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Children saving lives: training towards CPR excellence levels in chest compression based on age and physical characteristics.

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ABSTRACT

Background. The World Health Organization's endorsement of the "Kids save lives" statement fosters the implementation of cardiopulmonary resuscitation (CPR) training for school children worldwide. However, not every child achieves and maintains the recommended chest compression depth of 5-6 cm.

Purpose. To investigate the variability in compression depth for three age groups (grade 1: 12-14; grade 2: 14-16; grade 3: 16-18 years) as a function of physical characteristics and to define minimal compression excellence levels for training.

Methods. Compression depth of 265 subjects (111 girls, 154 boys) aged 12-18 years from one secondary school was individually assessed and reported in percentiles per age group. Pearson correlations between physical characteristics and CPR variables were calculated. Excellence level was defined as the percentage compressions with depth 5-6 cm.

Results. In grade 1 (12-14 years), achieved excellence levels were 1% for girls and 23% for boys at the 75th percentile. In grade 2 (14-16 years), it increased to 24% for girls and 80% for boys. In grade 3 (16-18 years) finally, it was 59% for girls and 87% for boys. Significant positive correlations were found between CPR and physical variables ($p < .05$), especially weight > 50 kg ($p < .01$).

Conclusion. A minimal excellence level of 25% is achievable by boys 12-14 year and girls 14-16 year and can be gradually improved to 60% and 90% according to age and gender. This might necessitate more exertion and training for some younger children, especially girls, and will probably be more easily achieved for children weighing > 50 kg.

INTRODUCTION

Out-of-hospital Cardiac Arrest (OHCA) is one of the leading causes of death both in Europe and the United States. In the 2015 European Resuscitation Council (ERC) Guidelines, the importance of immediate initiation of bystander cardiopulmonary resuscitation (CPR) in the chain of survival was stressed once more.¹ To increase the rate of bystander CPR, the World Health Organisation (WHO) and the ERC promote CPR training for schoolchildren.^{2,3} This has many advantages as children have a positive attitude towards CPR learning and can facilitate their family and friends to learn CPR.^{2,4,5} Several authors report that children are perfectly able to perform ventilations and chest compressions with an adequate rate (100-120/min) after training, but have difficulties in obtaining the ERC advised compression depth of 5-6 cm.^{6,7,8} Achieving adequate compression depth is age-, height- and weight dependent and therefore children's physical characteristics play a role in the quality of chest compressions.⁹⁻¹³ The influence of gender on the compression depth in children is yet not clear, but most likely related to body weight.^{10,14} Moreover, the influence of rescuer fatigue, especially in younger children will also impact on compression depth over time.^{8,12}

Both ERC and American Heart Association (AHA) recommend that schoolchildren graduating from secondary school should be able to perform high-quality chest compressions with minimal interruptions.¹⁵ In order to measure competence (i.e., high-quality chest compressions) and assess training outcome it is recommended to use a pre-defined pass level and define the proportion of compressions with depth 5-6 cm to achieve.^{16,17,18} This can be defined as the compression excellence level to achieve. When it comes to define such excellence levels in young children an educational problem arises. It is known that a depth of 5-6 cm is only reached by a

majority of children around the age of 14.^{9,12} From an educational point of view it would be unacceptable to teach or accept compression depths that differ from the ERC/AHA guidelines. Applying the mastery learning theory by gradually improving the proportion of adequate skills over time, might be a solution to train children in high-quality CPR over time.¹⁹ This educational strategy would require adjusted learning objectives (i.e., minimal achievable excellence levels) taking the physical characteristics of different age groups or clusters into account. The aim of this study is to gain insight in the variability of compression depth in different age groups in relation to physical characteristics and define minimal compression excellence levels for training.

2. METHODS

2.1. School and subjects

In 2014 and 2015, 339 participants constituting 18 classes from a secondary school in Flanders, Belgium, participated in this study. The school was gender-mixed, heterogeneous on the level of students' socio-economic background, and CPR was not previously taught as a part of the school curriculum. In Flanders, secondary education comprises three grades (i.e., three 2-year cycles). To ensure a balanced study sample six classes from each grade participated in this study. Physical education teachers (n= 6, 1 female and 5 males) trained all children in CPR. They were aged between 35 and 53 years and had an average teaching experience of 12 years in that school (range 5-30 years). None of the teachers was certified in CPR. Approval to conduct the study was obtained from the school board, the physical education teachers and the children's parents.

2.2. Study design

Prior to Basic Life Support (BLS) training, all students completed a questionnaire comprising demographics and physical characteristics concerning height and weight. The questionnaire was completed individually under exam conditions to avoid distraction from peers. Next, students received a standardized 45-min BLS training from their physical education teacher. During an initial 5-minute introduction, the teacher explained the instructional model of reciprocal peer learning with iPads (Apple, Cupertino, US). Reciprocal peer learning with iPads or task cards as instructional tools has previously been used in BLS education.^{20–22} During reciprocal peer learning, students cooperate in pairs of doer and helper to maximize each other's learning. While the helper is instructing, observing and providing performance-related feedback based on the doer's actions and the instructions on the iPad, the doer is performing BLS. Students were prompted to switch roles every 5 minutes by the teacher for a total of 20 minutes, meaning that every student worked twice in the role of doer and helper. Following the 20 minutes training episode, students performed a 10 minutes peer assessment. The assessors (i.e., helpers) evaluated their partner's performance using a scoring sheet on the iPad. This sheet listed all steps of the BLS procedure and allowed the assessor to mark the performance of each step as correct or incorrect. The BLS procedure was based on the ERC 2010 guidelines and comprised the instruction of 9 BLS items, namely 1) safe approach, 2) check responsiveness by shaking gently and shouting loudly, 3) shout for help, 4) open airway, 5) check for breathing, 6) call 112, the European emergency number, 7) perform 30 chest compressions, 8) perform two ventilations, and 9) continue the 30 compressions and 2 ventilations sequence until you become exhausted, professional rescuers take over or the victim starts breathing normally.

Following the peer assessment students could discuss their performance. After 5 minutes, students switched roles. During the 5 min closure the teacher repeated the steps of the BLS procedure. Little Anne manikins (Laerdal Medical, Stavanger, Norway) were used during the learning and peer assessment episodes. One week after training a research assistant assessed the CPR performance of every participant individually during three cycles of 30:2 CPR.

2.3. Intervention fidelity

To guarantee intervention fidelity all teachers attended a 1-hour workshop in which the second author of this study explained the standardized instructional model (i.e., reciprocal peer learning with iPads). The author demonstrated the pedagogical model with two research assistants, stressing teacher behaviour during student learning. At the end of the workshop, teachers took a multiple-choice test to check their understanding of the model. All teachers passed the test and then instructed a training lesson to one of their classes, randomly selected using an online randomizer tool (<http://www.randomizer.org>). To ensure teachers implemented the standardized instructional model, our research assistants supervised the training lesson. After receiving feedback from the research assistants, the teachers were ready to teach CPR to their classes.

2.4. Data collection

A trained research assistant conducted individual CPR assessment. Performance was recorded on a Laerdal Resusci Anne Skillreporter manikin connected to a laptop running the PC-Skill Reporting-system version 2.21 (Laerdal Medical, Stavanger, Norway). During three cycles of 30:2 CPR the following variables were registered:

chest compression depth, incomplete release and compression frequency. Compressions with correct hand placement, depth 5-6 cm and frequency 100-120/min were coded as having no errors. The achieved level of excellence was defined in terms of the percentage of chest compressions with a depth of 5-6 cm.

2.5. Statistical analysis

Percentiles of students' physical characteristics (i.e., height, weight, and BMI) and compression variables were reported per grade for females and males. Pearson's correlation (r) was conducted to analyse the relationship between physical characteristics and quality of CPR compression variables. A significance level was set at 0.05.

3. RESULTS

As shown in the participant flow chart (Fig. 1) the school counted a total of 29 eligible classes. Five classes in this school served as training classes for the 6 teachers. One training class was trained twice by two different teachers due to the interference of the students' curriculum and the teachers' teaching assignments. Six classes dropped out because there was no time in their schedule for CPR training. The remaining 18 classes were equally distributed over each 2-year grade (i.e., 6 classes in each grade) and consisted of 339 students (142 girls and 197 boys) age range 12-18 years. Ninety-nine students dropped out because of absence during reciprocal peer learning, CPR assessment or because of not reporting their demographics. In grade 1, two full classes dropped out because of a school event scheduled at the moment of CPR assessment. Eleven students were excluded from analysis because they received a CPR course during the last year. The final sample consisted of 265

children (111 girls and 154 boys) age range 12-18 years. Average training time was 43 minutes (range 40-46).

INSERT FIGURE 1

3.1. PERCENTILES OF PHYSICAL CHARACTERISTICS AND CPR PERFORMANCE IN GRADES 1, 2 AND 3

Percentiles of physical characteristics and CPR compression variables for girls and boys per grade can be consulted in Table 1. In grade 1 (12-14 years), height, percentiles are not meaningfully different between girls and boys. For weight, starting from the 75th percentile, differences between girls and boys grew larger which coincides with boys being able to achieve 23% of chest compressions with sufficient depth. From the 90th percentile onwards, boys achieve sufficient chest compression depth for almost all compressions performed. At percentile 95 however, girls only achieve sufficient depth in 57% of chest compressions.

Similar to grade 1, differences in weight for children in grade 2 (14-16 years) grow larger from the 75th percentile onwards which coincides with a drastic increase in the percentage of chest compressions with sufficient depth. Although only 14% of compressions have sufficient depth for girls in the 75th percentile, this percentage rises to 87% at percentile 90.

At percentile 50, 40% of the performed compressions of grade 3 boys (16-18 years) have sufficient depth, for girls, this is only 4%. From the 75th percentile onwards, the amount of compressions with sufficient depth increases meaningfully: girls 59% and boys 87%. At the 95th percentile, about all compressions reach sufficient depth for both genders.

INSERT TABLE 1 AND FIGURE 2

3.2. CORRELATIONS BETWEEN PHYSICAL CHARACTERISTICS AND CPR VARIABLES

Correlations between physical characteristics and CPR compression variables are shown in Table 2. Significant positive correlations were found for all physical characteristics with CPR compression variables. Weight was responsible for the highest correlations ($p < .01$).

INSERT TABLE 2

4. DISCUSSION

Sufficient chest compression depth, and in particular a good level of excellence in terms of percentage compressions achieved between 5-6 cm, is one of the key determinants of high-quality CPR because of its strong association with survival outcomes.²³ Our study demonstrates that the variability in proportions of compressions with depth 5-6 cm is age, height and weight dependent. A strong correlation for all physical characteristics and the proportion of compressions with depth 5-6 cm is shown, with weight being the highest correlate. This finding is in line with other authors and underpins the fact that children's physical characteristics play a role in the quality of chest compressions.⁹⁻¹³

According to the literature the influence of gender on the compression depth in children is yet not clear.^{10,14} Our data provide insight on the gender dependent evolution of the skills proficiency throughout the three different age groups (i.e., grades). The highest proportion of compressions with sufficient depth is observed in subjects weighing 60-70 kg. This relationship between weight and compression depth is also described in adults.²⁴⁻²⁶ Previous research showed that in order to achieve minimally 38mm chest compression depth, a force of 50 kg should be applied which is achievable for an average sized, fit adult.²⁷ In Flanders (Belgium), the 50th percentile of weight for boys and girls reaches 50 kg at 13.6 years. Flexion at the hip joints contributes to the total force generated when a person performs

chest compressions during CPR.²⁸ Therefore, a total body mass of <50 kg does not by definition limit a person's ability to perform adequate compressions but would necessitate much more exertion from that person than someone with greater body mass. For this reason, we believe that primarily age and secondary physical characteristics could guide the tailoring of achievable compression excellence levels. Discussions on the best age for initiating CPR training have mainly focused on the physical ability to perform CPR (physical fitness). Our manuscript confirms the findings that a depth of 5-6 cm is only reached by a majority of children around the age of 14 (grade 2).^{9,12} Research with 12-14 year olds by Isbye and colleagues reported CPR percentages of 50% following training²⁹, Iserbyt and colleagues reported average CPR scores of 60% with 11-12 year olds³⁰, and Beck and colleagues an overall pass- rate of approximately 40%.³¹ Shallow chest compressions reported in previous work with children might be partly explained by the fact that a strong emphasis on sufficient depth was lacking. It would be worthwhile to investigate chest compression depths with children using an explicit 'push as hard as you can' strategy, tailored to children by taking age and physical characteristics into account.

Children with a higher weight (upper percentile of their age group) are more likely to achieve higher excellence levels. However, results might be underestimated since children were not trained to achieve a specific excellence level. In previous research, we demonstrated that when trained against a pre-defined excellence level of 70%, adult participants of both genders were capable of gradually achieving it, and in particular girls were able to "catch up" with boys.²⁴ For instructors, providing children with a particular target in terms of excellence level could be more challenging and foster performance as opposed to being satisfied with lower compression depths.

When teaching CPR, it is not only important to achieve just “some” compressions with correct depth, but over time to evolve to achievement and maintenance of an excellence level in CPR skills. Applying the principles of mastery learning can gradually allow learning progress from skills acquisition (performing chest compressions) to skills mastery (achieving 5 cm compression depth) and finally achieving an excellence level in chest compression (achieving an acceptable proportion of 5 cm deep compressions). Several authors described skills acquisition starting at the age of 8-10 years old^{6,32} and there is good evidence that even younger children are capable of being successfully taught CPR.^{33–35} Other studies already indicated that all age groups show progress in learning, regardless of the starting age^{14,36}, which underpins the use of a mastery learning educational approach for children as suggested in our manuscript.

Taking into account that children, who are physically unable to perform those compressions to the desired excellence level during training, might become discouraged or disinterested, it is reasonable to apply different excellence levels related to age and physical characteristics. Although positive reinforcement and motivation to strive for better results should arise from training, lowering the compression depth to achieve this goal is not an option. As mentioned previously, it is not acceptable to teach or accept any other compression depth than the one defined by the ERC/AHA guidelines. Training children according to a non-guidelines compliant compression depth might create the false perception that this lower compression depth is the correct one, which may lead to confusion and adverse outcomes.

Our data show that boys (75th percentile) achieved an excellence level (i.e., percentage compressions 5-6 cm) of almost 25% in grade 1 and girls (75th percentile)

in grade 2. Girls (75th percentile) only achieved an excellence level of 60% in grade 3. At the same time boys (75th percentile) of grade 3 almost achieved a 90% excellence level. Therefore, it seems feasible to recommend a minimum excellence level of 25% and gradually improve it to 60% and 90% over time according to growing age and gender (Table 3). In some cases, this might necessitate more exertion and training from younger children and especially girls, and will probably be more easily achieved for children weighing >50 kg.

INSERT TABLE 3

Limitations

The observational aspect and small study population limits the generalizability of our results. With regard to BLS training, although teachers were trained following a standardized protocol under supervision of the second author, they were not CPR certified. In addition, the achievement of an excellence level was not particularly stressed or defined during training. As such, the results in this study might be underestimated. Since our results are based on a three-cycle CPR test, we cannot take exertion into account, which in real life will be an additional constraint to maintain a certain excellence level during CPR.

Another potential limitation might be the self-report of the physical characteristics, although literature showed no statistical differences between self-reported and measured data for weight (-1.2 kg) and height (0.8 cm) in an adult population.³⁷ Studies with adolescents in Europe show that self-reported height and weight are highly correlated with measured data. Weight is often underreported and moderated by gender and weight. Previous studies showed that weight was underreported with a range of 0.5 to 1.2 kg.³⁸⁻⁴⁰ Based on these previous studies, we can conclude that

results from our paper would be similar if measured weight and height had been used.

5. CONCLUSION

A minimum excellence level of 25% is achievable by boys 12-14 year and girls 14-16 year and can be gradually improved to 60% and 90% according to age and gender. This might necessitate more exertion and training for some younger children, especially girls, and will probably be more easily achieved for children weighing >50 kg.

CONFLICT OF INTEREST STATEMENT

Dr. Mpotos is owner of a company providing CPR self-learning and assessment for hospital staff.

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LEGEND TO THE FIGURES

FIG. 1 PARTICIPANT FLOW CHART

FIG. 2 PROPORTION OF CHEST COMPRESSIONS WITH DEPTH 5-6 CM FOR FEMALES AND MALES (75TH WEIGHT PERCENTILE) IN GRADES 1 (N= 49), 2 (N= 118), AND 3 (N=98)

Table 1. Percentiles of physical characteristics and CPR compression variables for children in 1st grade (12-14 years), 2nd grade (14-16 years), and 3rd grade (16-18 years).

Variable	Gender	Grade 1 (24 girls, 27 boys)			Grade 2 (42 girls, 76 boys)			Grade 3 (45 girls, 53 boys)		
		50	75	95	50	75	95	50	75	95
Height (cm)	Female	163	169	174	167	172	176	165	169	178
	Male	165	171	178	175	180	188	177	180	191
Weight (kg)	Female	45	50	54	55	58	70	57	63	75
	Male	49	55	73	60	65	75	68	71	76
Body Mass Index	Female	17	18	20	19	21	25	21	22	27
	Male	18	20	24	19	21	24	21	23	24
Compressions with depth 5-6 cm (%)	Female	0	1	57	0	24	98	4	59	99
	Male	1	23	99	31	80	99	40	87	100
Compressions with incomplete release (%)	Female	0	0	2	0	0	10	0	0	23
	Male	0	0	17	0	0	6	0	2	60
Compressions with no errors (%)	Female	0	0	54	0	6	77	0	27	85
	Male	0	11	61	2	31	91	10	53	96

Table 2. Correlations between physical characteristics and cardiopulmonary (CPR) variables

	Height (cm)	Weight (kg)	Body Mass Index
Compressions sufficient depth (%)	.35**	.42**	.30**
Compressions with incomplete release (%)	.15*	.21**	.16*
Compressions with no errors (%)	.18**	.24**	.21**

* p < .05
 ** p < .01

Table 3. Expected excellence level (% compressions 5-6 cm) according to age for boys and girls

	25%	60%	90%
Girls (age)	14	16	*
Boys (age)	12	14	16

* a 90% excellence level was not observed for girls in our data