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Simulation and education

Influence of rescuer position and arm angle on chest compression quality: An international multicentric randomized crossover simulation trial

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ABSTRACT

Background: Success in resuscitation depends not only on the timeliness of the maneuvers but also on the quality of chest compressions. Factors such as the rescuer position and arm angle can significantly impact compression quality.
Aim: This study explores the influence of rescuer positioning and arm angle on the quality of chest compressions among healthcare professionals experienced in cardiopulmonary resuscitation.
Methods: In this international, multicentric, randomized crossover simulation trial with independent groups, healthcare professionals were assigned to one of four positions: kneeling on the floor, standing, standing on a step stool, and kneeling on the bed. Participants performed two 3-minute trials of uninterrupted chest compressions at arm angles of 90° and 105°. Compression quality was assessed, using manikin derived data.
Results: A total of 76 participants entered the study. Those using a 90° arm angle exhibited higher compression scores than those at a 105° angle. Rescuers standing on a step stool maintained higher scores over time when compared to other groups. In contrast, rescuers kneeling on the bed consistently scored below 75% throughout the trial, with particularly low scores at the 105° angle.
Conclusion: Rescuer position and arm angle significantly influence CPR quality, with a 90° arm angle and elevated positioning optimizing compression depth and effectiveness. The results recommend against kneeling on the bed due to its negative impact on chest compression quality.

Introduction

Cardiopulmonary resuscitation (CPR) is a crucial intervention for managing cardiac arrest, a major public health issue with persistently low survival rates despite significant advancements in resuscitation science[1,2]. High-quality chest compressions (CC) during CPR are crucial for improving patient survival and neurological outcomes[3]. Effective CC can increase survival rates by 2 to 4 times and enhance subsequent interventions in the chain of survival[4].

The success of resuscitation depends on both the timeliness and quality of CC[3,4]. Effective CC require correct hand placement on the lower sternum with arms extended at a 90° angle to the chest, a rate of 100 to 120 compressions per minute, a depth of 5 to 6 cm, while allowing complete chest recoil[3,5]. Training is essential for improving and maintaining CPR quality, impacting skill acquisition and retention[6]. Technology-enhanced training tools that provide directive feedback on compression parameters have been shown to enhance training outcomes, for both laypeople and healthcare professionals[6].

Despite evidence that technology-enhanced training improves CPR quality, it has not been consistently translated to better patient outcomes in clinical settings[2,6]. This disconnect highlights the need for ongoing research into CPR quality and the factors influencing rescuer performance.

Factors such as rescuer fatigue and the physical setting can significantly impact compressions quality[3,7,8]. The rescuer's position relative to the patient, often dictated by the surrounding environment (e.g.,

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patient on the floor or bed), can affect compression depth and chest recoil[8,9], especially if the patient is on a soft surface or the rescuer is in an unstable or uncomfortable position[10].

Rescuers must adapt their position according to the environment, with common positions including kneeling on the floor, standing beside the bed, standing on a step stool, or kneeling on the bed. The choice of position depends on the environment (pre-hospital vs. in-hospital)[3], the ergonomics of the space (e.g., bed height)[11,12], and the rescuer's comfort (e.g., difficulties associated with kneeling)[13], among other factors. The goal is to optimize a 90° arm angle perpendicular to the patient's chest[8], allowing the rescuer to use body weight to achieve effective CC. Inadequate arm angles, often exceeding 90°, can result from insufficient knowledge or experience, fatigue, or suboptimal settings[8,14].

Adjusting the bed height or using a step stool can help bring the rescuer closer to the ideal 90° angle and potentially improving CC quality[8,14,15]. CPR seems to be most effective when the rescuer kneels on the ground beside the patient's chest in pre-hospital settings or stands beside the bed in hospital settings, with the patient placed on a firm surface[3]. While some studies have found similar outcomes in both positions[16,17,18], others have reported conflicting results, with better effectiveness noted when kneeling on the ground[19] or standing beside the bed[20]. Additionally, the use of a step stool is not consensual, with some studies favoring its use[9,14], and others suggesting alternative positioning[13]. The variability in findings across different studies underscores the need for this research.

This study explores the influence of rescuer position and arm angle on the quality of CC in healthcare professionals experienced in CPR, in a simulated setting. By studying the impact of these variables on CPR performance, this research aims to develop recommendations that enhance rescuer efficiency and effectiveness. The ultimate goal is to improve patient outcomes by providing insights that could lead to improved training protocols and more effective CPR delivery.

Methods

This study is an international, multicentric, randomized crossover manikin trial, with an independent group design, conducted in Portugal, Germany, and Finland.

The study protocol was developed collaboratively, through online meetings and a site visit to standardize data collection across all locations. The protocol was registered in ClinicalTrials.gov (NCT05405569) and received ethical approval from the respective institutional committees: Portugal (58/CEFMUP/2022), Germany (23–0215), and Finland (21/2022). Written informed consent was obtained from all participants, and data were anonymized with unique IDs. The Data Protection Committee of the University of Porto also approved the study (A-3/2023).

Participants and sample size

Recruitment and data collection took place at the Simulation Center of the Faculty of Medicine of the University of Porto (Portugal), the Human Simulation Center at the Institute for Emergency Medicine and Management in Medicine, Ludwig-Maximilians University Munich (Germany), and the Arcada Patient Safety and Learning Center at Arcada University of Applied Sciences (Finland).

A convenience sample strategy was used to recruit healthcare professionals—nurses, physicians, and paramedics. Inclusion criteria required participants to be aged 18 to 65, in good health, physically fit, and experienced in CPR. Pregnant women and those self-reporting physical fatigue or muscle pain were excluded.

The sample size was calculated considering the four independent groups, corresponding to the different rescuer positions, and two paired variables, reflecting the arm angles. An ANOVA test for repeated measures with within-between interactions was used, with a significance level (α) of 0.05 and a power (1-β) of 0.80, and an effect size of 0.25. This resulted in a minimum sample size of 48 participants, calculated using G*Power software.

Study design

Each site adhered to the defined protocol and utilized identical equipment for data collection. A comprehensive guideline document, including equipment setup and a flow diagram of the process, was distributed to all institutions prior to data collection. This process was overseen by a local expert to ensure consistency. Data collection occurred from May to October 2023.

Participants were allocated into four independent groups using a stratified randomization process, based on rescuer positioning and gender: (1) Manikin laying on the ground and rescuer kneeling on the floor; (2) Manikin laying on a bed and rescuer standing (without a step stool); (3) Manikin laying on a bed and rescuer standing on a step stool; and (4) Manikin laying on a bed and rescuer kneeling on the bed. No mattress was used, to prevent chest compression damping, and the bed was adjusted to the rescuer's patella level to ensure consistent conditions.

A randomized crossover design was implemented within each group, with participants assigned by coin flip to start with either a standard arm angle of 90° or an altered angle of 105°. The latter angle was chosen as it represents a significant, yet common, deviation from the optimal 90°. This difference is substantial enough to potentially elicit a measurable effect while still being within a practical range of motion. Each participant performed CC twice, with a 10-minute rest period between trials to minimize fatigue effects. Each CC trial consisted of 3 min of uninterrupted CC, aligned with the durations used in other similar studies[21]. Participants received no performance feedback or elapsed time updates during the trials, except corrections for arm angle deviations. Fig. 1 illustrates the study flow diagram.

The Laerdal Resusci Anne Simulator equipped with Laerdal SimPad was used for all trials. Before the study trials, participants underwent a 2-minute manikin familiarization session, receiving real-time feedback to calibrate their performance.

Each trial simulated a standard asystole scenario, with CC waveform data captured by the Laerdal system. Data was processed and analyzed using MATLAB R2023b, employing a validated script[22,23] to extract and calculate relevant CPR parameters, including rate, depth, and recoil. From these metrics, an overall CC quality score was derived.

Before each trial, participants were briefed, and demographic data were collected through an electronic questionnaire. Physical activity was assessed using the Stanford Brief Activity Survey (SBAS)[24], which categorizes physical activity levels based on job-related and leisure-time activities. Depending on the participant self-assessment, the SBAS tool will classify the physical activity as inactive, light, moderate, hard, and very hard.

Arm angles during CPR were monitored through real-time video analysis with Kinovea software[8], as depicted in Fig. 2. During the trials, participants were promptly informed if their arm angles deviated from the predefined settings and were guided to correct their positioning through voice commands (e.g., shift slightly forward).

Due to the nature of the study design, blinding of participants and researchers to the protocol and study aims was not possible.

Primary outcomes and covariates

The primary outcomes of this study were CPR quality parameters, including (1) CC overall score (%), (2) CC depth (cm), (3) CC rate (compressions per minute – cpm), and (4) chest recoil (cm). A MATLAB algorithm[22,23] was used to process and analyze the continuous raw data from chest compressions in each CPR trial. The algorithm detected each compression peak and calculated quality parameters every 15-seconds using a 4-second window. These parameters were then converted into percentage score (%) using a piecewise linear function[22,23]. The overall

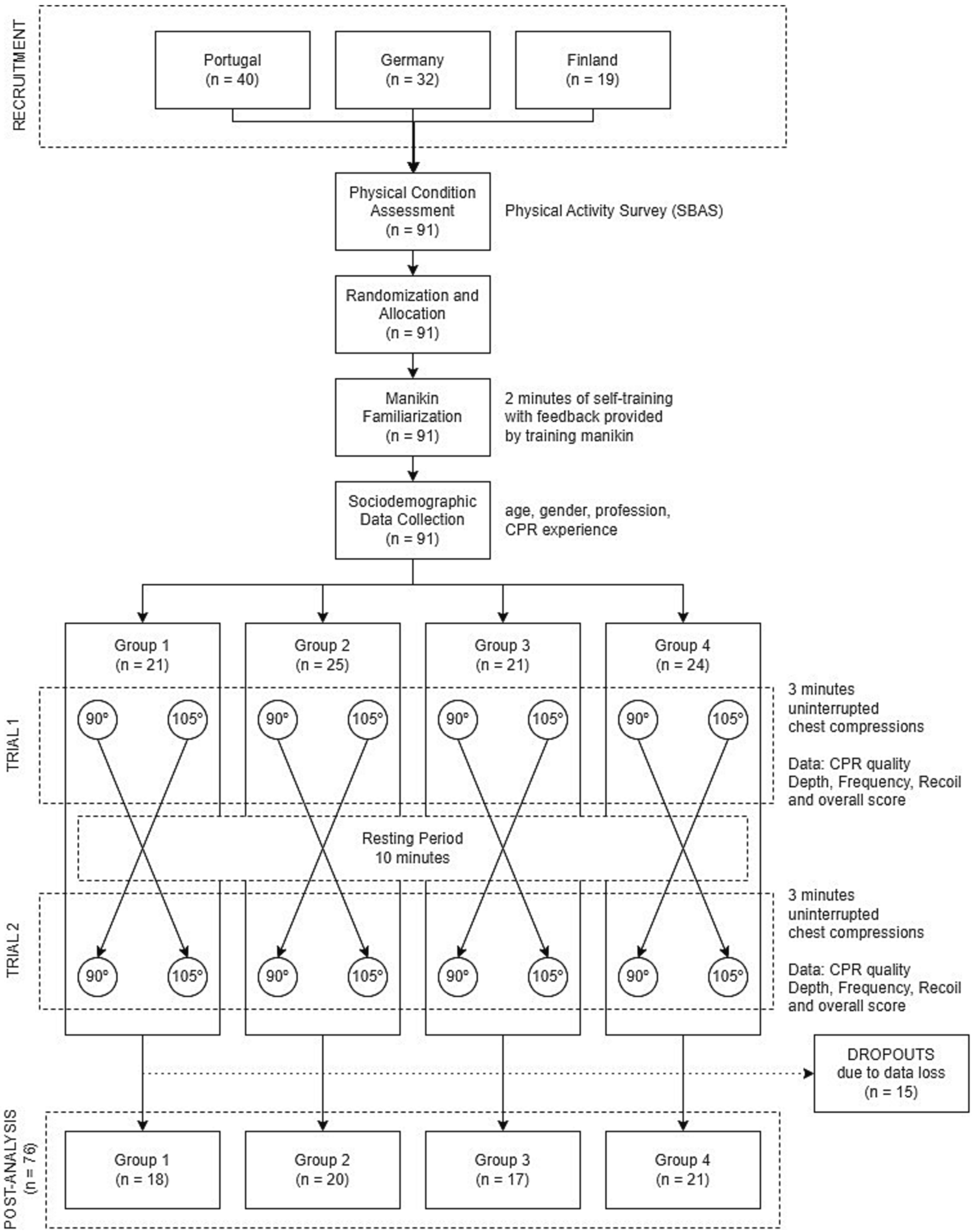

Fig. 1. Participant flow diagram. Group 1: Manikin laying on the ground and rescuer with knees on the floor; Group 2: Manikin laying on the bed and rescuer standing (no step stool); Group 3: Manikin laying on the bed and rescuer with step stool; Group 4: Manikin laying on the bed and rescuer with knees on the bed.

Fig. 2. Example of participant position for 105° arm angle, in Group 1 (Manikin laying on the ground and rescuer with knees on the floor). The angle is assessed through video recording and Kinovea software.

score (%) was the average of these individual parameter scores. Across each 3-minute trial, this approach generated 13 epochs where the parameters were calculated.

Covariates included gender, age (years), nationality, profession, and elapsed time since last CPR training dichotomized into $<$ 24 months and $\geq$ 24 months. The two-year timeframe is representative of CPR courses validity[2]. Physical activity was categorized using SBAS, and dichotomized into two groups: "active", which includes moderate-intensity activity, hard-intensity activity and very hard-intensity activity, and "sedentary", which includes light-intensity activity and inactive. This approach is consistent with other studies[24,25] and reflects the World Health Organization (WHO) definition of physical activity and sedentary behavior[26]. Additional rescuer characteristics, such body mass index (BMI), were collected but found to be non-significant covariates and therefore were not included in the final analysis.

Statistical analysis

Differences between groups were explored using a Kruskal-Wallis test for continuous data and a chi-square test for categorical data.

Linear mixed-effect models were used to analyse outcomes, incorporating both fixed and random effects. The fixed effects included three independent variables: group as a between-subject factor with four levels, arm angle as a within-subject factor with two levels, and time as a within-subject covariate across 13 measurements. The model also accounted for second-order interactions among these variables, specifically group-by-angle, group-by-time, and arm angle-by-time. Each data point in the analysis was classified according to time, participant, and arm angle. Participant and arm angle were treated as nested classification factors to effectively capture their interactions. The random effects were modelled to include the participant and the arm angle nested within the participant, to adequately represent the within-subject correlation. A general positive-definite Log-Cholesky parametrization was used for the covariance matrix. The model was adjusted for covariates, including gender, SBAS, and the time since the last CPR training, to account for potential confounding factors that might influence the outcomes. Assumptions of normality and homogeneity were assessed by visually inspecting the qq-plots and scatter plots of standardized residuals versus fitted values.

Statistical analysis was conducted using IBM SPSS Statistics software (version 29.0) for the Kruskal-Wallis and chi-squared tests, and software R (version 4.2.2) for linear mixed models. A significance level of 5 % was used.

Results

Participants' characteristics

The study initially included 91 participants across the three participating countries. Throughout the data collection process, there were no losses, however, 15 participants were excluded due to data recording issues, resulting in a final sample of 76 participants: 30 (39.5 %) from Portugal, 28 (36.8 %) from Germany, and 18 (23.7 %) from Finland (Fig. 1).

Participants were allocated into the 4 study groups with a balanced distribution based on demographic characteristics. Subsequent analysis revealed no significant associations between any demographic variable and the study groups (Table 1).

The mean age of the participants was 35.8 ± 8.9 years old, with 38 (50 %) identifying as female. The professional background of the sample consisted of 34 (45 %) nurses, 22 (29 %) physicians, and 20 (26 %) paramedics. Approximately 63 % of the participants were classified as active. Notably, nearly 33 % of the participants had not received formal CPR training in the past 2 years.

Table 1
Demographics of the participants. Group 1: Manikin laying on the ground and rescuer with knees on the floor; Group 2: Manikin laying on the bed and rescuer standing (no step stool); Group 3: Manikin laying on the bed and rescuer with step stool; Group 4: Manikin laying on the bed and rescuer with knees on the bed. SD corresponds to standard deviation.

		Group 1 (n = 18)	Group 2 (n = 20)	Group 3 (n = 17)	Group 4 (n = 21)	p-value*
Age (mean ± SD) Overall: 35.8 ± 8.9 years		35.3 ± 10.2	35.7 ± 10.3	35.1 ± 7.7	37.0 ± 7.8	0.900
Gender	Male (n = 38)	10	10	8	10	0.955
	Female (n = 38)	8	10	9	11	
Profession	Physician (n = 22)	4	7	5	6	0.866
	Nurse (n = 34)	8	9	9	8	
	Paramedic (n = 20)	6	4	3	7	
Location	Portugal (n = 30)	8	9	5	8	0.696
	Germany (n = 28)	7	6	8	7	
	Finland (n = 18)	3	5	4	6	
SBAS	Active (n = 48)	11	10	13	14	0.403
	Sedentary (n = 28)	7	10	4	7	
Last CPR training	< 24 months (n = 51)	13	14	13	11	0.387
	>= 24 months (n = 25)	5	6	4	10	

*Pearson's chi-squared test for categorical data. For the variable Age it was used a non-parametric test: Kruskal–Wallis. p-value < 0.05 is statistically significant.

Quality of compressions with different rescuer positions and arm angle

Table 2 and Fig. 3 present the CC scores for each study group and both arm angles. Fig. 3 details the compression parameters throughout the 3-minute trials, sampled every 15 s (13 epochs), providing a comprehensive view of performance over time. For simplicity and ease of reading, Table 2 presents these values at 60-second intervals (4 epochs), offering a summarized view of the data. The shadowed areas in Fig. 3 represent the correct or acceptable range, with overall scores above 75 % considered indicative of effective compressions[27]. Adequate recoil was defined as chest depression less than 5 mm, with 0 mm representing full chest decompression.

Overall compression score

The overall compression score (OCS) declined over time across all groups, regardless of the arm angle. Groups using a 90° arm angle generally exhibited higher initial compression scores compared to those using a 105° angle. This pattern was consistent across all groups. Group 3 (rescuers standing on a step stool beside the bed) maintained relatively higher scores over time, particularly in the 90° angle. In contrast, Group 4 (rescuers kneeling on the bed) consistently scored below 75 % throughout the trial, especially with the 105° arm angle. The mixed-effects model analysis (Table 3) corroborates these observations, showing a significant decrease in OCS with the 105° arm angle (Coeff = -2.58, SE = 3.59) and a negative coefficient for time, indicating a general decline as the trial progressed. Furthermore, Group 4 had a significant negative effect on the score compared to the reference group (Group 2).

Other covariates also significantly influenced the OCS. Active participants had significantly higher scores (Coeff = 12.46, SE = 3.58),

Table 2
Cardiopulmonary resuscitation (CPR) quality based on rescuer position and arm angle. Results presented as mean ± SD. Group 1: Manikin laying on the ground and rescuer with knees on the floor; Group 2: Manikin laying on the bed and rescuer standing (no step stool); Group 3: Manikin laying on the bed and rescuer with step stool; Group 4: Manikin laying on the bed and rescuer with knees on the bed. SD corresponds to standard deviation, cpm corresponds to compressions per minute.

Variable	Group	Arm angle	Time (s) 0	60	120	180
Overall Compression Score, % (mean ± SD)	1 (n = 18)	90°	83.0 ± 18.4	78.4 ± 19.0	76.9 ± 19.4	69.8 ± 19.1
		105°	80.9 ± 19.9	75.4 ± 22.6	74.0 ± 20.9	68.9 ± 21.0
	2 (n = 20)	90°	87.5 ± 17.1	82.1 ± 19.0	80.3 ± 21.1	74.8 ± 21.9
		105°	84.8 ± 15.1	77.3 ± 16.8	73.8 ± 18.7	71.2 ± 20.0
	3 (n = 17)	90°	85.8 ± 15.6	83.7 ± 15.1	80.8 ± 19.7	78.8 ± 20.2
		105°	83.9 ± 15.8	80.7 ± 18.0	73.9 ± 22.4	70.1 ± 24.1
	4 (n = 21)	90°	72.9 ± 25.9	69.4 ± 25.9	69.7 ± 26.2	68.8 ± 25.5
		105°	67.8 ± 21.8	68.6 ± 18.7	67.0 ± 19.5	65.9 ± 17.8
	All (n = 76)	90°	82.0 ± 20.4	78.1 ± 20.8	76.7 ± 22.0	72.9 ± 21.9
		105°	79.0 ± 19.4	75.2 ± 19.2	72.0 ± 20.1	68.9 ± 20.3
Compression Depth, cm (mean ± SD)	1 (n = 18)	90°	5.6 ± 0.6	5.2 ± 0.7	5.0 ± 0.9	4.8 ± 1.0
		105°	5.0 ± 0.8	4.7 ± 0.9	4.6 ± 1.0	4.4 ± 1.1
	2 (n = 20)	90°	5.7 ± 0.5	5.4 ± 0.6	5.0 ± 1.1	4.8 ± 1.0
		105°	5.0 ± 0.6	4.5 ± 0.8	4.2 ± 0.9	4.0 ± 1.1
	3 (n = 17)	90°	5.7 ± 0.5	5.4 ± 0.7	5.1 ± 1.0	5.0 ± 1.0
		105°	5.1 ± 0.9	4.7 ± 1.1	4.5 ± 1.3	4.2 ± 1.4
	4 (n = 21)	90°	5.2 ± 1.0	5.0 ± 1.2	4.8 ± 1.2	4.6 ± 1.2
		105°	4.4 ± 0.9	4.1 ± 1.1	3.9 ± 1.1	3.8 ± 1.1
	All (n = 76)	90°	5.5 ± 0.7	5.2 ± 0.8	5.0 ± 1.0	4.8 ± 1.1
		105°	4.8 ± 0.8	4.5 ± 1.0	4.3 ± 1.1	4.1 ± 1.2
Compression Rate, cpm (mean ± SD)	1 (n = 18)	90°	114.4 ± 13.0	112.3 ± 11.2	111.7 ± 12.2	112.5 ± 13.2
		105°	112.1 ± 13.2	113.8 ± 15.1	112.6 ± 16.4	113.1 ± 17.0
	2 (n = 20)	90°	113.1 ± 10.1	111.2 ± 12.2	110.8 ± 12.9	111.2 ± 13.9
		105°	112.5 ± 10.0	111.5 ± 12.1	111.9 ± 12.0	111.8 ± 14.4
	3 (n = 17)	90°	116.1 ± 12.2	114.6 ± 12.4	115.0 ± 14.5	115.3 ± 16.0
		105°	114.4 ± 10.5	112.6 ± 11.9	113.2 ± 14.6	112.9 ± 16.3
	4 (n = 21)	90°	117.9 ± 13.1	117.0 ± 15.4	115.9 ± 15.0	116.6 ± 16.6
		105°	117.7 ± 17.6	116.7 ± 14.3	116.9 ± 16.1	113.8 ± 16.4
	All (n = 76)	90°	115.4 ± 12.1	113.8 ± 13.0	113.4 ± 13.6	113.9 ± 14.9
		105°	114.3 ± 13.3	113.7 ± 13.3	113.7 ± 14.7	112.9 ± 15.7
Compression Recoil, cm (mean ± SD)	1 (n = 18)	90°	0.38 ± 0.31	0.35 ± 0.33	0.32 ± 0.30	0.33 ± 0.31
		105°	0.30 ± 0.31	0.22 ± 0.29	0.21 ± 0.23	0.22 ± 0.25
	2 (n = 20)	90°	0.44 ± 0.32	0.51 ± 0.40	0.49 ± 0.39	0.48 ± 0.40

(continued on next page)

Table 2 (*continued*)

Variable	Group	Arm angle	Time (s) 0	60	120	180
		105°	0.24 ± 0.31	0.31 ± 0.30	0.28 ± 0.26	0.27 ± 0.30
	3 (n = 17)	90°	0.45 ± 0.33	0.41 ± 0.28	0.36 ± 0.28	0.36 ± 0.27
		105°	0.29 ± 0.34	0.23 ± 0.26	0.25 ± 0.29	0.23 ± 0.31
	4 (n = 21)	90°	0.48 ± 0.32	0.45 ± 0.28	0.46 ± 0.27	0.45 ± 0.28
		105°	0.20 ± 0.27	0.19 ± 0.24	0.15 ± 0.21	0.17 ± 0.24
	All (n = 76)	90°	0.44 ± 0.31	0.43 ± 0.32	0.41 ± 0.32	0.41 ± 0.32
		105°	0.25 ± 0.30	0.24 ± 0.27	0.22 ± 0.25	0.22 ± 0.27

highlighting the impact of physical fitness on CPR performance. Additionally, participants who had received CPR training within the last two years had better scores (Coeff = -7.35 for training ≥ 24 months, SE = 3.67), underscoring the importance of regular training to maintain or improve CPR skills.

Compression depth

Similarly to the overall score, the compression depth decreased throughout the 3-minute trial for all groups. The 90° arm angle consistently allowed for deeper compressions than the 105° angle. Participants with the 90° arm angle maintained adequate depth (5–6 cm) up to 2 −minutes, except for Group 4, which fell below this threshold after 75 s. In contrast, those using the 105° arm angle exhibited a decline from nearly the beginning of the trial, with Group 4 starting with a mean depth of 4.4 cm (Fig. 3, Table 2). The mixed-effects model (Table 3) showed that the 105° arm angle significantly reduced compression depth (Coeff = -0.77, SE = 0.16).

Compression rate and recoil

Compression rate remained stable across all groups and time points, suggesting that rescuers maintained the recommended rate despite the observed decline in other metrics. Moreover, recoil values remained below 5 mm, across all groups and both arm angles, demonstrating effective chest recoil across all settings. Notably, the 105° angle was associated with significantly better recoil (Coeff = -0.208, SE = 0.073).

Discussion

This study provides a comprehensive analysis of how rescuer position and arm angle influence the quality of CC among experienced healthcare professionals. Conducted across three European countries, this international multicentric study, was grounded in a robust protocol to ensure data standardization and mitigate confounding variables. The international scope of the study introduces a diverse participant pool, enhancing the generalizability of the findings across different settings, professional backgrounds, and cultural characteristics.

The results demonstrate that both rescuer position and arm angle significantly impact the quality of CC during cardiopulmonary resuscitation, among healthcare professionals. Groups using a 90° arm angle consistently achieved higher overall compression scores compared to those using a 105° angle. However, scores declined over time in all groups, indicating that rescuers are susceptible to fatigue even with optimal arm positioning.

Compression depth mirrored overall scores, with deeper and more effective compressions achieved at a 90° angle, reinforcing the ergonomic advantage of arms perpendicular to the patients' chest[3,4]. However, achieving full recoil was more challenging at this angle, though still within acceptable limits (chest depression < 5 mm).

The compression rate remained stable across all conditions, suggesting that maintaining the recommended rate is an intrinsic mechanism, not affected by fatigue or arm angle.

Notably, rescuers standing on a step stool (Group 3) maintained higher scores over time. This suggests that elevated position, combined with 90° arm angle, optimize the effectiveness of compressions by allowing more efficient use of body weight and reducing arm fatigue.

Conversely, rescuers kneeling on the bed (Group 4) showed consistently lower scores, highlighting the potential physical discomfort and poor biomechanical support associated with this position, which increases fatigue and diminishes the quality of CC[19]. This finding suggests the need for alternative setups, such as equipping hospital rooms with step stools, to improve rescuer ergonomics and compression effectiveness.

The study also highlights the role of physical fitness and recent CPR training in performance. Participants who were physically active or had received recent training performed better, underscoring the importance of regular physical conditioning and continuous professional development to maintain CPR proficiency.

Recent studies[28–30] have explored several factors influencing CPR quality, including rescuer fatigue, rotation timing, anthropometric characteristics, and innovative positioning techniques, highlighting that this area of research remains complex and requires further investigation. Anthropometric characteristics, such as BMI and height, have been associated with deeper compressions in settings using a fixed bed height[7,28]. In the present study, BMI was not found a significant covariate as the bed height was adjusted to the rescuers' patella. This finding is supported by Charungwatthana et al.[30], who tested various rescuer positions and concluded that high-quality CPR could be achieved in any position, provided the bed was adjusted to the rescuer's knee height. These results emphasize the importance of considering ergonomics and dynamically adjusting the environment based on rescuer's physical characteristics.

Rescuer fatigue is associated to CC and tensiomyography data suggest that 2-min cycles of continuous chest compressions may induce to neuromuscular fatigue, compromising CPR quality[7]. Kim et al.[29] examined the effect of rotation timing on CC quality, finding that rescuers who rotated every minute achieved significantly better CC depth. These findings align with the results of this study, where CC depth was consistently lower, across all groups, at 120 s, compared to 60 s (Table 2). Rotation intervals recommendations may need to be adjusted to maintain high-quality CPR.

This study demonstrated that, several factors contribute to the quality of CC, including rescuer position, arm angle, rescuing duration, physical fitness, and recent training. Maximizing the quality of CC requires understanding these factors and deliberately adapting the ergonomics of the resuscitation environment. Training programs should integrate these findings into their curricula, moving beyond traditional kneeling positions. Training should be context-aware and customizable, addressing the ergonomic realities of different environments. The technology could play a pivotal role in providing real-time feedback on arm angles and body positioning to optimize training effectiveness. Training should move beyond technical skills to enhance awareness of the factors influencing CPR quality, offering personalized experiences that allow practitioners to identify and mitigate potential performance challenges. These findings advocate for a shift in CPR training paradigms, ensuring that different settings are considered, leading to training that is adaptive and responsive to the ergonomic realities faced by healthcare professionals in critical care situations.

Limitations

This study has some limitations. The study design did not allow for blinding, which may have introduced bias in the performance and quality of compressions. Having carried out a multicentric, international and multiprofessional study, introduced some heterogeneity in participant profiles, however efforts were made to minimize this when

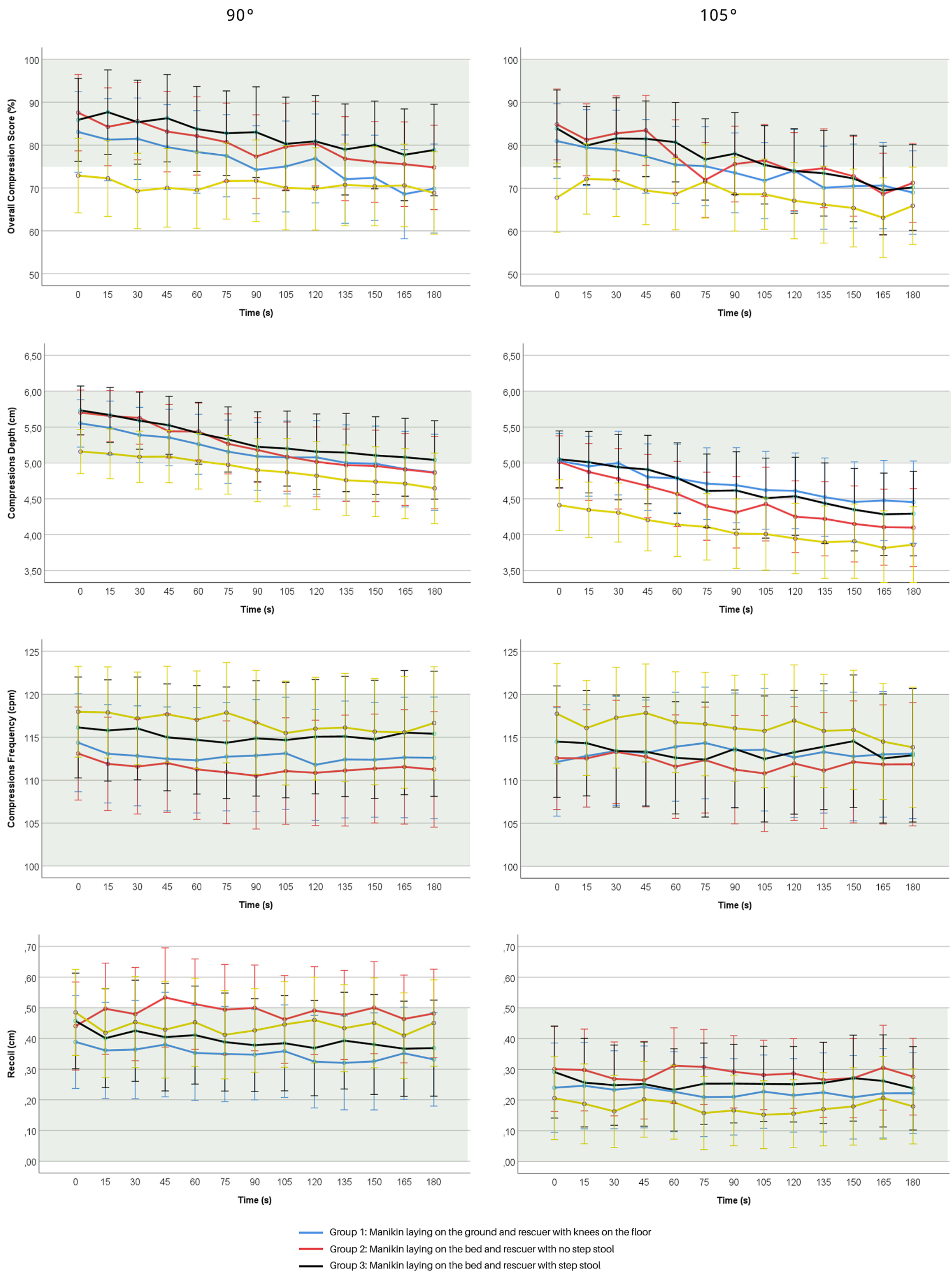

Fig. 3. CPR Quality based on rescuer position and arm angle (overall compression score (%), rate (cpm), depth values (cm) and recoil (cm)). Green areas represent guidelines recommendations. Error bars represent 95% confidence interval.

Table 3
Assessment of statistical significance based on the coefficients of linear mixed models, adjusted for gender, SBAS and last CPR training. The group G2 and the arm angle at 90° were considered the reference group. Group 1: Manikin laying on the ground and rescuer with knees on the floor; Group 2: Manikin laying on the bed and rescuer standing (no step stool); Group 3: Manikin laying on the bed and rescuer with step stool; Group 4: Manikin laying on the bed and rescuer with knees on the bed. OCS – overall compression score.

	OCS	Depth	Rate	Recoil
Fixed effects model[1]	**Coeff (SE)**	**Coeff (SE)**	**Coeff (SE)**	**Coeff (SE)**
Intercept	81.59 (4.65)***	5.52(0.21)***	115.14 (3.51)***	0.535(0.078)***
Groups				
G1	−5.92(5.49)	−0.24(0.25)	1.71(4.03)	−0.118(0.096)
G3	−2.31(5.64)	−0.01(0.25)	4.87(4.15)	−0.056(0.098)
G4	−14.91 (5.34)**	−0.44(0.24)	6.43(3.94)	−0.003(0.093)
Arm angle				
105°	−2.58(3.59)	−0.77 (0.16)***	0.56(1.81)	−0.208(0.073)**
Time	−0.06 (0.02)***	−0.004 (0.001)***	−0.006 (0.011)	−0.000(0.001)
Position:Arm angle				
G1:105°	1.98(5.15)	0.31(0.23)	−0.12(2.61)	0.075(0.105)
G3:105°	−1.94(5.23)	0.10(0.24)	−2.39(2.65)	0.061(0.107)
G4:105°	1.36(4.96)	−0.05(0.23)	−1.12(2.51)	−0.061(0.101)
Position: Time				
G1:Time	0.00(0.03)	0.001(0.001)	0.003(0.01)	−0.000(0.001)
G3:Time	0.01(0.03)	0.000(0.001)	0.002(0.01)	−0.000(0.001)
G4:Time	0.05(0.02)*	0.002(0.001)	−0.007 (0.01)	−0.000(0.001)
Arm angle:Time				
105°: Time	−0.01 (0.01)*	−0.000 (0.001)	0.000(0.001)	0.000(0.001)
Gender				
Male	1.24(3.38)	0.43(0.15)	−2.61(2.68)	0.096(0.053)
SBAS				
Active	12.46 (3.58)***	0.08(0.16)	−4.90(2.85)	−0.100(0.056)
Last Training				
>= 24 *m*	−7.35 (3.67)*	−0.32(0.17)	2.07(2.92)	−0.127(0.058)
Random effects model	**SD (95 %CI)**	**SD (95 %CI)**	**SD (95 %CI)**	**SD (95 %CI)**
Participant (Time)				
Intercept	12.33 (9.59–15.85)	0.57 (0.44–0.73)	10.96 (9.05–13.28)	0.18 (0.13–0.25)
Slope	0.07 (0.06–0.09)	0.004 (0.003–0.005)	0.05 (0.04–0.06)	0.0005 (0.0004–0.0006)
Arm angle within participant				
Intercept	11.02 (9.3–13.0)	0.51 (0.43–0.60)	5.62 (4.76–6.64)	0.22 (0.19–0.26)
Residuals	7.55 (7.30–7.80)	0.24 (0.23–0.25)	2.90 (2.80–2.99)	0.08 (0.08–0.09)

Statistical significance: *p < 0.05; **p < 0.01; ***p < 0.001. Coeff: Coefficient; SE: Standard error; SD: standard deviation; CI: Confidence interval.
[1]The main effects and 2nd order interaction are presented. The 3rd order interaction was non-significant and therefore was not included in the models.

allocating participants to groups. Additionally, 15 participants were excluded due to data collection issues, potentially introducing selection bias. The stiffness of the manikin was reported to be unrealistic, causing increased fatigue and potentially affecting compression quality, despite participants having a familiarization session before the trials. Similar equipment was used across all 3 sites, ensuring that the results remained comparable. Lastly, the results of this study were obtained in a simulated setting, which may not fully reflect the real clinical environment. Factors such as the adrenaline surge experienced during a real emergency were not considered.

Conclusions

This study highlights the significant influence of rescuer position and arm angle on CPR quality. The 90° arm angle and elevated positions, such as standing on a step stool, were found to optimize compression depth and effectiveness, while kneeling on the bed was detrimental to performance. Additionally, physical fitness and recent training are key factors in improving CPR performance.

CRediT authorship contribution statement

Abel Nicolau: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Ingrid Bispo:** Writing – review & editing, Visualization, Investigation, Formal analysis, Data curation. **Marc Lazarovici:** Writing – review & editing, Validation, Supervision, Methodology, Investigation, Conceptualization. **Christoffer Ericsson:** Writing – review & editing, Validation, Supervision, Methodology, Investigation, Conceptualization. **Pedro Sa-Couto:** Writing – review & editing, Software, Methodology, Formal analysis, Data curation. **Inês Jorge:** Writing – review & editing, Software, Investigation, Formal analysis, Data curation. **Pedro Vieira-Marques:** Writing – review & editing, Software, Methodology, Formal analysis, Data curation. **Carla Sa-Couto:** Writing – review & editing, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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