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Clinical paper

Use of personal protective equipment and cognitive load during cardiopulmonary resuscitation – A randomized cross-over simulation-based study

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Abstract

Background: The use of personal protective equipment (PPE) is essential during cardiopulmonary resuscitation (CPR) to prevent disease transmission, but its impact on rescuer fatigue and CPR quality remains debated.

Aim: To simultaneously evaluate the effect of PPE on cognitive load and resuscitation quality.

Methods: In a simulation-based trial at a German tertiary care hospital, 31 healthcare workers performed two 2-minute chest compression (CC) cycles on a manikin, once with PPE and once without. Compression quality (rate, depth, hand position, chest recoil) was assessed. Cognitive load was measured post-task using NASA- and Simulation Task Load Index (NASA- and SIM-TLX). Primary outcome was the difference in cognitive load with and without PPE, and secondary outcomes included differences in CC quality parameters.

Results: SIM-TLX identified a significant impact of PPE on task complexity and perceptual strain, while situational stress, distractions, task control, and NASA-TLX parameters (mental, physical, temporal demand, frustration, effort, performance) showed no significant differences. No significant differences were found in compression rate (113 bpm without PPE vs. 109 bpm with PPE), depth (61 mm without vs. 62 mm with PPE), correct hand position (81% without vs. 78% with PPE), and complete chest recoil (94% without vs. 84% with PPE). However not significant, PPE use showed more negative outliers in hand position and chest recoil.

Conclusion: PPE increases values on two subscales of the SIM-TLX (task complexity and perceptual strain), but does not significantly impact chest compression quality in CPR simulations.

Keywords: PPE, Simulation training, Cognitive load, Fatigue, SIM-TLX, Human factors, Non-technical skills

Introduction

The use of personal protective equipment (PPE) is highly recommended during cardiopulmonary resuscitation (CPR) with aerosol generation and resulting risk of transmission of diseases such as severe acute respiratory syndrome (SARS).[1–3] Various studies have been published discussing the impact of PPE on CPR quality. During the COVID-19 pandemic, research suggested that PPE significantly compromises chest compression quality during CPR.[4–6] However, recent findings indicate that PPE does not reduce CPR quality.[7,8] Despite these differences, a common finding is that rescuers wearing PPE report higher levels of fatigue, even though PPE does not significantly affect vital parameters of rescuers.[9,5–7] So far, this commonly reported fatigue caused by wearing PPE during CPR has been difficult to define. In the assumption that the need to wear PPE during CPR adds supplementary mental and emotional demands, along with the previously reported undefined fatigue due to PPE, we hypothesize that cognitive load increases with PPE use. Since the COVID-19 pandemic, our center has been conducting

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regular resuscitation simulation training for our CPR teams with and without PPE. Mechanical parameters of CPR quality are routinely assessed during these sessions. However, an evaluation of the training regarding the effect of PPE has not taken place so far. For this purpose, we used simulation as investigational methodology and initiated a simulation training in which the mechanical parameters of chest compressions were examined, and the mental load was evaluated using a questionnaire based on the National Aeronautics and Space Administration and Simulation task load index (NASA- and SIM-TLX). Our aim was to simultaneously assess the effect of PPE on both – the cognitive load and mechanical quality parameters of resuscitation.

Methods

Study design and setting

The study was designed as a randomized cross-over simulation-based trial according to the reported guidelines for health care simulation research with extensions to the CONSORT statement.[10] The corresponding checklist can be found in the attachment. The study took place at a simulation center of a large, tertiary care hospital in Germany from January to November 2024. All study participants, hereafter referred to as professional healthcare workers (HCW), were members of an interdisciplinary team composed of resident physicians and specialized nurses caring for critically ill patients in the internal intensive care unit. No further eligibility criteria were required. Thirty-one HCW performed as individuals two sets of 2-minute chest compressions (CCs), once with personal protective equipment (PPE) and once without PPE in a randomized order. Block randomization was used to ensure that half of the HCW started the cycle with PPE and the other half without. At the beginning of each training session, participants were divided into two groups, with group assignment (A: PPE first, B: without PPE first) determined by a random number generator.

The PPE consisted of FFP 2 mask, gown, gloves, goggles and a hair net. CCs were carried out on the Ambu® Man W (Wireless) manikin. Using the Ambu® Man self-training module, we evaluated the quality parameters of compression rate, depth, correct hand position and correct chest recoil. Compression rate was measured in beats per minute (bpm), compression depth in millimeters (mm), and both correct hand position and correct chest recoil were recorded as a percentage of the total number of compressions.

To assess subjective cognitive load, each participant completed a questionnaire based on the National Aeronautics and Space Administration and Simulation task load index (NASA- and SIM-TLX) directly after each CPR sequence.

The NASA-TLX is a widely used self-report measure of workload in a multi-dimensional scale originally applied for aviation. It consists of six subscales that represent independent clusters of variables: Mental, physical, and temporal demands, frustration, effort and performance. The assumption is that some combination of these dimensions are likely to represent the workload experienced by most people performing a task.[11,12] In 2011, Wilson et al. adapted the NASA-TLX for surgery-specific workload measure (the SURG-TLX), which contains the additional dimensions task complexity, situational stress and distractions. Based on NASA- and SURG-TLX Harris et al. (2019) developed the simulation task load index (SIM-TLX) for assessing mental workload in simulated environments. The SIM-TLX contains the dimensions mental, physical, temporal and frustration demands from the NASA-TLX, as well as the dimensions complexity, stress and distractions from the SURG-TLX. For assessment of workload in simulation it contains additionally the dimensions perceptual strain and task control. Finally, it contains the dimension of presence, which refers to the feeling of "being there". For this dimension it is noticeable, that the SIM-TLX was developed in virtual reality (VR) while participants completed a VR puzzle game. In our study, the SIM-TLX is used for the first time in a simulation-based training setting. In accordance to this, we removed the dimension of presence. In summary, our used SIM-TLX includes the dimensions mental, physical, temporal and frustration demand and task complexity, situational stress, distraction, perceptual strain and task control.[13] Each workload dimension is measured using a 21-point Likert scale, ranging from 0 (very low) to 100 (very high), with increments of 5 points between each level. We used the "raw version" for both the NASA- and SIM-TLX without applying any individual weighting of the subscales performed secondarily by the participants.

The questionnaire was submitted to and approved by the staff council of our hospital (Klinikum Stuttgart, Katharinenhospital, Stuttgart, Germany).

Study outcomes

The difference between cognitive load with and without PPE was defined as primary outcome. Secondary outcomes were defined as differences in quality parameters of CCs with and without PPE during 2-minute chest compression.

Sample size

There was limited data to adequately perform an accurate sample size calculation since the SIM-TLX has not been used to evaluate CPR simulation training.

Among the studies conducted so far, Cheng et al. explicitly examined perceptual load in addition to fatigue measured via visual analog scale, including questions about impairments in vision and hearing. Significant differences were observed with a sample size of 30 participants.[9] To estimate the required sample size, we used the data from the validation study for the SURG-TLX by Wilson et al. (2011).[14] In this study with 30 participants, the researchers observed a large effect size in the categories mental demand, distraction and task complexity. Using the g*power software for wilcoxon matched-pair test, we calculated a minimal sample size of 26 participants given a large effect size ($d_z = 0.8$), a power of 0.95 and an alpha error probability of 0.05.

Each training session includes eight participants. We therefore planned to randomize the participants in four different training sessions to exceed the calculated sample size and account for possible dropouts. Ultimately, 31 participants were included after four training sessions.

Statistical analysis

The database was collected in Microsoft 365 Excel and statistical analysis was performed using GraphPad Prism 10 for macOS. The results of quality parameters of chest compression and the 21-point Likert scale of NASA- and SIM-TLX were recorded as individual values for each participant and then analyzed using the Wilcoxon matched-pairs signed-rank test.[15] The value of each individual parameter from the 21-point Likert scale and the quality parameters of CCs were plotted separately for each HCW. The Wilcoxon test calculates the difference for each pair of connected data points and tests whether the median of the differences deviates from zero. To remain robust against outliers and to assess the direction and magnitude of the differences, it uses rank data. Due to the small sample size, we expected the data to be not normally distributed. We confirmed this using the Shapiro-Wilk test.

Results

Cognitive load

For assessment of subjective cognitive load, we used a questionnaire based on the NASA- and simulation task load index (NASA- and SIM-TLX) after each CPR cycle.

The NASA-TLX survey, which includes the parameters mental demand, physical demand, temporal demand, frustration, effort and performance, showed no significant difference of cognitive load due to using PPE during CPR (see Fig. 1).

The SIM-TLX survey, including the parameters of mental demand, physical demand, temporal demand, frustration, task complexity, situational stress, distractions, perceptual strain and task control, revealed a significant impact of PPE on the perception of task complexity and perceptual strain (see Fig. 2). The parameters situational stress, distractions and task control as well as the common parameters of NASA-TLX showed no impact of PPE.

Chest compression quality parameters

After each CPR cycle of 2-minutes duration the mechanical chest compression parameters of compression rate, depth, correct hand position and correct chest recoil were evaluated. Compression rate was measured in beats per minute (bpm), compression depth in millimeters (mm), and both correct hand position and complete chest recoil were recorded as a percentage of the total number of compressions.

The mean compression rate and depth as well as the percentage of correct hand position and complete chest recoil is shown in Table 1.

As shown in Table 1 and Fig. 3, the use of PPE did not lead to significant differences in chest compression quality parameters. However, a higher prevalence of negative outliers was observed in the categories of correct hand position and complete chest recoil within the “with PPE” group.

Discussion

The aim of our study was to simultaneously evaluate the effect of personal protective equipment (PPE) on subjective mental load and mechanical quality parameters of resuscitation.

Regarding subjective mental load, defined as our primary outcome, we observed a significant impact of PPE on the perception of task complexity and perceptual strain.

Current literature predominantly describes increased fatigue as a consequence of PPE use.[9,5–7] The level of fatigue has been evaluated in these studies using the Borg Scale or Visual Analog Scale, highlighting that fatigue is a subjective phenomenon. However, defining fatigue uniformly remains challenging.[16,17] Derived from the Latin

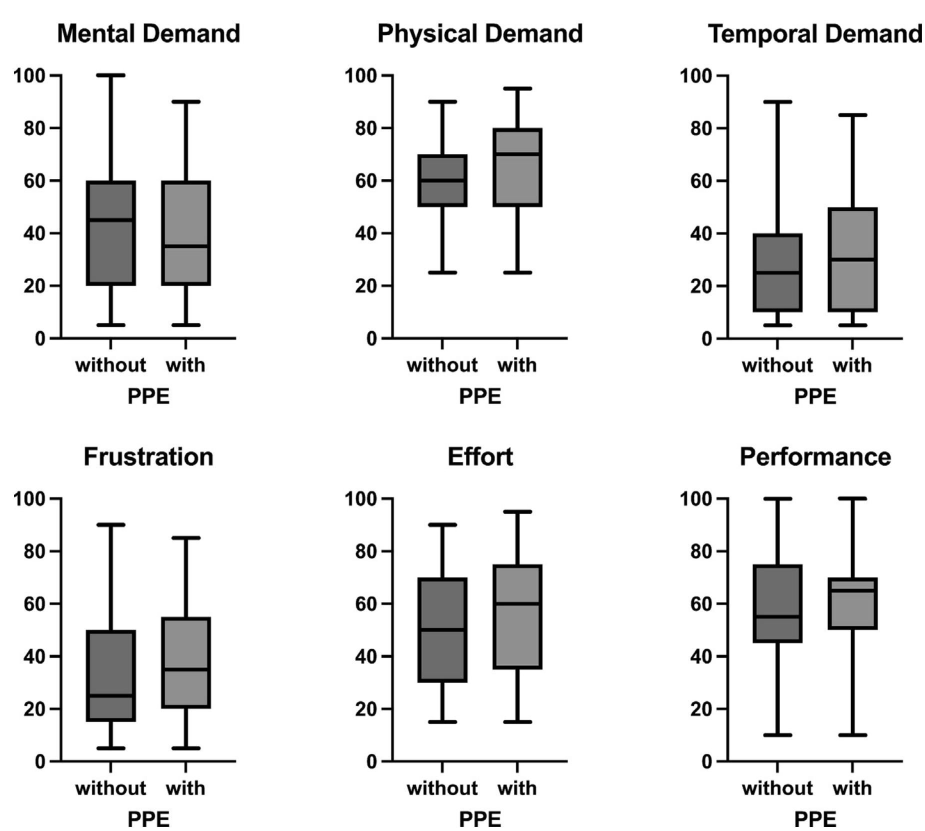

Fig. 1 – The use of personal protective equipment (PPE) does not compromise parameters of NASA-Task load index: mental demand (*p* = 0.9674), physical demand (*p* = 0.2198), temporal demand (*p* = 0.6387), frustration (*p* = 0.6733), effort (*p* = 0.7038) and performance (*p* = 0.7302). *n* = 31 Healthcare workers. Statistical analysis using wilcoxon matched-pairs signed rank test.

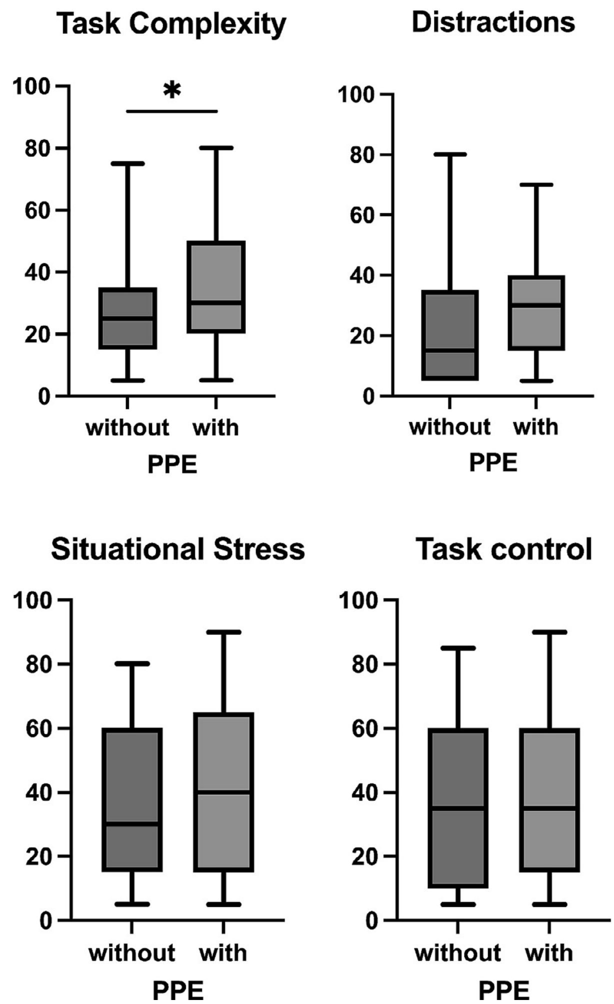

Fig. 2 – The use of personal protective equipment (PPE) does compromise parameters of SIM-Task load index: task complexity (p = 0.0177) and perceptual strain (p = 0.0199). Situational stress (p = 0.3485), distractions (p = 0.0691) and task control (p = 0.9576) are not compromised due to PPE. Similarly, the common parameters of the NASA-Task load index (mental demand, physical demand, temporal demand, frustration, effort, and performance) remain unchanged. n = 31 Healthcare workers. Statistical analysis using wilcoxon matched-pairs signed rank test.

Table 1 – Compression rate, depth, correct hand position and complete chest recoil with and without PPE. Values are given as mean ± standard deviation, Difference with 95% confidence interval.

Parameter	Without PPE	With PPE	Difference
Compression rate, bpm	113 ± 13	109 ± 16	−3.7; −10.3–2.9
Compression depth, mm	61 ± 10	62 ± 8	0.9; −3.8–5.5
Correct hand position, %	81 ± 31	78 ± 32	−2.9; −18.4–12.3
Complete chest recoil, %	94 ± 18	84 ± 34	−10.1; −22.4–10.1

word “fatigare” (meaning to exhaust as with riding or working, to weary or to harass) and the French word “fatiguer” (meaning to tire), Ream et al. describe fatigue as a multidimensional concept encompassing physical, cognitive, and emotional dimensions.[17] The previous focus on merely assessing the severity or level of fatigue fails to capture its multidimensional nature. In our study, we investigated for the first time the multidimensional impact of PPE on cognitive load using the NASA/SIM-TLX. Our findings, demonstrating significant effects on task complexity and perceptual strain, provide a valuable contribution to refining and differentiating fatigue, which was previously only assessed in terms of its severity.

From our prior research, we know that healthcare workers (HCW) are generally reluctant to train while wearing PPE. Notably, the use of protective goggles is often perceived as disruptive.[18] This discomfort, potentially caused by a restricted field of vision, may explain the significant perceptual strain observed in our study. Additionally, pre-

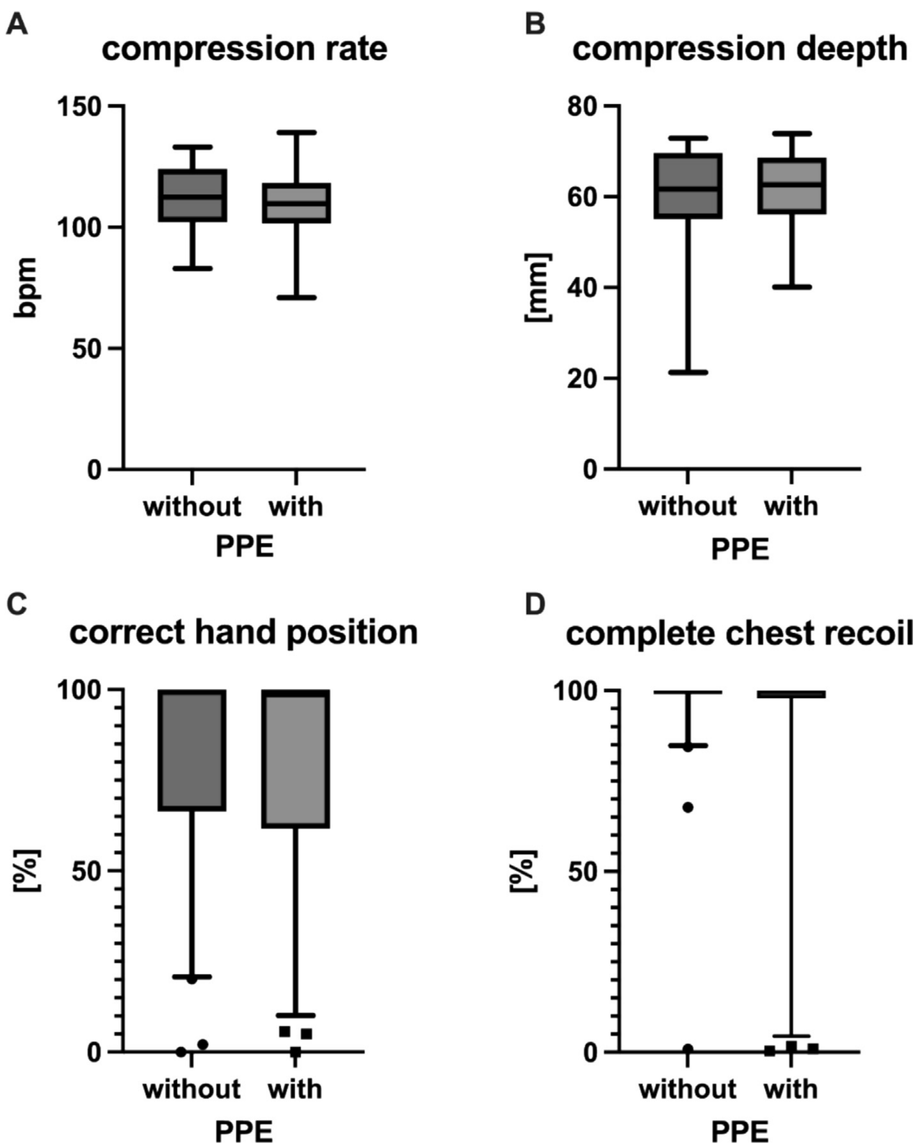

Fig. 3 – The use of personal protective equipment does not compromise chest compression quality parameters (compression rate, depth, hand position and chest recoil). ***n*** **= 31 Healthcare workers. Statistical analysis using wilcoxon matched-pairs signed rank test.**

viously reported communication limitations associated with the use of face masks could contribute to the now documented increase in task complexity.[18,19]

A notable aspect of our data is that the increase in task load was only significant in the SIM-TLX scores, while the NASA-TLX parameters showed no significant changes due to PPE use. This contrasts with the findings of Sellmann et al. (2022), who reported a higher task load index in the PPE group during simulation training based on NASA-TLX.[20] A possible explanation for the significant task load index in the NASA-TLX in Sellmann et al.'s study could be the use of a more complex simulation scenario involving an unwitnessed cardiac arrest with ventricular fibrillation. However, it is important to note that our studies are not directly comparable due to differences in simulation scenarios and participant group assignments.

Our study is the first to use the SIM-TLX to investigate the impact of PPE in a simulation training context. It is important to acknowledge that the SIM-TLX was initially designed for use in virtual reality simulation. The fact that even our basic scenario – a two-minute chest compression – resulted in a significantly higher task load as measured by SIM-TLX underscores the instrument's applicability and value in simulation-based research. Based on our findings, the use of SIM-TLX in more complex CPR simulation scenarios like in the study of Sellmann et al. (2022) appears to be feasible.[20] In future simulation settings it could also be of interest whether the total task load increases in a more complex scenario, compared to the currently investigated 2-minute CCs basic scenario. Our actual basic scenario may also explain why our results generally show a relatively low cognitive task load.

In our defined secondary outcome, the use of PPE did not show a significant impact on the quality parameters of chest compressions (compression rate, depth, hand position, and chest recoil) in our data. These findings align with the current body of evidence, which suggests that PPE is not associated with reduced CPR quality or lower cardiac arrest survival.[7,8] Although not statistically significant, our data do indicate a higher number of negative outliers, particularly in the complete chest recoil, within the PPE group. This finding highlights the need for an expanded study cohort, as these negative outliers may reach statistical significance with a larger sample size. Proper chest recoil requires heightened focus, for example, due to adaptation to different patient body types, surfaces, or limited space at the emergency site, and could be affected by increased cognitive load associated with PPE.

While no significant impact on the measured quality parameters of chest compressions was observed, the question arises as to what extent the significantly increased cognitive load may influence human factors and non-technical skills (NTS) during CPR.

Over the past few years, the importance of human factors and NTS has been increasingly recognized. These include non-manual behavioral elements such as situational awareness, team and task management, planning, and decision-making.[21,22] In 2020, Peltonen et al. demonstrated that resuscitation teams with strong NTS also performed better technical aspects of advanced life support (ALS).[22] The European Resuscitation Council defines human factors as equally important as technical skills, emphasizing their crucial role in achieving high-quality CPR and improving patient safety.[21]

Simulation of cardiac arrest scenarios has been identified as a highly effective strategy for teaching human factors and NTS.[21] At present, there is limited evidence examining the impact of PPE on NTS during CPR so far. Andersen et al. (2021) identified challenges in teamwork and communication, emphasizing the necessity of contextualized in-situ training.[23] An intriguing question is whether regular training in PPE could positively influence cognitive load. However, many HCW are reluctant to participate in simulation training while wearing PPE[18] – likely due to its mentally exhausting nature. This creates a paradox: avoiding PPE during training may limit preparedness for real-world scenarios. From our perspective, it is essential that HCW regularly train CPR in PPE through realistic in-situ simulation scenarios, following the principle of "train as you fight." This aligns with current research, which emphasizes that regular use of realistic CPR simulations enhances skill acquisition and retention for many critical tasks.[24–26]

For this reason, we strongly advocate for more simulation training to be conducted with the use of PPE, with cognitive load systematically evaluated using tools like the SIM-TLX. In our view, this is essential for a potential reduction of cognitive load, achieving high-quality CPR and enhancing both patient and provider safety.

Limitations

Our study has several limitations that should be acknowledged. First, the single-center design and small sample size limit the generalizability of our findings to a broader population. Additionally, the sample size calculation was intended for the evaluation of the SIM-TLX. The lack of precise and reliable SIM-TLX cognitive load data for sample size calculation in a resuscitation scenario may render our study underpowered to detect clinically meaningful differences. Actually, with no statistical significance, our higher number of negative outliers, for example in the complete chest recoil within the PPE group, may reach statistical significance with a larger sample size. Furthermore, we did not assess demographic data of our HCW to guarantee anonymity to the participants who were all members of the same ICU team. Additionally, as a manikin-based simulation study, the results are restricted in their applicability to actual patient outcomes. The fact that an evaluation of patient outcomes in a randomized study with a non-PPE group is not feasible for self-protection reasons, underscores the need to expand the sample size in a simulation-based setting. Our study is the first to use the SIM-TLX to investigate the impact of PPE in a simulation training context. At present, a direct comparison of this measurement method with other studies is not possible. In addition, the comparison of multiple subscales of SIM-TLX increases the risk of type 1 errors. Furthermore, it should be noted that the SIM-TLX assessment was conducted after the simulation scenario, making it a retrospective rather than a real-time assessment method, which may introduce recall bias. Additionally, the SIM-TLX was validated in a virtual reality simulation. However, given that it is based on the widely used NASA- as well as SURG-TLX, its application in a real simulation-based medical setting appears to be justifiable. For future simulation-based studies, it should be considered that our basic scenario of 2-minute chest compressions could be a limiting factor for capturing an increased task load index.

Conclusion

Our observation of statistically significantly increased values on two subscales of the SIM-TLX (perception of task complexity and perceptual strain), alongside non-significantly increased values on other subscales, is overall consistent with our hypothesis that the use of PPE can lead to increased cognitive load and, consequently, greater fatigue. At the same time, no significant negative impact of PPE on chest compression quality parameters (compression rate, depth, hand position, and chest recoil) was observed. Since the generalizability of our results is limited due to the small sample size, future studies should be conducted with a larger number of participants and within a fully in-situ simulation scenario. This would allow for an assessment of the effect of PPE on cognitive load in real resuscitation situations and an examination of the impact of training in full PPE.

CRediT authorship contribution statement

Johannes Heymer: Writing – review & editing, Visualization, Project administration, Methodology, Investigation, Data curation, Conceptualization. **Daniel Räpple:** Supervision, Resources. **Matthias Ott:** Writing – review & editing, Validation. **Florian Dengler:** Writing – review & editing, Validation. **Christina Jaki:** Writing – review & editing, Resources. **Daniel Bent:** Supervision, Resources. **Anna Hegar:** Writing – original draft, Visualization, Methodology, Investigation, Formal analysis.

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Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: "Johannes Heymer, Matthias Ott, Florian Dengler, Christina Jaki, Daniel Bent and Anna Hegar have no conflict of interest to disclose. Daniel Räpple receives book royalties from Springer Verlag for a medical textbook. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper".

Appendix A. Supplementary material

Supplementary material to this article can be found online at https://doi.org/10.1016/j.resplu.2025.100936.

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