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Simulation and education

Impact of anthropometric factors on chest compression depth during CPR provided by children aged 11–14 in a community-wide study

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Abstract

Objective: To assess the depth of chest compressions (CC) provided by schoolchildren and their relation with providers's anthropometric characteristics.

Methods: We organized 1-hour hands-on training sessions for 11-14y.o. in volunteering schools. After training, willing subjects performed 2 min of recorded continuous CCs by means of Laerdal Resusci Anne® with CPRMeter2®, with visual feedback. Compression pace was given by metronome; instructors supervised the correct body position. Collected data included age, sex, as well as measured body weight and height.

Results: We analyzed records from $N = 702$ children (mean age: 12.76 ± 1.02 years, 379 (51.63%) boys) out of 761 participating in the study. Their mean median compression depth (MCD) was 46.70 ± 7.74 mm, which was below minimal effective CC depth advised by current guidelines (50 mm). This corresponded to low mean fraction of CCs ≥ 50 mm (CCF ≥ 50 mm, 42.86 ± 33.67%), and only 42.88% of children achieving at least 50% of compressions ≥ 50 mm. Boys had significantly higher mean MCD and CCF ≥ 50 mm than girls (MCD: 49.34 ± 7.05 mm vs 45.97 ± 8.07 mm, $p < 0.0001$; CCF ≥ 50 mm: 50.23 ± 32.90% vs 40.40 ± 34.97%, $p < 0.0001$). Age differentiated children who achieved at least 50% of compressions ≥50 mm from those who did not with AUC of 0.69 (for cut-off of 12.1 years: 85% sensitivity, 41% specificity), whereas weight offered an improved prediction (AUC 0.74; for cut-off 44.8 kg: 77.4% sensitivity, 61.1% specificity).

Conclusions: Sex, age and anthropometric factors are significant CC quality factors. Children with higher body weight are more likely to deliver CCF50%≥50 mm. Among the studied population, children ≥12 years old provided more effective chest compressions.

Keywords: Resuscitation, Education, Basic life support, Compression depth, Children, CPR quality

Introduction

Approximately 700,000 Sudden Cardiac Arrest (SCA) deaths occur annually in Europe and North America. It is the third leading cause of death worldwide after cardiovascular diseases and cancer.[1] Despite the improvements in guidelines, out-of-hospital cardiac arrest (OHCA) is still associated with poor survival rates and, thus, a worldwide challenge.[2] One of the answers to that challenge might be education and training of the society in first aid, as cardiopulmonary resuscitation (CPR) delivered by bystanders predicts positive outcomes for patients with OHCA.[3–6] One of the groups targeted for training as possible CPR providers is children.[7] The World Health Organization (WHO) and International Liaison Committee on Resuscitation (ILCOR) support the KIDS SAVE LIVES program, which promotes school-based CPR training for all pupils starting at least at age 12.[8–10] Organizing CPR training at schools is facilitated due to children being organized in 20–30-people classes and scheduled plan for the whole school year. Their training can be repeated annually and knowledge acquired in childhood can be used in the future. In some cases, CPR training is offered even in 10-year-olds.[11] The ILCOR statement from 2023 recommends training schoolchildren independent of their age.[40] However, there is limited evidence on the effectiveness of CPR that youth can provide after short group training. This is especially true after the change of ERC guidelines, which recommend minimal effective chest

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compression depth (CC) during CPR as 50 mm (range 50–60 mm) in place of the previous optimal range of 38–51 mm.[12] Quality of training aside, a question arises if school-age children can deliver effective chest compressions as a population.[13]

In this study, we aimed to evaluate the effectiveness of CC performed by children aged 11 to 14 years old and analyze its associations with the anthropometric parameters of these individuals as the only factors that CPR training cannot change. Additionally, we aimed to determine a cutoff point for weight at which the children have enough power to reach at least the recommended depth of CC.

Methods

This prospective study was performed under the Bioethical Committee of the University of Opole approval (No UO/0013/KB/2022). A free CPR course was offered to schools from the Opolskie voivodeship between 22.09.2022 and 20.04.2023. The information about the course and invitation was sent to every primary school in the Opolskie voivodeship and shared by social media. Students aged 11 to 14 years (5^{th}–8th grade of primary school) without physical and/or mental disability, and signed informed consent from their legal guardians from all of the schools that volunteered to participate in this CPR course were included in the study. The target sample size was 750 children to provide a reliable snapshot of the population, with participants balanced by sex and age.

After 1 h of CPR training led by an experienced instructors (10 min of theoretical introduction, 50 min of practice, 3 instructors supervised by the most experienced instructor), children were asked to perform 2 min of hands-on CPR on the Laerdal® Resusci Anne manikin. To limit the impact of parameters that can be modified by training, the metronome gave the predefined pace of the CC, and the instructor supervised the children in keeping the correct position. Laerdal® CPRMeter2 was placed on the manikin to ensure the proper hand placement and provide real-time visual feedback during CC. The CPRMeter2 recorded each CC (time, depth) for each child. We recognized the correct CC depth as ≥ 50 mm, without an upper limit, as too-deep compressions can be easily corrected with training. Body mass (light-clothed) and height (barefoot/in socks) were recorded using the SECA 799 digital column scale (accuracy up to 5 mm and 0,1kg), and body mass index (BMI) was calculated. All measurements were transformed into z-scores and percentiles using the Polish most recent national growth charts from the OLAF study.[14] Children with a BMI above the 85th percentile and beneath the 95th percentile were considered overweight and above the 95th percentile obese.

Data analysis

Raw CPR records were processed before analysis. First, we removed the first 4 presses as they were considered warm-up, and then selected compressions from the first 2 min of CPR (from press 5th onwards). The resulting records were filtered into two sets based on the quality of the available data: the duration of CPR and compression rate. Set 1 included records with a duration of at least 1.8 min irrespective of compression rate, encompassing most of the study group and setting likely resembling real-life scenarios. This set was used for the primary analysis. Set 2 included records with a duration of at least 1.99 min and a CPR rate of 100–120 compression per minute, representing complete CPR cycles delivered with target rate and likely by most diligent children. This set was used to validate the results from Set 1.

For each processed record, we calculated median compression depth (MCD), the fraction of compression above 50 mm (CCF ≥ 50 mm), and the ability to perform at least 50% of effective compressions (CCF50%≥50 mm).

Continuous variables were assessed for normality using Shapiro-Wilk test as a standard procedure. Given that most were approximally normally distributed, parametric tests were used for hypothesis testing and mean and standard deviations were used for summaries. ANOVA test was used for comparison of chest compression quality parameters (MCD and CCF ≥ 50 mm) between children in different sex- and age-groups. Age, which is a continuous characteristic, was categorized into full years categories because we suspected that parameters might not change proportionally to age. ANOVA procedure first calculated global p-values for each predictor (age group, sex group, interaction). HSD Tukey‘s post hoc tests were used to calculate pairs of comparisons driving significance of global tests. All data were summarized by mean and standard deviations, as most variables were normally distributed (tested with Shapiro-Wilk's test). Between-group differences were compared using a *t*-test for two groups and an analysis of variance (ANOVA) for multiple groups (with Tukey's post-hoc test). Interactions were inspected for the association of age and sex on CPR quality parameters. Age was used in the analyses either as a continuous variable for correlations or was divided into categories (11-14y.o.). Associations between continuous variables were assessed with Pearson's correlations. Anthropometric measures (body height, weight, and BMI) were compared between groups both in absolute values (cm, kg, kg/m^2) and relative to sex and age (z-scores).

Additionally, the median compression depth achieved by the children was illustrated with smoothed percentile charts obtained using the LMS method.[38]

To explore relationship between CPR quality and trainee's characteristics we performed multivariate linear regression. Firstly, sex, age and anthropometric (body weight, heigh, BMI – absolute values and z-scores) were tested as independent predictors. Those significant at this stage ($p < 0.05$) were used for further modelling, avoiding strong ($r > 0.9$) colinearity. The best set of multivariate predictors was chosen based on adjusted R^2 as a measure of explained variability.

Finally, we explored multivariate relationships between CPR depth and trainee's characteristics. For MCD [in mm] and CCF ≥ 50 mm [in %], we constructed linear regression models using the best predictors from previous univariate analyses. For each model, adjusted R^2 was used as a measure of explained variability. A child's ability to perform CCF50%≥50 mm (coded 0 or 1) was modeled using logistic regression. Univariate models were performed first and summarized, and significant predictors were included in multivariable model development using forward stepwise selection. (both alpha-to-enter and alpha-to-remove set at 0.15). Each model was summarized by its parameters, the Odds Ratio (OR) of each predictor, and the receiver operating characteristic (ROC) with the appropriate area under the curve (AUC). Cut-offs were established using Youden's index where necessary, and sensitivity/specificity was calculated. All models were compared to univariable model utilizing age as the only predictor, which is emphasized in the current guidelines.

Analysis was performed using STATISTICA software (TIBCO, version 13.3) and RStudio (4.3.1). The significance threshold for all tests and comparisons was set at 0.05.

Results

We recruited and trained 761 children (mean age: 12.76 ± 1.02 years, 379 (51.63%) boys) from 15 schools during the study period. Two children performed visibly inadequate and too short CPR, and in 25 cases, CPR sessions were not recorded due to technical errors. The remaining 734 CPR records were processed and filtered as described and stratified according to CPR length and quality (Fig. 1). As a result, we included records of $N = 702$ children in the exploratory set (Set 1) (mean age: 12.75 ± 1.02 years 360 (51.28%) boys). Out of those, a subgroup of $N = 351$ children with best quality CPR records (mean age: 12.85 ± 1.04 years, 179 (51.00%) boys) were labeled as Set 2. Children filtered out from Set 1 ($N = 351$) were slightly younger than those retained in Set 2 (12.7 ± 1 vs. 12.9 ± 1 years, $p = 0.0096$) and moderately shorter (height z-score 0.2 ± 1.1 vs. 0.4 ± 1.0, $p = 0.0361$; details in sTable 1). The following results will primarily pertain to Set 1 as the main focus of the study. Analyses of Set 2 provided corresponding, confirmatory results – critical findings included in the Supplementary File.

The overall age and gender structure of the study group is presented in Fig. 1. We managed to recruit groups fairly balanced for sex across all ages. However, the 14-years-olds were undersampled (Fig. 1). Children's weight, height, and BMI were significantly higher than the reference population's (z-scores: weight 0.44 ± 1.08, height 0.41 ± 1.06, BMI 0.41 ± 1.06, all p-values < 0.0001). Detailed age- and sex-specific anthropometric characteristics of children are summarized, with comparisons between boys and girls in Table 1 for Set 1 and sTable 2 for Set 2. Overall, boys were higher across almost all age groups and heavier in older children (13–14 years), with similar relative measures (z-scores). The prevalence of overweight and obesity in the studied group was 12.2% and 13.53% respectively.

Mean MCD was beneath minimal effective CC depth of 50 mm (46.70 ± 7.74 mm), which corresponded with low mean CCF ≥ 50 mm (42.86 ± 33.67%), and only 42.88% of children achieving at least 50% of successful compressions. Detailed outcomes across gender and age groups are included in sTable 3.

Boys had significantly higher mean MCD (MCD: 49.34 ± 7.05 mm vs 45.97 ± 8.07 mm, $p < 0.0001$) and CCF ≥ 50 mm than girls (CCF ≥ 50 mm: 50.23 ± 32.90% vs 40.40 ± 34.97%, $p < 0.0001$). Generally, boys delivered deeper CCs and more CCs above 50 mm among almost all age groups compared to girls, except for 12-years-olds where effectiveness was similar. In younger children, boys significantly more often than girls delivered at least 50% of CCs with target depth 11y.

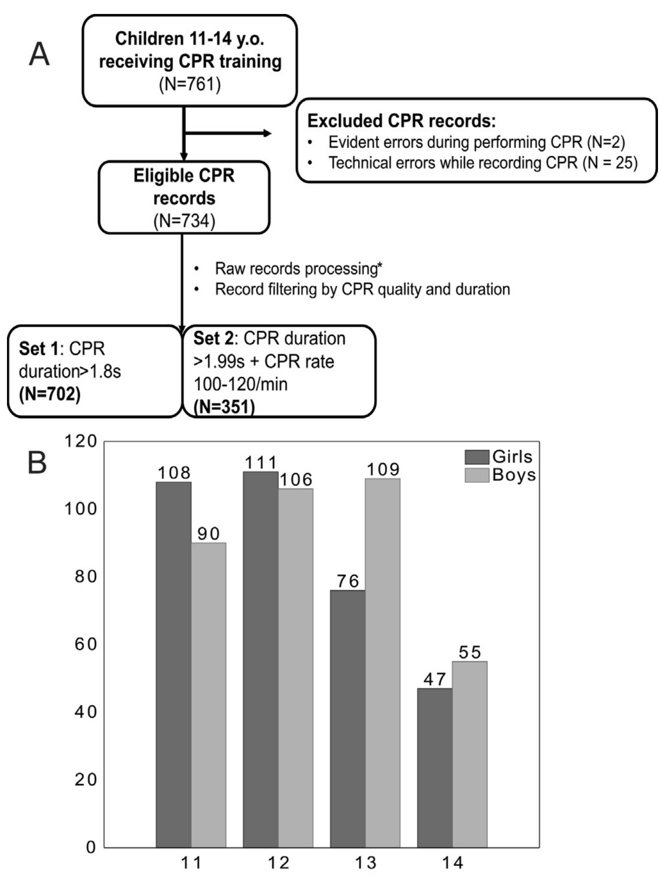

Fig. 1 – Summary of recruitment, data collection, processing (A), and resulting age and gender structure of the study group (B).

Table 1 – Anthropometric characteristics of children.

Characteristic	Age group [years]	Units	M (N = 360)	F (N = 342)	Total (N = 702)	p-value
Height	11 (N = 198)	cm	151.62 (6.67)	152.83 (8.01)	152.28 (7.44)	<0.0001
		Z-score	0.21 (0.97)	0.27 (1.20)	0.24 (1.10)	0.1124
		Percentile	55.24 (27.56)	57.06 (31.75)	56.23 (29.86)	–
	12 (N = 217)	cm	158.82 (8.28)	159.38 (6.46)	159.11 (7.39)	0.5896
		Z-score	0.23 (1.09)	0.39 (1.00)	0.31 (1.05)	0.2782
		Percentile	56.90 (30.38)	61.31 (28.41)	59.15 (29.40)	–
	13 (N = 185)	cm	166.39 (8.71)	162.47 (6.18)	164.77 (7.99)	0.0014
		Z-score	0.27 (1.05)	0.29 (1.03)	0.28 (1.04)	0.8789
		Percentile	58.45 (29.17)	57.47 (27.96)	58.05 (28.61)	–
	14 (N = 102)	cm	171.98 (8.26)	163.27 (5.76)	167.96 (8.41)	<0.0001
		Z-score	0.41 (1.04)	0.09 (0.94)	0.26 (1.00)	0.1126
		Percentile	60.67 (28.68)	51.62 (26.89)	56.50 (28.10)	–
	Total (N = 702)	cm	161.32 (10.71)	158.53 (7.97)	159.96 (9.57)	<0.0001
		Z-score	0.27 (1.04)	0.29 (1.07)	0.41 (1.06)	0.7754
		Percentile	57.53 (29.00)	57.78 (29.25)	57.65 (29.10)	–
Weight	11 (N = 198)	Kg	47.64 (12.60)	46.97 (12.86)	47.27 (12.71)	0.7152
		Z-score	0.46 (1.03)	0.41 (1.15)	0.43 (1.10)	0.7434
		Percentile	62.70 (28.30)	60.60 (29.39)	61.56 (28.85)	–
	12 (N = 217)	Kg	51.20 (12.60)	52.81 (12.69)	52.02 (12.65)	0.3596
		Z-score	0.31 (1.01)	0.52 (1.06)	0.42 (1.03)	0.1372
		Percentile	58.78 (28.75)	63.26 (28.22)	61.07 (28.50)	–
	13 (N = 185)	Kg	60.95 (16.05)	54.65 (12.37)	58.36 (14.94)	0.0052
		Z-score	0.57 (1.11)	0.34 (1.06)	0.47 (1.09)	0.1711
		Percentile	65.73 (29.23)	58.66 (28.48)	62.83 (29.06)	–
	14 (N = 102)	Kg	67.68 (18.13)	55.09 (13.63)	61.88 (17.33)	<0.0001
		Z-score	0.74 (1.14)	0.12 (1.07)	0.46 (1.14)	0.0062
		Percentile	68.45 (28.01)	52.77 (28.66)	61.23 (29.25)	–
	Total (N = 702)	Kg	55.78 (16.29)	51.69 (13.18)	53.78 (14.98)	<0.0001
		Z-score	0.49 (1.07)	0.39 (1.09)	0.44 (1.08)	0.2168
		Percentile	63.34 (28.76)	59.96 (28.78)	61.69 (28.80)	–
BMI	11 (N = 198)	kg/m2	20.56 (4.55)	19.90 (4.26)	20.20 (4.40)	0.2955
		Z-score	0.50 (1.01)	0.38 (1.13)	0.44 (1.07)	0.4596
		Percentile	63.50 (28.33)	60.68 (28.66)	61.96 (28.47)	–
	12 (N = 217)	kg/m2	20.17 (4.15)	20.71 (4.40)	20.44 (4.28)	0.3543
		Z-score	0.31 (0.95)	0.44 (1.10)	0.38 (1.03)	0.3746
		Percentile	58.67 (27.15)	61.36 (29.49)	60.05 (28.34)	–
	13 (N = 185)	kg/m2	21.77 (4.41)	20.62 (3.99)	21.30 (4.27)	0.0623
		Z-score	0.58 (1.03)	0.27 (1.03)	0.45 (1.04)	0.0494
		Percentile	66.30 (28.25)	56.59 (29.20)	62.31 (28.96)	–
	14 (N = 102)	kg/m2	22.76 (5.40)	20.58 (4.40)	21.75 (5.06)	0.0297
		Z-score	0.62 (1.17)	0.09 (1.06)	0.38 (1.15)	0.0188
		Percentile	64.85 (30.51)	51.85 (28.85)	58.86 (30.32)	–
	Total (N = 702)	kg/m^2	21.15 (4.62)	20.41 (4.26)	20.79 (4.46)	0.0289
		Z-score	0.49 (1.03)	0.33 (1.09)	0.41 (1.06)	0.0579
		Percentile	63.13 (28.36)	58.78 (29.14)	61.01 (28.80)	–

o: 24 (26.67%) vs 17 (15.74%), $p = 0.0002$; 12y.o.: 48 (45.28%) vs 42 (37.84%), $p < 0.0001$). This tendency was similar in older age-groups but did not reach statistical significance [13y.o.: 75 (68.81%) vs 28 (36.84%), $p = 0.0589$; 14y.o.: 45 (81.82%) vs 22 (46.81%), $p = 0.0589$].Detailed outcomes across gender and age groups are included in sTable 3. However, we noted a significant interaction between age and gender for CCF ≥ 50 mm ($p = 0.0092$, Fig. 2): boys demonstrated constant increase in CCF > 50 mm with increasing age, whereas girls‘ efficacy plateaued above 12 years. A similar trend for MCD was also notable but statistically non-significant ($p = 0.0622$, Fig. 2). Results from best-quality records (Set 2) agreed with those observations, though the discrepancy between 13–14-year-old boys and girls was less pronounced (sTable 4 and sFig. 1).

Both MCD and CCF ≥ 50 mm were significantly and positively correlated with age, weight, height, and BMI measured in absolute values and z-scores – the correlation coefficients are shown in Table 2 for Set 1 and sTable 5 for Set 2. The correlations were similar across age groups and gender (data not shown). In the multivariable linear model, gender, age, height, and BMI were significantly associated with higher MCD and CCF ≥ 50 mm. However, the overall model explained only a small part of overall variability (adjusted R2 0.24–0.26, sTable 6).

Afterwards, we performed logistic regression analysis to elucidate children's characteristics associated with successful CPR, defined as achieving at least 50% of successful chest compressions (≥50 mm) within the CPR cycle. In univariate comparisons, weight,

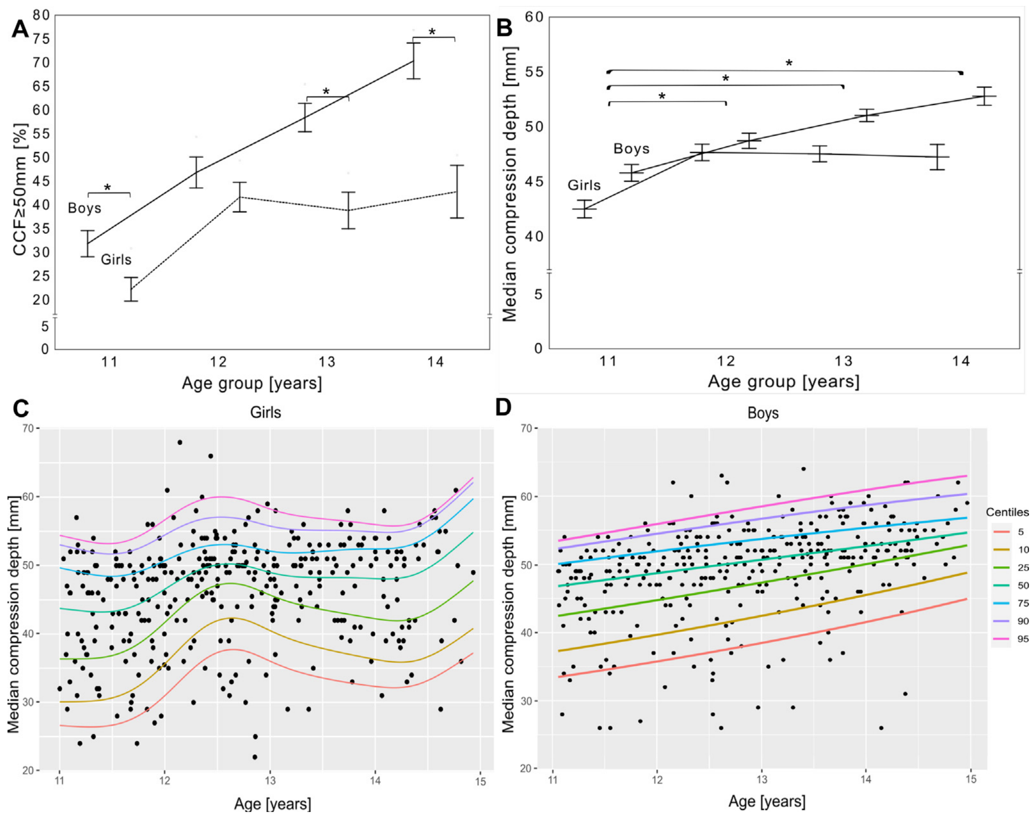

Fig. 2 – Depth characteristics of chest compressions delivered by the children participating in the study. A: Percent of delivered chest compressions with depth equal to or exceeding 50 mm (CCF $\geq$ 50 mm). Lines denote means, whiskers span one standard error. Analysis of variance demonstrated statistically significant interaction between age and gender (p = 0.0092). Post-hoc tests were performed with HSD Tukey's method. While boys presented higher CCF $\geq$ 50 mm in almost all age-groups (* denote significant post-hoc comparisons within age-group), and that boys improved proportionally with age (post-hoc tests not shown for clarity), in girls age-related progress flattened after 12 years of age. B: Median compression depth. Lines denote means, whiskers span one standard error. Analysis of variance revealed that compression depth was higher for boys (p < 0.0001) and increased with age (p < 0.0001, categories differing significantly in post-hoc comparison were marked with *) for boys but plateaued for children older than 12 y.o. There was some disproportion between boys and girls dynamics with age, but interaction was not significant (p = 0.0533). C and D: Percentile curves for median compression depth in girls (C) and boys (D) MCD – median compression depth, CCF $\geq$ 50 mm – chest compression fraction above 50 mm.

height, BMI, gender, and age were associated with higher odds of performing successful CPR (Fig. 3 for Set 1 and sFig. 2 for Set 2). The univariable model confirmed that odds for performing effective CPR increased with age, and utilizing a cut-off of 12.1 years old identified successful children with 85% sensitivity, 41% specificity, and overall AUC of 0.69. A comparison of ROC curves between models for age and anthropometric data revealed that weight is a better predictive factor of CPR effectiveness – data are shown in sTable 7 and sFig. 2. Among other candidate predictors, weight [in kg], height [in cm], and BMI [in kg/m2] all demonstrated significantly higher ROC AUCs compared with the model for age. Among those, weight offered the best discriminatory properties, with a cut-off of 44.8 kg yielding 77.4% sensitivity, 61.1% specificity, and AUC = 0.74 (Fig. 4). In set2, this cut-off resulted in sensitivity 90.9%, specificity 37.1%.

Repeated modelling in Set 2 yielded similar results, with, with a close cut-off for age equal to 12.6 years old but higher for body weight (50 kg) (sTable 7).

In the multivariable analysis, BMI, height, age, and gender were established as the best discriminants, with AUC 0.78 (0.75 – 0.81) and sensitivity/specificity of 87/51%, respectively. It proved significantly better than the univariable model, including age or body weight only (both p < 0.0001).

Discussion

In our study, we investigated children 11 to 14 years old to assess their capability to provide effective CPR according to current guidelines and possibly associate those capabilities with trainees' anthropometric characteristics.

ERC 2005 guidelines suggested that children aged 10 to 11 years can provide effective CC,[15] and the 2010 update recommended that CPR training should start at the age of 12.[7–10] Those recommendations are still in place despite the changes in target compression depth, which increased from 38-51 mm to 50–60 mm, according to

Table 2 – MCD (median compression depth) and CCF ≥ 50 mm (fraction of compression above 50 mm) correlation with anthropometric parameters.

Characteristic	Units	Parameter	M (N = 360)	F (N = 342)	Total (N = 702)
CCF > 5 cm					
Weight	kg	N	360	342	702
		r	0.43	0.42	0.44
		p	<0.0001	<0.0001	<0.0001
	Z-score	N	360	342	702
		r	0.43	0.37	0.37
		p	<0.0001	<0.0001	<0.0001
Height	cm	N	360	342	702
		r	0.48	0.33	0.43
		p	<0.0001	<0.0001	<0.0001
	Z-score	N	360	342	702
		r	0.27	0.22	0.22
		p	<0.0001	<0.0001	0.0242
BMI	kg/m^2	N	360	342	702
		r	0.30	0.36	0.34
		p	<0.0001	<0.0001	<0.0001
	Z-score	N	360	342	702
		r	0.31	0.34	0.34
		p	<0.0001	<0.0001	<0.0001
MCD					
Weight	kg	N	360	342	702
		r	0.42	0.39	0.42
		p	<0.0001	<0.0001	<0.0001
	Z-score	N	360	342	702
		r	0.39	0.36	0.37
		p	<0.0001	<0.0001	<0.0001
Height	cm	N	360	342	702
		r	0.46	0.36	0.42
		p	<0.0001	<0.0001	<0.0001
	Z-score	N	360	342	702
		r	0.30	0.25	0.26
		p	<0.0001	<0.0001	<0.0001
BMI	Kg/m^2	N	360	342	702
		r	0.30	0.31	0.32
		p	<0.0001	<0.0001	<0.0001
	Z-score	N	360	342	702
		r	0.33	0.32	0.33
		p	<0.0001	<0.0001	<0.0001

ERC 2015.[12] This change creates a need to provide updated analyses. Given that youths widely vary in terms of physical development depending on age and sex, with puberty introducing additional dynamics, a question arises if 11–12-year-olds are capable of reliably delivering effective CPR.

Our study was focused on the association between anthropometric parameters and the ability to achieve recommended CC depth during CPR according to ERC 2021 guidelines. We noted that among the many children trained, mean MCD was below the target effectiveness threshold (46.7 mm vs. 50 mm), and only ~43% of children achieved consistently effective CPR (defined as at least 50% of successful compressions). Both mean MCD and the proportion of children achieving consistently effective CPR increased with the child's age, but there was a widening discrepancy between boys and girls.

Our results regarding the correlations between age, weight, BMI, and CC depth are consistent with previous studies. Similar associations were found in studies based on ERC 2005 and ERC 2010 guidelines. Based on these two guidelines, authors confirmed that the minimal age for effective CPR should be 10 [11,15,18] or 11 years,[29] though after an update of ERC guidelines in 2015, it is suggested that children should be 12 years old [10,16–21] or even older.[22–24] Our study is consistent with those findings, showing that the majority of children below 12 years old delivered ineffective CPR. However, there was great variability among the trainees' efficacy.

Some of it could be attributed to the differences in children's physiques. Our data demonstrated that body weight was a more optimal predictor of effective depth CPR than age. This is in line with the reports from Otero-Agra,[18] who found that the most effect on CC depth have: weight, femur, and forearm length. Out of these three, weight is by far the most easily assessed, which is essential for application in the general population. Utilizing this cut-off is not only statistically more effective than age-based ones but also accounts for ethnical differences – 44.8 kg corresponds (for 12-year-olds) to 58th percentile in Poland, between 50th and 75th percentile[34] for Spanish children and between the 75th and 90th percentile[35] in Saudi Arabia.[36] Those differences should be kept in mind when creating local training guidelines. Unfortunately, direct comparisons

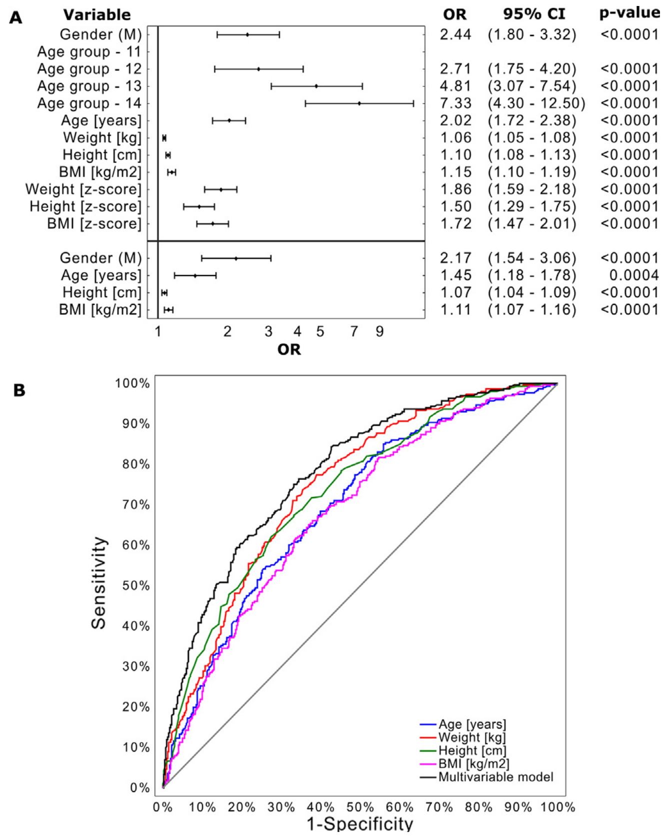

Fig. 3 – Summary of logistic regression models predicting the child's ability to achieve ≥ 50% of delivered chest compressions with depth equal to or exceeding 50 mm. A: Forrest plot summarizing constructed models. Above the horizontal line univariable models utilizing Gender are included, categorized or continuous age, as well as absolute and relative values of body weight, height, and BMI. Diamonds denote odds ratios (ORs), and whiskers span 95% confidence intervals. Below the line, we included a multivariable model with adjusted predictors. B: Receiver operating curves corresponding to chosen univariable models (models utilizing z-scores were dropped due to low applicability), as well as multivariable model.

between the cut-off identified in our study and those from previous reports are impossible due to different study methodologies.[33,29,21]

However, it must be admitted that body weight alone and even multivariable models were limited in their efficiency in identifying those performing effective CPR among multiple failed attempts. This likely resulted from multiple additional factors impacting the recorded sessions that were beyond quantification or control.

First, the scenarios were practiced in a group environment. Thus, social interactions, emotions, crowd effect, and peer pressure likely impacted the children's concentration, motivation, and disposition during the training and assessment. Nevertheless the impact of these factors in real-life situations on CC depth may be different. The above effects could be nestled within classes and schools. However, precise analysis of such data structure was not possible. Moreover, due to the study's school-based setting, we could not perform more accurate anthropometric measurements (like extremities lengths that have already been shown to impact CPR performance) or measure muscle strength. We were also not able to reliably assess the children's sexual development, which can vary among age- and sex-groups and affects factors such as muscle strength. The relationship between body weight or BMI and muscle mass or overall physical capacity is also not straightforward,[39] thus possibly generating some classification errors.

The technical setting of our study should be discussed as well. The utilized equipment could affect children's performance and, to a slight extent, impact the noted differences between our study and the findings of other authors. Real-time feedback provided by the CPRMeter2, placed on the manikin to ensure the proper hand placement, was reported to be a positive factor of effective CPR.[22,25] Previous studies evaluated multiple variables[10,11,15,19,22,26,27,28,24,17] compared to our attempt to focus on anthropometric factors and control for the variables that training can modify. Also, the CC depth provided on Ambu and Laerdal manikins differs from that on the former version of the CPRmeter.[30,31] To our knowledge, there is no data on the differences between the two devices and the CPRmeter2. We applied it in our study as it is widely used in clinical practice.[32] We acknowledge that the CPRmeter2 shifts the hand placement position 25 mm proximally than on the manikin only. We found no study showing a significant difference between the thickness of a manikin and CPR quality.

Finally, our study was performed in a controlled environment in a scenario-training regime. It is likely that in real-life situations, children's performance could differ considerably. Also, the manikin has different flexibility than the human chest, and human chests differ according to anthropometric factors. However, using manikins is standard for studies like ours.

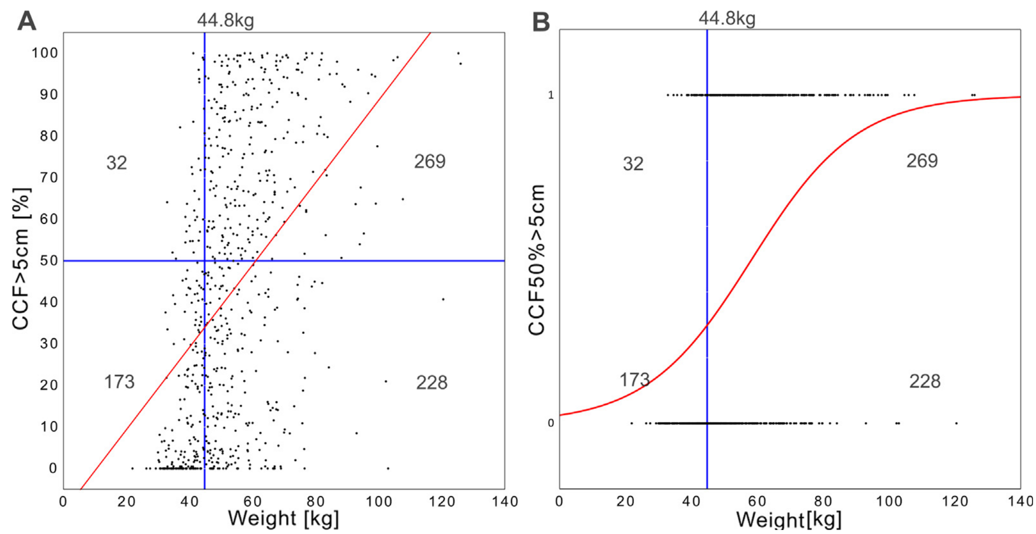

Fig. 4 – Example classification of children into effective/ineffective resuscitation providers based on body weight. A: scatter plot of body weight vs CCF ≥ 50 mm – chest compression fraction above 50 mm. Horizontal blue line denote arbitrary cut-off of effective resuscitation. Red line shows fitted linear regression. B: scatter plot of body weight vs nominal variable scoring whether at least of 50% of chest compressions delivered within a cycle had depth equal to or greater than 50 mm (1 if yes, 0 otherwise). Red shows log-linear function fitted. Both plots have marked cut-off point from univariable logistic regression model (body weight 44.8 kg, vertical blue line), and numbers of True positive (upper-right corners), False-positive (lower right corners), true negative (lower left corners) and false negative (upper left corners) classifications. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

In terms of generalizability, our study has the following strengths and limitations. First, our sample size was considerable and should reflect the underlying general population. Secondly, the training sessions were carried out by 4 instructors, thus ensuring good consistency between each group. On the other hand, the children were recruited in a single region of Poland (Opolskie Voivodeship). Therefore, we cannot guarantee that this group reliably represents the whole Polish pediatric population, let alone an international one. Furthermore, training lasted only one hour, and we could not assess whether prolonging the training could improve CC depth. However, this is a standard protocol for similar previous studies, and 45 min of training have been proven sufficient in the adolescent population.[37] It needs to be also underlined that are not a proof against teaching younger children CPR as also those <12 years old are able to recognize cardiac arrest, call for help and instruct other witnesses how to provide CPR.

Conclusions

We demonstrated that children 11–14 years old visibly struggle with delivering CCs on a manikin in a simulated situation adequate to the recommendations depth (i.e.,≥50 mm), with boys outperforming girls in this age group. Those with higher body weight are more likely to deliver effective CCs, though multiple factors are likely at play. CPR training has many aspects: recognizing cardiac arrest, calling for professional help, instructing others and providing adequate chest compressions. The result may suggest that in adolescents the scope of teaching and expectations regarding the effectiveness of the CPR could be adapted to the participant's abilities.

CRediT authorship contribution statement

Jarosław Jarosławski: Writing – review & editing, Writing – original draft, Methodology, Investigation, Data curation, Conceptualization. **Jacek Burzyński:** Writing – review & editing, Writing – original draft, Visualization, Formal analysis. **Krzysztof Kryczka:** Writing – review & editing, Investigation, Data curation. **Arkadiusz Michalak:** Writing – review & editing, Visualization, Methodology, Formal analysis. **Wiktor Warda:** Writing – review & editing, Investigation, Data curation. **Krzysztof Zieliński:** Writing – review & editing, Investigation, Data curation. **Wojciech Fendler:** Writing – review & editing, Formal analysis. **Agata Chobot:** Writing – review & editing, Supervision, Methodology.

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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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.resplu.2024.100708.

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REFERENCES

1. Brooks SC, Clegg GR, Bray J, et al. Optimizing outcomes after out-of-hospital cardiac arrest with innovative approaches to public-access defibrillation: a scientific statement from the International Liaison Committee on Resuscitation. Circulation 2022;145: e776–801.
2. Berdowski J, Berg RA, Tijssen JG, et al. Global incidences of out-of-hospital cardiac arrest and survival rates: systematic review of 67 prospective studies. Resuscitation 2010;81:1479–87.
3. Lee SY, Ro YS, Shin SD, et al. Interaction effects between highly-educated neighborhoods and dispatcher-provided instructions on provision of bystander cardiopulmonary resuscitation. Resuscitation 2016;99:84–91.
4. Kragholm K, Wissenberg M, Mortensen RN, et al. Return to work in out-of-hospital cardiac arrest survivors: a nationwide register-based follow-up study. Circulation 2015;131:1682–90.
5. Strategies to Improve Cardiac Arrest Survival. http://www.nap.edu/catalog/21723/strategies-to-improve-cardiac-arrest-survival-a-time-toact. Accessed February 12, 2017.
6. Wissenberg M, Lippert FK, Folke F, et al. Association of national initiatives to improve cardiac arrest management with rates of bystander intervention and patient survival after out-of-hospital cardiac arrest. JAMA 2013;310:1377–84.
7. Berg KM et al. International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations: Summary From the Basic Life Support; Advanced Life Support; Pediatric Life Support; Neonatal Life Support; Education, Implementation, and Teams; and First Aid Task Forces. Resuscitation 2023. https://doi.org/10.1016/j.resuscitation.2023.109992.
8. Böttiger BW, Van Aken H. Kids save lives—Training school children in cardiopulmonary resuscitation worldwide is now endorsed by the World Health Organization (WHO). Resuscitation 2015;94:A5–7.
9. Bohn A, Lukas RP, Breckwoldt J, Böttiger BW, Van Aken H. 'Kids save lives': why schoolchildren should train in cardiopulmonary resuscitation. Curr Opin Crit Care 2015;21:220–5. https://doi.org/10.1097/MCC.0000000000000204. PMID: 25922895.
10. He D, Huang K, Yang Y, Jiang W, Yang N, Yang H. What is the optimal age for students to receive cardiopulmonary resuscitation training? Prehospital Disaster Med 2018;33:394–8. https://doi.org/10.1017/S1049023X1800047X.
11. Bohn A, Van Aken HK, Möllhoff T, et al. Teaching resuscitation in schools: annual tuition by trained teachers is effective starting at age 10. A four-year prospective cohort study. Resuscitation 2012;83:619–25.
12. Perkins GD, Handley AJ, Koster RW, et al. European Resuscitation Council guidelines for resuscitation 2015: Section 2. Adult basic life support and automated external defibrillation. Resuscitation 2015;95:81–99.
13. Böttiger BW, Semeraro F, Wingen S. 'Kids Save Lives': educating schoolchildren in cardiopulmonary resuscitation is a civic duty that needs support for implementation. J Am Heart Assoc 2017;6: e005738. https://doi.org/10.1161/JAHA.117.005738. PMID: 28292747; PMCID: PMC5524048.
14. Kułaga Z, Litwin M, Tkaczyk M, et al. Polish 2010 growth references for school-aged children and adolescents. Eur J Pediatr 2011;170:599–609. https://doi.org/10.1007/s00431-010-1329-x.
15. Hill K et al. Objective assessment of cardiopulmonary resuscitation skills of 10–11-year-old schoolchildren using two different external chest compression to ventilation ratios. Resuscitation 2008;80:96–9.
16. Bánfai B, Pandur A, Pék E, Csonka H, Betlehem J. At what age can children perform effective cardiopulmonary resuscitation? – Effectiveness of cardiopulmonary resuscitation skills among primary school children. Orv Hetil 2017;158:147–52.
17. Banfai B, Pek E, Pandur A, Csonka H, Betlehem J. 'The year of first aid': effectiveness of a 3-day first aid programme for 7–14-year-old primary school children. Emerg Med J. 2017;34:526–32. https://doi.org/10.1136/emermed-2016-206284. PMID: 28420689; PMCID: PMC5537527.
18. Otero-Agra M, Rodríguez-Núñez A, Rey E, et al. What biomechanical factors are more important in compression depth for children lifesavers? A randomized crossover study. Am J Emerg Med 2019;37:100–8. https://doi.org/10.1016/j.ajem.2018.05.003. ISSN 0735-6757.
19. Abelairas-Gómez C, Rodríguez-Núñez A, Casillas-Cabana M, Romo-Pérez V, Barcala-Furelos R. Schoolchildren as life savers: at what age do they become strong enough? Resuscitation 2014;85:814–9. https://doi.org/10.1016/j.resuscitation.2014.03.001. PMID: 24614187.
20. Oliveira KMG, Carmona MJC, Mansur AP, et al. CPR quality assessment in schoolchildren training. J Cardiovasc Dev Dis 2022;9:398. https://doi.org/10.3390/jcdd9110398.
21. Mpotos N, Iserbyt P. Children saving lives: training towards CPR excellence levels in chest compression based on age and physical characteristics. Resuscitation 2017;121:135–40. https://doi.org/10.1016/j.resuscitation.2017.10.024. PMID: 29107674.
22. Martínez-Isasi S, Abelairas-Gómez C, Pichel-López M, et al. Aprendiendo a reanimar en la escuela. Estudio en escolares de 8–12 ąnos. An Pediatr (Barc) 2022;96:17–24.
23. Kłosiewicz T, Zalewski R, Szkudlarek W, et al. Quality of chest compressions performed by school-age children — a quasi – - experimental simulation-based study. Med Res J 2021;6:295–300.
24. Fariduddin MN, Mohamed M, Jaafar MJ, Baharin K, Siau CS, Bashah K. Compression-only cardiopulmonary resuscitation and automated external defibrillator course for primary school students: a Malaysian pilot study. Children 2023;10:58. https://doi.org/10.3390/children10010058.
25. Buléon C et al. Improvement in chest compression quality using a feedback device (CPRmeter): a simulationrandomized crossover study. Am J Emerg Med 2013. https://doi.org/10.1016/j.ajem.2013.07.029.
26. Jones I, Whitfield R, Colquhoun M, et al. At what age can schoolchildren provide effective chest compressions? An observational study from the Heartstart UK schools training programme. BMJ 2007. https://doi.org/10.1136/bmj.39167.459028.DE.
27. Berthelot et al. Push hard, push fast: quasiexperimental study on the capacity of elementary schoolchildren to perform cardiopulmonary resuscitation. Scand J Trauma Resusc Emerg Med 2013;2013:41.
28. Fleischhackl R, Nuernberger A, Sterz F, et al. School children sufficiently apply life supporting first aid: a prospective investigation. Crit Care 2009;13:R127. https://doi.org/10.1186/cc7984. PMID: 19646229; PMCID: PMC2750181.
29. Uhm T, Oh J, Park J, Yang S, Kim J. Correlation between physical features of elementary school children and chest compression depth.

Hong Kong J Emerg Med 2010;17:218–23. https://doi.org/10.1177/102490791001700303.
30. Kim Chan Woong KC, Oh JeHyeok OJ. Are chest compression depths measured by the Resusci Anne SkillReporter and CPRmeter the same? Signa Vitae 2017;13:24–7.
31. Thomsen J, Stærk M, Løfgren Bo. The force-displacement relationship in commonly used resuscitation manikins: not very human. Circulation 2017;136. https://doi.org/10.1161/circ.136.suppl_1.20905.
32. Picard C. The clinical effects of CPR meter on chest compression quality: a QI project. Can J Emerg Nurs 2021;44:9–10. https://doi.org/10.29173/cjen149.
33. Beard M, Swain A, Dunning A, Baine J, Burrowes C. How effectively can young people perform dispatcher-instructed cardiopulmonary resuscitation without training? Resuscitation 2015;90:138–42. https://doi.org/10.1016/j.resuscitation.2015.02.035. PMID: 25779008.
34. Pérez-Bermejo M, Alcalá-Dávalos L, Pérez-Murillo J, Legidos-García ME, Murillo-Llorente MT. Are the Growth Standards of the World Health Organization Valid for Spanish children? The SONEV Study. Front Pediatr 2021;9:700748. https://doi.org/10.3389/fped.2021.700748. PMID: 34490160; PMCID: PMC8418137.
35. El-Mouzan M, Al-Herbish A, Al-Salloum A, Qurachi M, Al-Omar A. Growth charts for Saudi children and adolescents. Saudi Med J 2007;28:1555–68.
36. World Obesity Federation, World Obesity Atlas 2023. https://data.worldobesity.org/publications/?cat=19.
37. Watanabe K, Lopez-Colon D, Shuster JJ, Philip J. Efficacy and retention of Basic Life Support education including Automated External Defibrillator usage during a physical education period. Prev Med Rep 2017;5:263–7. https://doi.org/10.1016/j.pmedr.2017.01.004. PMID: 28138421; PMCID: PMC5271672.
38. Cole TJ, Green PJ. Smoothing reference centile curves: the LMS method and penalized likelihood. Stat Med 1992;11:1305–19. https://doi.org/10.1002/sim.4780111005. PMID: 1518992.
39. Manzano-Carrasco S, Garcia-Unanue J, Haapala EA, Felipe JL, Gallardo L, Lopez-Fernandez J. Relationships of BMI, muscle-to-fat ratio, and handgrip strength-to-BMI ratio to physical fitness in Spanish children and adolescents. Eur J Pediatr 2023;182:2345–57. https://doi.org/10.1007/s00431-023-04887-4. PMID: 36881145; PMCID: PMC9989582.
40. Schroeder DC, Semeraro F, Greif R, Bray J. International Liaison Committee on Resuscitation. KIDS SAVE LIVES: basic life support education for schoolchildren: a narrative review and scientific statement from the International Liaison Committee on Resuscitation. Resuscitation 2023;188:109772. https://doi.org/10.1016/j.resuscitation.2023.109772.