

Use of a Metronome in Cardiopulmonary Resuscitation: A Simulation Study

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abstract

OBJECTIVE: Determine whether the use of a metronome improves chest compression rate and depth during cardiopulmonary resuscitation (CPR) on a pediatric manikin.

METHODS: A prospective, simulation-based, crossover, randomized controlled trial was conducted. Participants included pediatric residents, fellows, nurses, and medical students who were randomly assigned to perform chest compressions on a pediatric manikin with and without an audible metronome. Each participant performed 2 rounds of 2 minutes of chest compressions separated by a 15-minute break.

RESULTS: A total of 155 participants performed 2 rounds of chest compressions (74 with the metronome on during the first round and 81 with the metronome on during the second round of CPR). There was a significant improvement in the mean percentage of compressions delivered within an adequate rate (90–100 compressions per minute) with the metronome on compared with off (72% vs 50%; mean difference [MD] 22%; 95% confidence interval [CI], 15% to 29%). No significant difference was noted in the mean percentage of compressions within acceptable depth (38–51 mm) (72% vs 70%; MD 2%; 95% CI, –2% to 6%). The metronome had a larger effect among medical students (73% vs 55%; MD 18%; 95% CI, 8% to 28%) and pediatric residents and fellows (84% vs 48%; MD 37%; 95% CI, 27% to 46%) but not among pediatric nurses (46% vs 48%; MD –3%; 95% CI, –19% to 14%).

CONCLUSIONS: The rate of chest compressions during CPR can be optimized by the use of a metronome. These findings will help medical professionals comply with the American Heart Association guidelines.

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Dr Zimmerman conceptualized and designed the study, coordinated and supervised data collection, carried out the initial analysis, and drafted the initial manuscript; Dr Cohen coordinated and supervised data collection, carried out the initial analysis, and drafted the initial manuscript; Drs Maniaci, Pena, and Linares carried out initial analysis and reviewed and revised the manuscript; Dr Lozano provided statistical advice on the study design, carried out initial analysis, and reviewed and revised the manuscript; and all authors approved the final manuscript as submitted.

This trial has been registered at www.clinicaltrials.gov (identifier NCT02511470).

www.pediatrics.org/cgi/doi/10.1542/peds.2015-1858

DOI: 10.1542/peds.2015-1858

Accepted for publication Aug 18, 2015

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PEDIATRICS (ISSN Numbers: Print, 0031-4005; Online, 1098-4275).

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WHAT'S KNOWN ON THIS SUBJECT: The frequency of cardiac arrest is significantly lower in children than in adults, rendering the delivery of high-quality cardiopulmonary resuscitation more difficult. Metronome-based studies in adults showed improvement in adequate compression rate, with a detrimental effect on the depth of chest compressions.

WHAT THIS STUDY ADDS: This is the first pediatric study to confirm that the use of a metronome during cardiopulmonary resuscitation significantly improves the delivery of adequate rate without affecting the compression depth. This effect was more prominent among medical students and pediatric residents and fellows than nurses.

Despite recent advances in resuscitation, such as defibrillation technology, survival from cardiac arrest remains poor.^{1,2} Without prompt care the chance of survival falls dramatically within minutes of arrest onset.³ Matos et al³ found that survival outcomes in the first 15 minutes are linear and decline rapidly, highlighting the importance of immediate return of spontaneous circulation. Pediatric survival to discharge rate after in-hospital cardiac arrests is >25%; in comparison, 5% to 10% survive after out-of-hospital cardiac arrests.⁴ Poor-quality cardiopulmonary resuscitation (CPR) has been cited as a contributing factor to this dismal statistic on outcomes.⁴ Optimizing the CPR technique improves resuscitation success. It is well known that immediate delivery of high-quality CPR increases survival rates. The key elements of high-quality CPR are to push hard, push fast, allow full chest recoil between compressions, avoid excessive ventilations, minimize interruptions, avoid preshock pause, resume CPR immediately after shock, and rotate compressor role every 2 minutes.⁵ Therefore, each minute is critical to achieving both survival and favorable neurologic outcomes.^{3,6} At the completion of a CPR course, health care professionals are examined and given a provider card that indicates course completion. It is assumed that when properly trained health care professionals perform CPR, the American Heart Association (AHA) standards are being met.

Very high compression rates may compromise coronary blood flow due to a significant shortening of the diastolic period, when the majority of coronary flow occurs. Too slow a rate delivers too few compressions per minute to achieve optimal resuscitation hemodynamics and outcomes.^{1,7} The notion of chest compression-only CPR (without ventilations) has gained support from

both clinical and animal investigations.^{8,9} Kern et al⁷ evaluated metronome guidance of both chest compressions and ventilation on adults, both before and after endotracheal intubation. The combined tone and voice prompt audio guidance they used was effective at maintaining the target chest compression rate and avoiding the common problem of hyperventilation during CPR by professional rescuers (ie, emergency medical technicians). Some studies have suggested that rescuer fatigue may decrease the quality of CPR even after 1 minute of chest compressions, and the rescuer may not recognize this decrease in performance.⁶ Jäntti et al⁸ were able to show that participants perceive more exhaustion when given chest compressions without metronome guidance, but the measured compression depth did not decrease during the 10-minute scenario. They mentioned that this effect might be the result of the experience of the participants (ICU nurses and members of the cardiac arrest team). A number of studies suggest that human factors contribute to poor CPR quality, which includes difficulty in performing CPR during stressful and chaotic cardiac arrest conditions, the lack of internal sense of chest compression rate and depth, rescuer fatigue, and infrequent CPR recertification.^{1,6} One possible solution to these problems is measuring the quality of resuscitation by use of an audible metronome during CPR to better train our pediatric health care providers.

Inadequate chest compression rate and depth are common during CPR even among skilled health care providers.^{1,10} This finding may be more prominent in the pediatric setting because of the infrequent occurrence of cardiac arrests in comparison with adults. Most of the recommendations for pediatric CPR are extrapolated from adult studies. Atkins et al¹¹ found the incidence of out-of-hospital nontraumatic cardiac arrest in pediatrics to be 8.04 per

100 000 person-years, compared with 126.52 per 100 000 person-years for adults. To our knowledge no study to date has evaluated pediatric practitioners in performing high-quality CPR in the setting of metronome use. The low frequency of pediatric cardiac arrests compared with adults is the basis of our study.

We report a study of CPR by pediatric care providers on a pediatric manikin with and without a metronome. We hypothesized that the use of a metronome would improve chest compression rate and depth during CPR.

METHODS

Selection of Participants

A total of 155 participants were recruited for this study. Participants included residents, fellows, and nurses specializing in pediatrics and medical students rotating in pediatrics, who voluntarily participated from January to July 2014. Recruitment took place through e-mails, flyers, and directly during conferences. Eligibility criteria included health professionals with a minimum of basic life support training according to the 2010 AHA guidelines and capable of performing chest compressions. Verbal consent was obtained and demographic data were collected from the participants, including time since last CPR training, professional background, and gender.

Study Design and Setting

A prospective, simulation-based, crossover, randomized controlled trial was conducted and approved by the Western Institutional Review Board, an independent institutional review board. Participants were randomly assigned into 2 CPR rounds by a Microsoft Excel 2010 random generator program. The simulation clinical educator used the Excel software to create a random list of numbers used for the allocation of participants. One round consisted

of chest compressions with an audible metronome and the other of chest compressions without an audible metronome that sounded at a rate of 100 times per minute. A monitor-defibrillator (Lifepak 15 from Physiocontrol, Redmond, WA) with a built-in CPR metronome was used; it was set to “pediatric with airway setting” for this study. The metronome was placed ~8 feet from the participants. The participants were blinded to the specific purpose of the study; they were told that they would be participating in an educational study about CPR training. Study investigators were not blinded to the study, but all measurements were collected directly by the software, so investigators had no impact on the data collected. Participants were informed that a metronome would be used randomly during 1 of their CPR sessions, and the rate and depth of chest compressions would be assessed according to the Pediatric Advanced Life Support (PALS) 2010 AHA guidelines. No participants were excluded or lost after randomization.

Methods and Measurements

Each participant performed 2 rounds of 2 minutes of chest compressions separated by a 15-minute break to avoid participant fatigue. Chest compressions were performed on a Resusci Anne pediatric torso simulator manikin (Laerdal Medical AS, Stavanger, Norway) placed on a board on a standard hospital bed and mattress and adjusted to the participant’s comfort level. In addition, a step stool was provided to those participants who chose to use one. Participants were also advised to take off any items (eg, ID badge, stethoscope, watch) that may interfere with delivery of high-quality chest compressions. All participants conducted chest compressions on the same manikin. To simulate a more accurate cardiac arrest environment, background “crowd noise” was used and measured with an SM-10 sound

level meter (Amprobe, Everett, WA) to ensure that the noise level (measured in decibels) was similar for each scenario. Video recording of each participant was obtained for feedback purposes only.

Data were collected in the simulation laboratory and emergency department setting with the equipment setup being identical in both locations. Resusci Anne Wireless SkillReporter software with a personal computer skill reporting system (Laerdal Medical AS, Stavanger, Norway) was used to record the data for each participant. The manikin wirelessly transmitted the information to the computer and captured data including rate, depth, hand position (hands compressing the sternum), release time (chest fully released back to resting position), and downstroke/upstroke ratio (amount of time compressing vs decompressing, optimal ratio 1.00 [50%/50%]). This information allowed us to determine whether the time interval between 2 compressions matched that of an adequate rate (90–110 per minute; shorter and longer intervals indicated compression rates that were too fast and too slow, respectively) and whether every compression was within adequate depth (38–51 mm). Then we determined, for every participant, the percentage of compressions that were within adequate rate and depth. Finally, we obtained the mean of the percentage of compressions within adequate rate and depth with and without the metronome, which were the primary outcomes.

Primary Data Analysis

We calculated sample size by using data provided by Buléon et al¹² in a crossover study involving medical students performing CPR on a manikin with and without a CPRmeter. Fifty-six percent of compressions were in the appropriate range without the use of a metronome. Assuming that use of

the metronome would increase this percentage to 70% (a relative improvement of about 25%), a sample of 152 participants was used ($\alpha = 0.05$, paired 2-tailed test, power 80%).

Descriptive data are given as means with SD or as proportions and 95% confidence intervals (CIs). Because this was a crossover trial, a formal test for a treatment by period interaction was conducted to assess whether the results had been affected by order or carryover effect. Given that no interactions were observed (data not shown, available upon request), the analysis was based on estimates of the within-subject difference in the average of the percentage of compressions that were within an adequate rate (90–110 per minute) or depth (38–51 mm) with and without the metronome. Accordingly, differences equal to 0 indicate that there were no changes with the metronome, positive values that the metronome improves the outcomes and negative values the opposite. 95% CI and *P* values, obtained via *t* test, were calculated to determine whether the differences observed were statistically significant. Statistical software used was SPSS Statistics version 21 (IBM SPSS Statistics, IBM Corporation).

RESULTS

A total of 155 participants were included in the study (medical students rotating in pediatrics, *n* = 55; pediatric nurses, *n* = 33; and pediatric residents and pediatric fellows, *n* = 67). There were varying levels of basic and advanced life support training, most obtained within the previous 12 months. See Table 1 for participant characteristics.

Of the 155 participants, 74 were randomly assigned to have the metronome on during the first round of CPR, and the remaining 81 participants had the metronome on during the second round. All participants completed the 2 rounds

TABLE 1 Characteristics of Study Participants (*n* = 155)

Characteristic	<i>N</i> (%)
Level of training and background	
Medical student rotating in pediatrics	55 (36)
Pediatric residents and fellows	67 (43)
Pediatric nurse	33 (21)
Women	87 (56)
Men	68 (44)
CPR training	
BLS only	30 (19)
BLS and PALS	125 (81)
Time (mo) since last CPR training	
<6	35 (23)
6–12	80 (52)
>12	40 (26)

BLS, basic life support; PALS, pediatric advanced life support.

of chest compressions (Fig 1). Mean levels of environment background crowd noise during rounds with the metronome on and off were almost identical (67.9 dB vs 67.5 dB; mean difference [MD] 0.4 dB; 95% CI, -0.01 to 0.7).

There was a statistically significant improvement in the mean percentage of compressions delivered within an adequate rate with the metronome on compared with the metronome off (72% vs 50%; MD 22%; 95% CI, 15% to 29%) (Table 2). This difference was explained by a decrease in the mean percentage of compressions that were too fast (21% vs 39%; MD -18% ; 95% CI, -24% to -12%). The total number of compressions during 2 minutes was lower with the metronome on than with the metronome off (210.6 vs 221.9; MD -11.3 compressions; 95% CI, -15.8 to -6.8). No statistically significant difference was noted when we compared the mean percentage of compressions within acceptable depth (72% vs 70%; MD 2%; 95% CI, -2% to 6%) or the mean compression depth (43.8 mm vs 44.0 mm; MD -0.2 mm; 95% CI, -1.0 to 0.6). Metronome guidance had no effect on percentage of good hand position, percentage of adequate release, or mean downstroke/upstroke ratio.

Exploratory subgroup analyses were performed on adequate compression rate by training level (Table 2). When we compared the percentage of adequate compression rate by training level, we noted that the metronome had a significant effect among medical students rotating in pediatrics (73% vs 55%; MD 18%; 95% CI, 8% to 28%) and pediatric residents and pediatric fellows (84% vs 48%; MD 37%; 95% CI, 27% to 46%) but not for pediatric nurses (46% vs 48%; MD -3% ; 95% CI, -19% to 14%).

DISCUSSION

To our knowledge, this is the first pediatric manikin-based simulation study assessing pediatric practitioners performing chest compressions with and without a metronome. Our results illustrate how metronome guidance improves the delivery of chest compressions at an adequate rate but has no effect on the depth. These findings are in accordance with several adult studies showing similar results.^{8,13} Our study focused on CPR with only chest compressions rather than the addition of ventilation, leading to a shorter delay to chest compressions. Initiating chest compressions early is of utmost importance, as emphasized by the changes in the traditional airway-breathing-circulation sequence to the current circulation-airway-breathing sequence put forth in the 2010 resuscitation guidelines.^{14–16} These guidelines are supported by Kern et al,⁹ who demonstrated that only chest compressions in early cardiac arrest provides reasonable circulation, does not compromise survival, and is associated with successful outcomes. In addition, in an attempt to minimize the effect of rescuer fatigue, we selected a 2-minute time limit for compressions. Furthermore, the importance of rescuer fatigue was highlighted by Hong et al¹⁷ to substantially diminish the quality

of CPR as early as the third minute of continuous chest compressions. These outcomes support the pediatric advanced life support concept of “push-as-fast-as-you-can” to emphasize organization of care around 2-minute periods of uninterrupted CPR.¹⁶

There have been metronome-based studies illustrating improvement of adequate compression rate, but, unlike our study, they demonstrated a negative impact on the depth of chest compressions.^{18,19} Our study focused on rate-only feedback from a metronome because it is easily accessible as part of the defibrillator machine on code carts and the defibrillators in the resuscitation room. The actual cause of suboptimal chest compression depth with metronome guidance is unknown. However, it has been hypothesized that various factors could contribute to shallower compressions, including multitasking, rescuer fatigue, and rescuer distraction (concentrating on rate management rather than maximal effort).^{18–20} The effect of greater compression depth is associated with increased coronary perfusion pressure, higher success of defibrillation, increased cardiac output, and improved clinical outcomes.^{21,22} A compression depth of 5 cm is more effective than 4 cm in children and adults. The most recent AHA guidelines recommend a compression depth of ≥ 5 cm in children and adults, in hopes to eliminate confusion when ranges of depth are provided.¹⁶ The overall quality of CPR is highly dependent on multiple factors, but most importantly on rate and depth. Therefore, devices that combine audible feedback on both rate and depth may improve CPR quality.¹⁸

In our study the level of background noise was controlled for and therefore similar in each group. The direct impact of background noise could not be assessed because the actual noise level in a pediatric

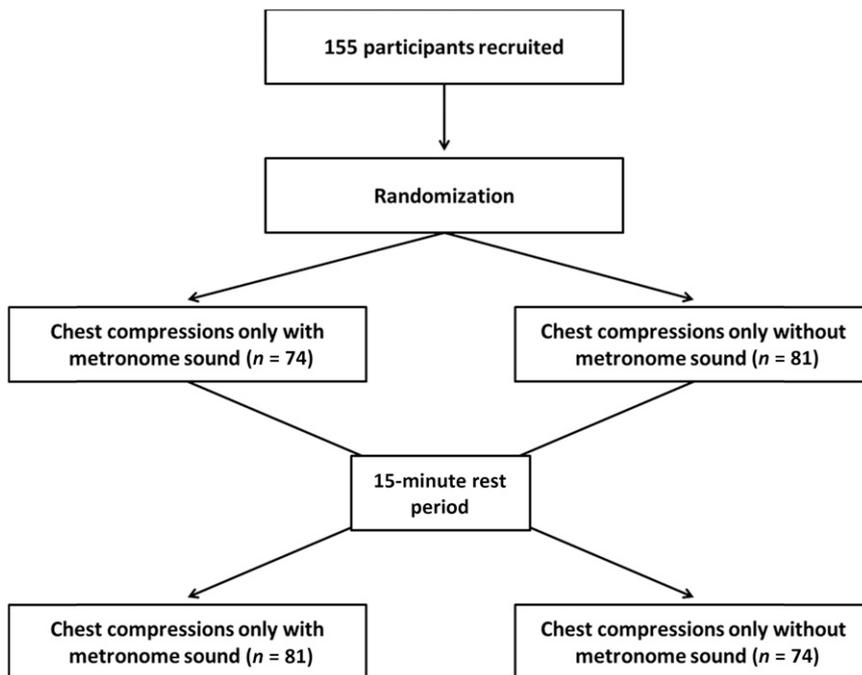


FIGURE 1
Participant flowchart.

cardiac arrest case is unknown. You et al²³ mentioned that in certain community environments noise levels measured to be >70 dB were found to cause irritation and hearing impairment. Additional studies

measuring the noise level in pediatric cardiac arrest cases might be helpful to determine the impact of noise level on quality of CPR.

Additional analysis allowed us to compare the effect of metronome

guidance on subgroups. The subgroups analyzed were not prespecified and were conducted for exploratory purposes only, to generate hypotheses for future research. Metronome guidance increased the percentage of adequate compression rate for medical students rotating in pediatrics and pediatric residents and fellows but not for pediatric nurses. This difference could be attributed to the level of training. Audible metronome guidance helped improve the percentage of compressions delivered at an adequate rate despite the length of time since participants completed their last CPR training. In agreement with Handley and Handley's²⁴ study regarding an audible feedback system, our study suggests that incorporating an audible metronome in monitors, defibrillators and automated external defibrillator devices, in both hospital and community settings, could lead to improved performance and delivery of high-quality CPR during pediatric resuscitation attempts. Not only can metronome guidance help with rate control of chest compressions, as demonstrated in our study, it can also help with ventilation rate (hyperventilation is a common problem during actual cardiac arrest resuscitation efforts).²⁰

The AHA recommends periodic assessment of rescuer knowledge and skills, although optimal timing and methods for these are not known.¹⁶ We recommend that metronome guidance be incorporated into CPR training, the rate of which could be easily adjusted to comply with the frequent guideline updates. Furthermore, we agree with the AHA recommendations and suggest an increased need for more frequent CPR training with the use of refresher courses. This training is especially necessary for medical professionals working within the pediatric population because of the low number of cardiac arrest events among children. Studies have shown

TABLE 2 Outcome Variables With and Without Metronome Guidance (n = 155)

	Metronome		Difference (95% CI)	P
	On	Off		
Percentage of compressions with adequate rate	72 (38)	50 (43)	22 (15 to 29)	<.001
Percentage of compressions within acceptable depth	72 (39)	70 (41)	2 (-2 to 6)	.29
Total number of compressions	210.6 (31.2)	221.9 (32.7)	-11.3 (-15.8 to -6.8)	<.001
Compression rate per min	106.6 (17.5)	112.0 (17.1)	-5.4 (-8.1 to -2.7)	<.001
Percentage of compression rate too fast	21 (36)	39 (45)	-18 (-24 to -12)	<.001
Percentage of compression rate too slow	8 (24)	11 (27)	-2 (-6 to 2)	.32
Mean compression depth (mm)	43.8 (10.8)	44.0 (11.3)	-0.2 (-10 to 0 6)	.63
Percentage of compressions too shallow	28 (39)	30 (40)	-2 (-6 to 2)	.31
Percentage of compression with correct hand position	90 (25)	92 (23)	-2 (-5 to 2)	.32
Percentage of compressions adequate release	83 (32)	82 (32)	1 (-3 to 4)	.78
Noise level (dB)	68 (4)	68 (4)	0.4 (-0.01 to 0.7)	.05
Downstroke upstroke ratio	90 (18)	89 (17)	2 (-1 to 4)	.2
Percentage of ACR, medical students rotating in pediatrics	73 (39)	55 (44)	18 (8 to 28)	.001
Percentage of ACR, pediatric residents and pediatric fellows	84 (30)	48 (43)	37 (27 to 46)	<.001
Percentage of ACR, pediatric nurses	46 (41)	48 (44)	-3 (-19 to 14)	.75

Data are presented in means (SDs) unless otherwise indicated. ACR, adequate compression rate.

that as one goes without CPR training refresher courses, the quality of CPR performance deteriorates in as little as 3 months.²⁰ Because of the low frequency of pediatric codes, we believe there should be more frequent pediatric code simulations or refresher courses during pediatric residency and pediatric fellowship training.

There are several limitations to our study. First, the actual environment in which the study was performed might be artificial. Although we attempted to simulate as close to a medical resuscitation environment as possible with background noise, the actual noise and stress level of being in a real resuscitation setting could not be simulated. Second, code situations with real-life cases were not used for the study. Instead, the compressions were performed on a pediatric manikin, so patient outcomes were not measured. Third, participants were asked only to perform chest compressions, and therefore the importance of pauses for ventilation and tracheal intubations was not taken into

account. Fourth, no formal feedback was obtained on how participants felt about the audible metronome and whether it affected the quality of their chest compressions. Finally, participant fatigue was not assessed, which is important especially with the ongoing changes in CPR guidelines (ie, the number of chest compressions and compression depth). Many of these limitations could affect future studies and should be taken into consideration when additional research is conducted.

CONCLUSIONS

It is well known that prompt response to cardiac arrest and proper delivery of high-quality chest compressions increases meaningful survival in patients. Our data indicate that the use of a metronome improves the accuracy of the rate of compressions delivered to a pediatric manikin. These data are encouraging and support the need for future clinical

trials assessing the effect of a metronome in delivering compressions at an adequate rate and depth in real-life pediatric cardiac arrest cases.

ACKNOWLEDGMENTS

Nicklaus Children's Hospital, formerly Miami Children's Hospital Human Patient Simulation Program Department, provided the equipment used to collect the data. The authors thank the simulation clinical educator, Beth Ann Ramey, RN, and the simulation technicians, Zeshan Khan and Jason Cheleotis, for their support and dedication to this study. We also thank all the participants who volunteered and made this study possible.

ABBREVIATIONS

AHA: American Heart Association
CI: confidence interval
CPR: cardiopulmonary resuscitation
MD: mean difference

FINANCIAL DISCLOSURE: The authors have indicated they have no financial relationships relevant to this article to disclose.

FUNDING: No external funding.

POTENTIAL CONFLICT OF INTEREST: The authors have indicated they have no potential conflicts of interest to disclose.

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Pediatrics 2015;136;905

DOI: 10.1542/peds.2015-1858 originally published online October 12, 2015;

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