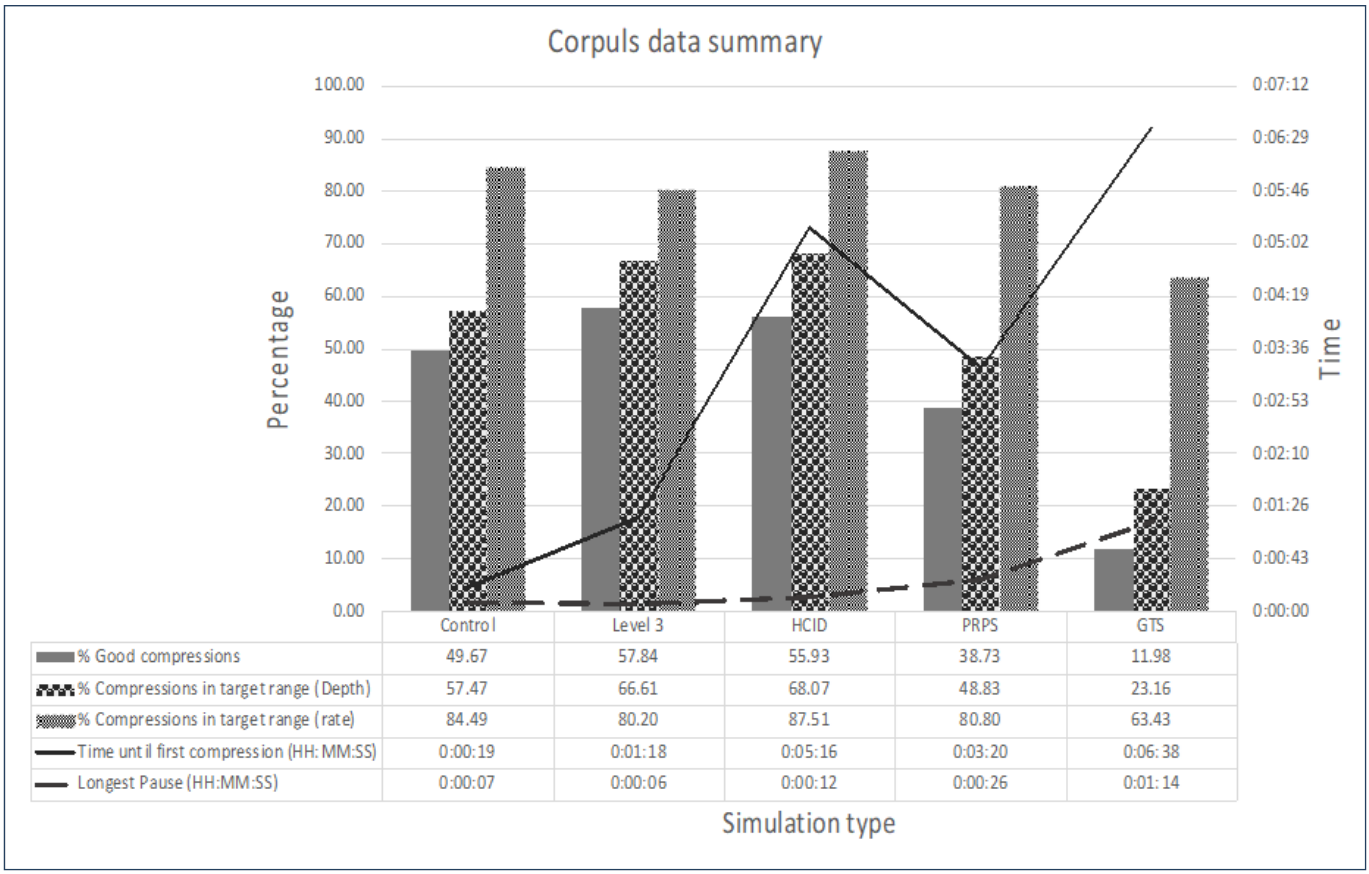
Results

Figures 2–5 show graphical representations of descriptive statistics of the results.

Figure 2 shows PPE's impact on compressions as recorded by the Corpuls-3.[36] The hypothesis that PPE would negatively impact ALS aligns with the literature[6–19] and is shown in Figure. 2. A downwards trend in 'good compressions' from the control group to Gas Tight Suits (of 49.67% and 11.98% respectively) showed correlation between level of PPE and the influence on '% good compressions' with the exception of level 3 and HCID PPE (57.84% and 55.93% respectively). Furthermore, upwards trends in time-based metrics showed correlation between PPE level and delays in either starting or length of intra-arrest pauses except for HCID.

Figure 3, and the data in Table 3, showed participant perception measured on Likert scales from 0–10, with zero being negative and 10 being positive towards to the enquired topic. Very generally all areas of participant perceptions showed downwards trends from the control to GTS groups.

Fatigue physiology is demonstrated in Figure 4. Heart rates from before/after simulations showed much greater changes in the



	Control	Level 3	HCID	PRPS	GTS
% Good compressions	49.67	57.84	55.93	38.73	11.98
% Compressions in target range (Depth)	57.47	66.61	68.07	48.83	23.16
% Compressions in target range (rate)	84.49	80.20	87.51	80.80	63.43
Time until first compression (HH: MM:SS)	0:00:19	0:01:18	0:05:16	0:03:20	0:06: 38
Longest Pause (HH:MM:SS)	0:00:07	0:00:06	0:00:12	0:00:26	0:01: 14

Figure 2. CPR performance: Corpuls-3 post simulation data summary showing mean averages of each value. N=24 participants in each study arm. Each simulation with teams of three participants. Time-based values shown on Y axis from the right. % based values shown on Y axis on the left.

GTS group when compared to control groups (mid-point heart rates rising from 74 bpm to 89 bpm and 71 bpm rising to 76 respectively) aligning with the self-reported increase in fatigue (Figure 3 and Table 3). Other physiological changes remained negligible and so are not reported.

Lastly Figure 5 demonstrates the distribution of participants unable to find pulses post simulation. GTS had the highest proportion with the lowest being level 3 PPE (50% and 0% respectively). However, this percentage represents 9 of the 24 participants in this study arm and so only 37.5% of participants in the GTS arm were unable to identify a pulse (see Table 4). It is difficult to draw a correlation between level of PPE and impedence of this specific skill.

Statistical analysis

IBM SPSS Version 28 analysed the difference between the means with a simple 2-sided independent samples T test. This allowed comparison between the control group and a test group i.e., GTS to establish statistical significance between the mean differences. This analysis was only run on the main study arm looking at the 'percentage good compressions' information produced by the Corpuls-3. These tests rejected the Levene's test that the variances in data between the two groups were the same for the PRPS and GTS comparisons ($p<0.01$ in both sets). As such Satterthwaite's method was used in these two groups. Statistical significance (showing that the difference between the means was different to 0) was established in the GTS comparison but not in the PRPS (Mean difference in GTS comparison of 37.69%, 95% CI [19.90, 55.47], $p<0.01$, whereas in PRPS 10.94% 95% CI [-7.22, 29.10], $p= 0.21$). In the level 3 and HCID comparators the null hypothesis that the variances in data between the 2 groups were the same was accepted ($p=0.15$ and 0.26 respectively). Subsequently a pooled variances estimator established the T test values. Statistical significance that the difference between the means was different to 0 was not established in the level 3 or HCID comparison (Mean difference in level 3 comparison of -8.18% 95% CI [-27.62, 11.27], $p=0.38$, whereas in HCID -6.26% 95% CI [-26.46, 13.93], $p=0.52$).

In summary, using a simple 2-sided independent sample T test to identify any statistical significance of difference between compared means of the 'percentage good compressions' for each test arm, showed that when comparing the control group to the GTS group, there is statistical significance in this difference, however, all other groups showed no statistical significance in their comparisons. All arms had confidence intervals that were very wide, as a result of the small sample sizes.

Discussion

Consideration should be paid into the frequency of chemical-based events in the civilian environment[1] measured against their risk without infinite budgets; weighed against societal perspectives in the current generation as ethical lenses on medical futility are changing with modern times.[40,41] With the time delays shown in this study, futility should be considered

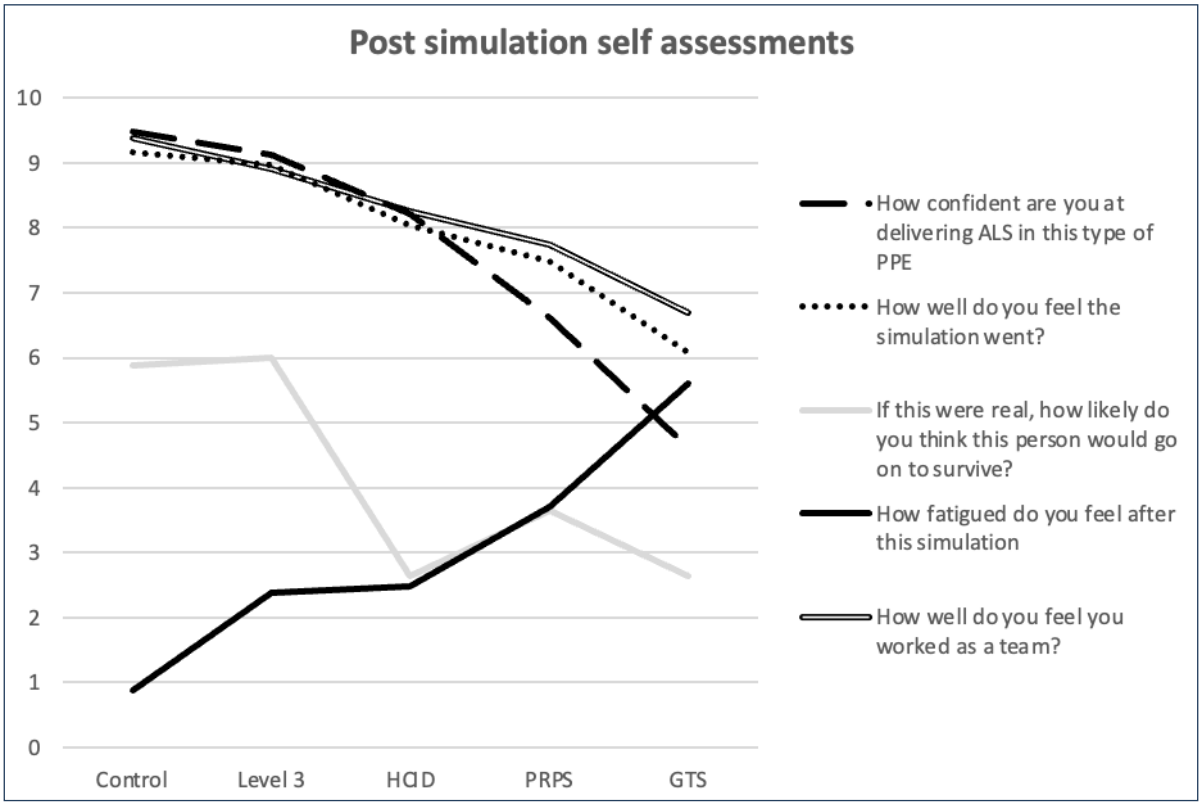


Figure 3. Comparative graph showing participant post simulation self-assessments on performance and fatigue.

Table 3. Participant post-simulation self-assessments on performance and fatigue

	Control	Level 3	HCID	PRPS	GTS
How confident are you at delivering ALS in this type of PPE	9.48 [1.5](8.83–10.13)	9.13 [0.97] (8.71–9.55)	8.22 [1.35] (7.63–8.80)	6.61 [1.53] (5.95–7.27)	4.61[2.21] (3.65–5.56)
How well do you feel the simulation went?	9.17 [0.96] (8.76–9.57)	8.96 [1.22] (8.43–9.49)	8.04 [1.33] (7.47–8.62)	7.48 [1.20] (6.96–8.00)	6.09 [2.13] (5.17–7.01)
If this were real, how likely do you think this person would go on to survive?	5.88 [2.58] (4.79–6.96)	6.00 [1.91] (5.18–6.82)	2.65 [3.35] (1.20–4.10)	3.65 [1.72] (2.91–4.40)	2.65 [2.67] (1.50–3.81)
How fatigued do you feel after this simulation	0.88 [1.08] (0.42–1.33)	2.39 [2.17] (1.45–3.33)	2.48 [2.13] (1.56–3.40)	3.70 [1.84] (2.90–4.49)	5.61 [1.44] (4.99–6.23)
How well do you feel you worked as a team	9.38 [0.71] (9.07–9.68)	8.91 [1.00] (8.48–9.34)	8.26 [1.10] (7.79–8.73)	7.74 [1.32] (7.17–8.31)	6.70 [1.89] (5.88–7.51)

N=24 participants in each study arm. Data presented as mean [standard deviation] (95% confidence interval) All responses measured on Likert scales from 0–10 where zero represented negative responses and 10 being positive.

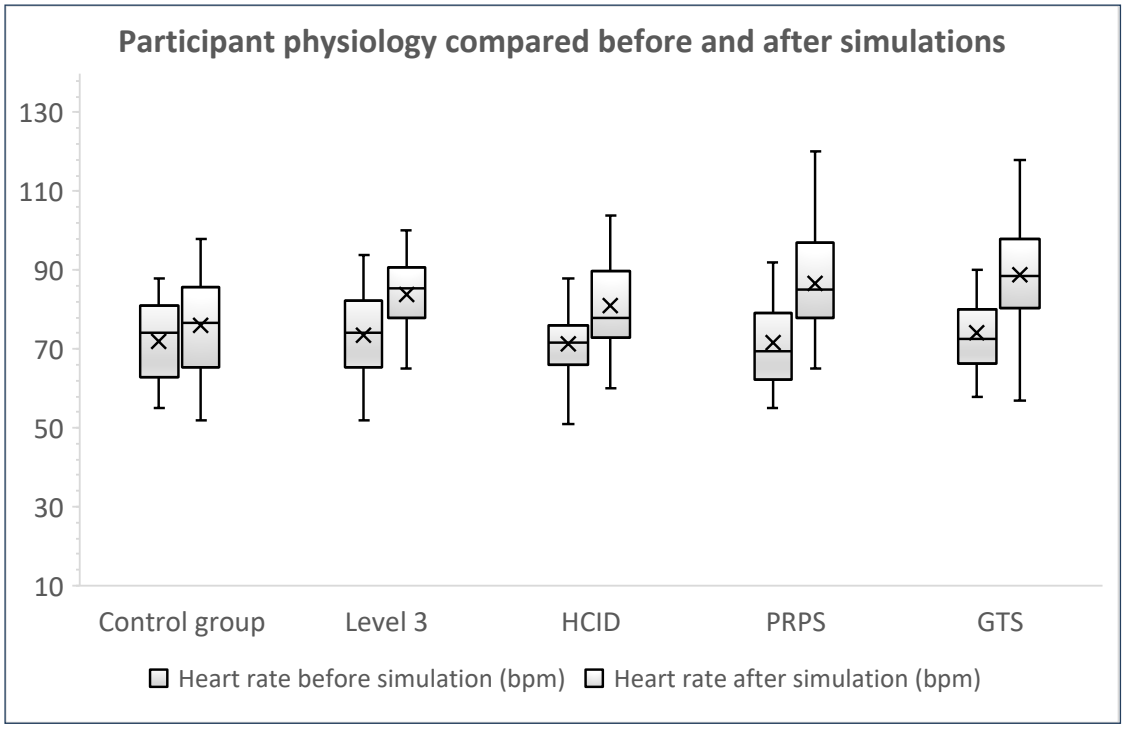


Figure 4. Changes in participant heart rates. Before simulation heart rates on the left and after simulation heart rates on the right paired in simulation groups. N=24 participants in each study arm.

as part of a holistic assessment of the application of ALS while needing high levels of PPE,[32] especially if the clinician is not already in full PPE and with the patient at the time of arrest. This is not supported by national guidance as an unequivocable cause of death[30] and highlights a gap in guidance and support for clinicians in this specialised circumstance. Modern guidance informed toxidromes should be used along with patient specific information to establish a toxicology and continue ALS until this is reversed.[30] This is supported by survival rates being reported in accidental exposures to poisons, however low these are.[2,3] These findings are multi-factorial, showing it is possible to survive if a poison is the cause of arrest. However, consideration

Table 4. Mannequin carotid pulse identification, post simulation.

	Total*	Identified*	Un-identified*	Average$	Min$	Max$	Range$
Control Group	24	21	3	61	50	70	20
Level 3	24	24	0	62	50	80	30
HCID	24	20	4	61	59	70	11
PRPS	24	22	2	60	50	70	20
GTS	24	15	9	63	54	80	26
Overall	120	102	18	61	50	80	30

*Value – number of participants; $Value – beats per minute (bpm)

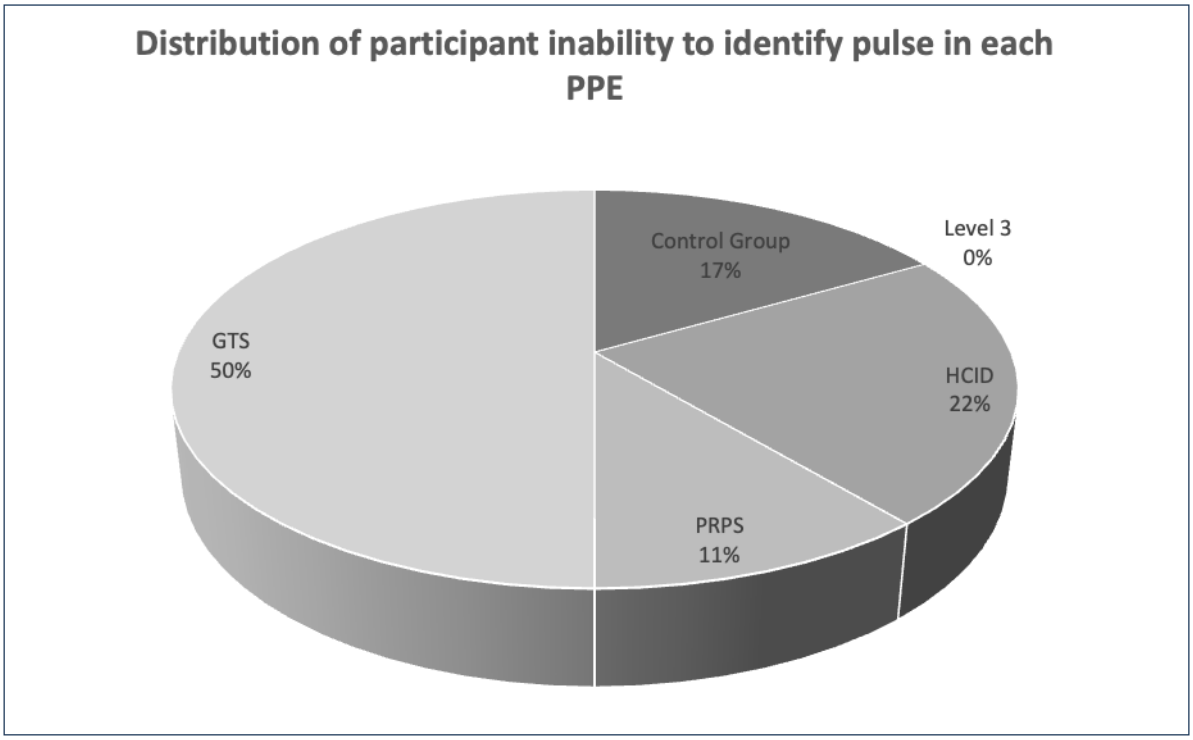


Figure 5. Distribution of participants unable to find pulses post-simulation in each category of PPE.

is needed toward the length of time it would take to start resuscitation if PPE is required. Evidence within this study shows ALS may be greatly impacted by PPE and will subsequently affect survivability (Figures 2–5).

Nevertheless, regular industrial accidents may require high levels of PPE and care, justifying the need to maintain this capability and protecting rescuers in the individual exposures.[2,3] This especially applies in the deteriorating patient delayed in definitive care awaiting lengthy decontamination processes to prevent secondary contamination of rescuers.[5,42]

Legislative compliance balances the rights of rescuers and victims alike while delivering prompt care[30,33,34]; given this, it is not as simple as removing the capability on the basis that it is difficult to deliver, frequency of use or concepts of futility. Therefore, while guidance[30] built on evidence of survivability supports delivery of ALS with toxic causes, an appreciation needs to be made towards the impact of PPE on specialist paramedics' ability.

This study design is unique in the evidence base by applying PPE and current equipment in line with SOPs for the application of the PPE i.e. not laying or kneeling on the floor in GTS.[5,22–25] It highlights effects from PPE on experienced specialist paramedics[20] during ALS,[30] showing negative impacts and aligning with the established literature.[6–19] Yet there remains no recognition of this in current guidance and how to overcome these special circumstances.[30]

Limitations

The limitations in this study reduce its generalisability. Furthermore, drawing an effect on survivability solely from this study would be tenuous given the low translational level.[27] However, with low frequency of these incidents,[2,3] it will be

difficult to safely establish a study outside of the simulated environment.[26] This is reflected in the current evidence base.[6–19] Subsequently, findings herein might lay foundations for further questions instead of enacting systemic change. In light that human factors impact on patient care in complex environments[39] it is essential that we not only acknowledge the impact of PPE but also take great care to fully understand this and how it impacts medicine.

This study brings in new primary data that aligns with the evidence-base further validating the findings, however, there are limitations:

Study design: When assessing for mannequin pulses a standard blood pressure and rate was set. This does not conform with aligning to real life practice as its likely these patients would have deranged observations.[42]

Allowing participants to review their post simulation feedback after each simulation and facilitating reflection may have created a learned effect allowing adjustment of practice to improve performance across repetitions of the simulation.[43] This may explain the increased performance in HCID simulations seen in Figure 2. instead of the expected linear decline as these simulations were all run towards the end of the study.

Lastly, real-life application of procedures was utilised in the study as much as possible. As such, in the control group, level 3 and HCID groups, compressions could be done on the floor, whereas in PRPS and GTS groups the manakin was required to be lifted from the floor to deliver care in line with SOPs. This is a large confounder of the data especially in relation to the timings. However, this still represents a 'real life' difference between these groups of PPE.

Statistical analysis: The statistical analysis assumes that all participants took part in all arms. If the original design was adhered to the data distribution may have been significantly different and use of a parametric statistical test may have been more appropriate dependent on whether the distribution was different and affecting statistical conclusions.

Application to practice: As much as the design attempts to mimic actual application of the equipment (which is a major limitation of the current evidence base), it does not account for all pre-deployment timings i.e. travel, joint planning, risk assessing, equipment checks etc. Each will have significant impacts on time delays seen in Figure 2 and the physiology data in Figure 4. Each could be a confounder of vast arrays of human factors further compounding performance.[39]

Equipment: The Laerdal SimMan ALS mannequin provided an advanced simulative platform to enact this study. Data drawn from the mannequin software for comparison instead of using the Corpuls-3 and PUC device may have given comparable data i.e., time to first compression. Common comments from participants about the carotid pulse on this mannequin was it felt far more lateral than they would expect. This may have contributed to inability to find pulses (Figure 5).

The data produced by the Corpuls-3 was a common reflection point. The average 'good compression' rate in the control group was 49.67% (Figure 2.) in the presence of live feedback consistently stating 'good compressions'. It is thought this value was reduced by compressions exceeding 6cm depth[30] and in this circumstance live feedback would not dispute compression quality. This contributed towards a learned effect[43] where participants openly discussed adjusting technique to manipulate the figures while maintaining live feedback of 'good compressions'.

Recommendations

Cardiac arrest survivability in the presence of toxic causes where inherent risks to rescuers who require high levels of PPE to deliver ALS requires assessment to inform the debate on futility. This should aid rescuers balancing personal risks against survivability of casualties in this circumstance. This should inform a 'rescue formula' type guideline, as is used in drowning,[44] and account for factors such as time, agent type, availability of specialist rescue and equipment alongside survivability.

An assessment of compression devices should be made. Availability of these devices doesn't offer an immediate solution. The fact that high level PPEs are required i.e., HCID and above necessitates decontamination.[5] This can be up to 12 minutes in length during which a chest compression device will need decontamination itself. This has not been tested before and would be difficult alongside ALS. As such, utilising a mechanical device may mitigate the findings regards chest compression quality, but it opens new problems around practical application.[5] This concept needs further exploration as a potential resolution to the stated problem.

Conclusion

This study is compliant to the current application of PPE in the process of delivering ALS. It established that PPE impacts the ability of specialist paramedics to deliver ALS through assessment of time-based metrics alongside chest compression quality. Additionally, assessment of participant physiology estimates PPE effects on fatigue, and this data reinforced by participant perceptions. However, limitations to this study lead to further recommendations for future research to build an evidence-base contributing towards formal guidance for clinical care in this specialised area of care.

Abbreviations

ALS	Advanced life support
CBRN	Chemical, biological, radiological, and nuclear

CPR	Cardiopulmonary resuscitation
GTS	Gas tight suits
HART	Hazardous Area Response Team
HCID	High Consequence Infectious Disease
PPE	Personal protective equipment
PRPS	Powered Respirator Protective Suit
SOP	Standard Operating Procedures

Acknowledgements

The author would like to thank Dr Shadman Aziz for his support with writing this manuscript alongside thanks to Amy Hughes and Sarah McLachlan, Gary Perkiss, Paul Bromley, Philip Cowburn, Stuart Reeves and Dawn Anderson in the supervision and delivery of this study.

Conflict of interests

The author is a UK HART Paramedic.

Ethics statement

Ethics were approved as part of Queen Mary University ethics approval process reference QMERC22.264. All participants gave informed consent prior to partaking in simulations.

Funding

The authors received no funding for this study.

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