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The rate of chest compression familiarized in previous training affects the depth of chest compression during metronome-guided cardiopulmonary resuscitation.

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Title: The rate of chest compression familiarized in previous training affects the depth of chest compression during metronome-guided cardiopulmonary resuscitation.

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Keywords: Cardiopulmonary Resuscitation; Prognosis; Education.

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ABSTRACT

Objectives: To assess how the quality of metronome-guided cardiopulmonary resuscitation (CPR) was affected by the chest compression rate familiarized by training before the performance and to determine a possible mechanism for any effect shown.

Design: Prospective, cross-over trial of simulated, one-person, chest-compression-only CPR.

Setting: Participants were recruited from a medical school and two paramedic schools of South Korea.

Participants: 42 senior students of a medical school and two paramedic schools participated and five were dropped.

Intervention: senior medical and paramedic student performed 1 min of metronome-guided cardiopulmonary resuscitation (CPR) with chest compressions only at a speed of 120 compressions/min after training for chest compression with three different rates (100, 120, and 140 compressions/min). Friedman's test was used to compare average compression depths based on the different rates used during training.

Results: Average compression depths were significantly different according to the rate used in training ($p < 0.001$). A post hoc analysis showed that average compression depths were significantly different between trials after training at a speed of 100 compressions/min and those at speeds of 120 and 140 compressions/min (both $p < 0.001$).

Conclusion: The depth of chest compression during metronome-guided CPR is affected by the relative difference between the rate of metronome guidance and the chest compression rate practiced in previous training.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- This is the first study to assess directly how the rate of chest compression used in previous training affects the quality of metronome-guided CPR.
- Our study suggests the necessity for considering the training status of rescuers regarding chest compression rate before planning metronome-guided CPR.
- Our results provides a clue to explain the discordance in the results of prior research assessing the effect of the rate of guiding sound on the quality of metronome-guided CPR
- Our results were derived from a simulated trial of chest compression only CPR, which may not represent whole feature of real clinical setting.

INTRODUCTION

Results of recent clinical studies which showed a significant relationship between chest compression rate and survival after out-of-hospital cardiac arrest suggested the necessity for keeping the rate of chest compressions between 100 and 120 /min.[1 2] Metronome-guidance may be a good assistance to keep chest compression rate at this relatively narrow range of target, considering the prior evidences which showed its efficacy in keeping chest compression rate without compromising other quality components of cardiopulmonary resuscitation (CPR).[3-5]

Performance of chest compression following metronome-guidance at a certain rate may be a slow-down of chest compression for a rescuer who is familiarized with faster chest compression by training, while it may be a speedup of chest compression for a rescuer who is familiarized with slower chest compression. Limitation of chest compression speed may limit its depth, considering the linear

correlation of chest compression rate and depth shown in a prior study performed in an experimental condition which the effect of rescuer-fatigue could relatively be excluded.[6] However, any of the prior studies did not specifically assess how a baseline training status regarding chest compression rate affects the quality of metronome-guided CPR. We hypothesized that induction of chest compression at a certain rate during metronome-guided CPR would decrease its depth if a rescuer was familiarized with faster chest compression in previous training, while it would increase the depth if he (or she) was familiarized with slower chest compression. To test the hypothesis, we aimed to assess how the quality of metronome-guided CPR was affected by the change of chest compression rate used in training. We also aimed to determine a possible mechanism for any such difference regarding critical quality factors such as the depth of chest compression.

METHODS

This study was performed under the approval of the CHA University Bundang Medical Center Institutional Review Board. This was a prospective, cross-over trial of simulated, one-person, chest-compression-only CPR.

We enrolled senior students of a medical school and two paramedic schools who, within the previous year, had finished two sessions of regular CPR training courses based on the American Heart Association (AHA) Basic Life Support course according to the 2010 AHA guidelines for CPR and emergency cardiovascular care.[7] Informed consent was obtained from every participant.

A ResusciAnne® manikin with a PC skill-reporting system (Laerdal, Stavanger, Norway) was used to measure and record CPR data. Chest compression guiding sounds at speeds of 100, 120, and 140 compressions/min were synthesized using Reason® audio synthesis software (Propellerhead, Stockholm, Sweden).

The experimental procedure consisted of three trials with two phases: a training phase for the participants to become accustomed to a certain chest compression rate, and a measuring phase to measure the quality of chest compressions while performing CPR following metronome guidance at a conventional rate of chest compression (120/min). The participants practiced chest compression-only CPR following the metronome-guided sound at a rate randomly selected from 100, 120, or 140 compressions/min for 2 hours as a training phase. The rate of chest compression without metronome guidance was measured for 1 min shortly after the practice. After 1 hour of rest, the participants performed chest compression-only CPR for 1 min following the metronome-guided sound at a rate of 120 compressions/min, and their quality was measured. This was the first trial. As the training phase for the second trial, the participants again performed chest compression-only CPR following the metronome-guided sound at a rate randomly selected between the two not selected in the first trial. Then, the rest of the trial was repeated. For the third trial, a training phase was performed using the guiding sound at the rate unselected in the prior two trials. The duration of the interval between each trial was guaranteed to be least 2 days to prevent a possible interaction of different chest compression rates practiced in each training phase (Fig 1).

The sex, age, body weight, and height of the participants were collected. Average compression depth (ACD, mm), average compression rate (ACR, counts/min), duty cycle (%), and the fractions of chest compressions with incomplete release and incorrect hand position (%) were measured and recorded during the measuring phase of the procedure using the PC skill-reporting system.

The data following a normal distribution were described as mean ± standard deviation, and non-parametric data were described as median (interquartile range). A repeated measures analysis of variance was conducted to compare normally distributed variables, and a paired t-test with a Bonferroni correction was performed as a post hoc test. A Friedman test was used to compare non-normally distributed variables, and a Wilcoxon signed rank test with Bonferroni correction was performed as a post hoc test. Statistical significance was set at $p < 0.05$. A sample size of 32 was required to detect a 25% difference in the ACDs at a power of 0.80. Microsoft® Office Excel 2010 (Redmond, WA, USA) was used to record and analyse data, and IBM® SPSS® Statistics 21.0 (IBM Corp., Armonk, NY, USA) was used for statistical calculations. R 3.1.3 (R-project, http://www.r-project.org) was used to build a parallel-coordinates plot and a box plot of the between-group

difference for visualizing the results of Friedman's test. G*Power 3.1 (Heinlich-Heine Universität, Düsseldorf, Germany) was used to calculate the sample size.[8]

RESULTS

A total of 42 senior medical and paramedic students participated in the study. Five participants dropped out during the performance due to physical restraint, so data from 37 students were included in the analysis. The baseline data of the participants are summarized in Table 1.

Table 1. Characteristics of the participants

Age (year)		26 (24-28)
Sex (count, %)	Male	19, 51.4
	Female	18, 41.6
Background (count, %)	Medical	26, 70.3
	Paramedic	11, 29.7
Weight (Kg)		59.4 ± 11.6
Height (cm)		168.0 ± 7.7

Age was described median (interquartile range). Weight and height were described as mean ± standard deviation.

There was a significant difference of ACD in the measuring phase according to the rate of chest compression used in a training phase which was 100, 120, or 140/min [ACD = 55.0 (50.0-60.0), 53.0

(45.5-57.5), and 51.0 (43.5-59.0), mm, respectively] ($p < 0.001$). Post hoc analysis revealed the differences between the trials with a rate of 100/min used in a training phase (t100) and those with a rate of 120/min (t120) ($p< 0.001$), and between t100 and those with a rate of 140/min (t140) ($p = 0.001$). There was no significant difference between t120 and t140 ($p = 0.517$) (Fig 2).

There was also a significant difference of duty cycle among t100, t120, and t140 [duty cycle = 37.0 (33.5-39.0), 40.0 (37.0-43.5), and 40.0 (38.0-42.5), %, respectively] ($p < 0.001$). Post hoc analysis revealed differences between t100 and t120 ($p<0.001$) and between t100 and t140 ($p < 0.001$). There was no significant difference between t120 and t140 ($p = 0.801$) (Fig 3).

The rate of chest compression measured shortly after the training phase was significantly different according to the rate of metronome guidance used (rate = 96.9±8.3, 125.7 ± 9.6, and 142.4 ± 7.4 compressions/min, respectively) ($p < 0.001$), with significant post-hoc test results ($p < 0.001$ for all comparisons). There was not any significant difference of the ratio of incomplete release or improper hand position in the measuring phase according to the rate used in the training phase (both $p = 0.232$ and 0.368).

DISCUSSION

This is the first study to assess directly how the rate of chest compression used in previous training affects the quality of metronome-guided CPR. Our results suggest that the relative difference in the rate of chest compression familiarized in practice affects the depth of chest compression when CPR is performed following metronome guidance at a certain rate.

We observed a significant difference of ACD in the measuring phase according to the rate practiced in the training phase and showed that the depth of chest compression, which is one of the most important quality factors of CPR, can differ based on the rate of chest compression trained in practice,

even under the guidance of identical metronome sound. Moreover, the results of our post hoc analysis showed that deeper chest compression was induced when the rate of metronome-guided sound was faster than in practice. This finding, which is that limitation of chest compression speed at a rate equal to or below than that familiarized by training may limit its depth, supports our hypothesis, and suggests that the consideration for training status of rescuers regarding chest compression rate is quite necessary before planning metronome-guided CPR. This may also provide a clue to explain the discordance in the results of prior research assessing the effect of the rate of guiding sound on the quality of metronome-guided CPR.[6 9 10] Difference in the trained status of the studied population regarding the practiced rate of chest compression may be a cause of the discordance, because any of those researches did not consider it.

The duty cycle in the measuring phase was significantly shorter when the rate of chest compression in the training phase was slower than the rate of metronome guidance in the measuring phase. This trend regarding duty cycle is similar to those regarding ACD, suggesting that the difference of chest compression depth according to the pre-trained rate, shown in our experiment, might be related with duty cycle of chest compression. We think that limitation of chest compression rate comparing with that in practice causes a longer duty cycle, resulting in a lower depth, based on a prior study that showed an inverse correlation of compression fraction and chest compression depth.[11] This effect of the training status regarding the rate of chest compression on its depth may be more critical if CPR is performed by a female or light-weight rescuer, considering the results of another study.[12]

The results of our analysis of chest compression rates measured just after the training phase showed that our experimental intervention to make the participants accustomed to a certain rate of chest compression worked successfully. Additionally, the results regarding the ratios of incomplete release or improper hand position showed that alteration of the rate of chest compression in training phase did not affect the error rate of chest compression performance. These results confirmed that our experiment was performed as intended.

According to our results, deeper chest compression is induced during metronome-guided CPR if the rate of metronome-guidance is faster than in practice. This may be interpreted as that the slower rate of chest compression than that recommended in CPR guidelines during practice, would be better to

acquire higher chest compression depth in the real practice of metronome-guided CPR, which is expected to use the rate recommended in the guidelines. However, great caution is necessary to translate our results in this manner, because our experiment was only designed to assess how the baseline training status of the participants regarding chest compression rate affects the quality of metronome-guided CPR. Rather, the results would better be understood as that metronome-guided CPR without any consideration for trained chest compression rate of rescuers can be useless according to circumstances.

Our study had a few limitations. First, our results were based on data measured from simulated chest compression-only CPR. Hence, great caution is needed before implementing our results in clinical settings. Second, our study was designed as a crossover trial. Subsequently, there could be an interaction caused by the different rate of chest compression trained in each trial. However, we tried to overcome this limitation by placing enough intervals (more than 2 days) between each trial and full randomization of the sequence of the trials. Moreover, we performed the analysis of chest compression rate data measured just after the training phase without metronome-guidance to rule out the possibility of that interaction.

CONCLUSION

The depth of chest compression during metronome-guided CPR is affected by the relative difference between the rate of metronome guidance and chest compression rate practiced in training. Limiting chest compression rate equal to or below than that familiarized in training may lower chest compression depth during metronome-guided CPR.

CONFLICT OF INTERESTS

The authors have no commercial associations or sources of support that might pose a conflict of interest.

Contributor statement

All three authors have made substantial contributions to all of the following: (1) the conception and design of the study, or acquisition of data, or analysis and interpretation of data, (2) drafting the article or revising it critically for important intellectual content, (3) final approval of the version to be submitted. In detail: JB – acquisition of data, analysis and interpretation of data, drafting of the manuscript, final approval given; TNC – conception, design, analysis and interpretation of data, drafting of the manuscript, final approval given; SMJ – acquisition of data, critical revision of manuscript, final approval given.

Data Sharing Statement

There is no unpublished data to be shared from current study.

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deeper chest compression during metronome-guided cardiopulmonary resuscitation: a manikin study. Emergency medicine journal : EMJ 2013;**30**(7):551-4.

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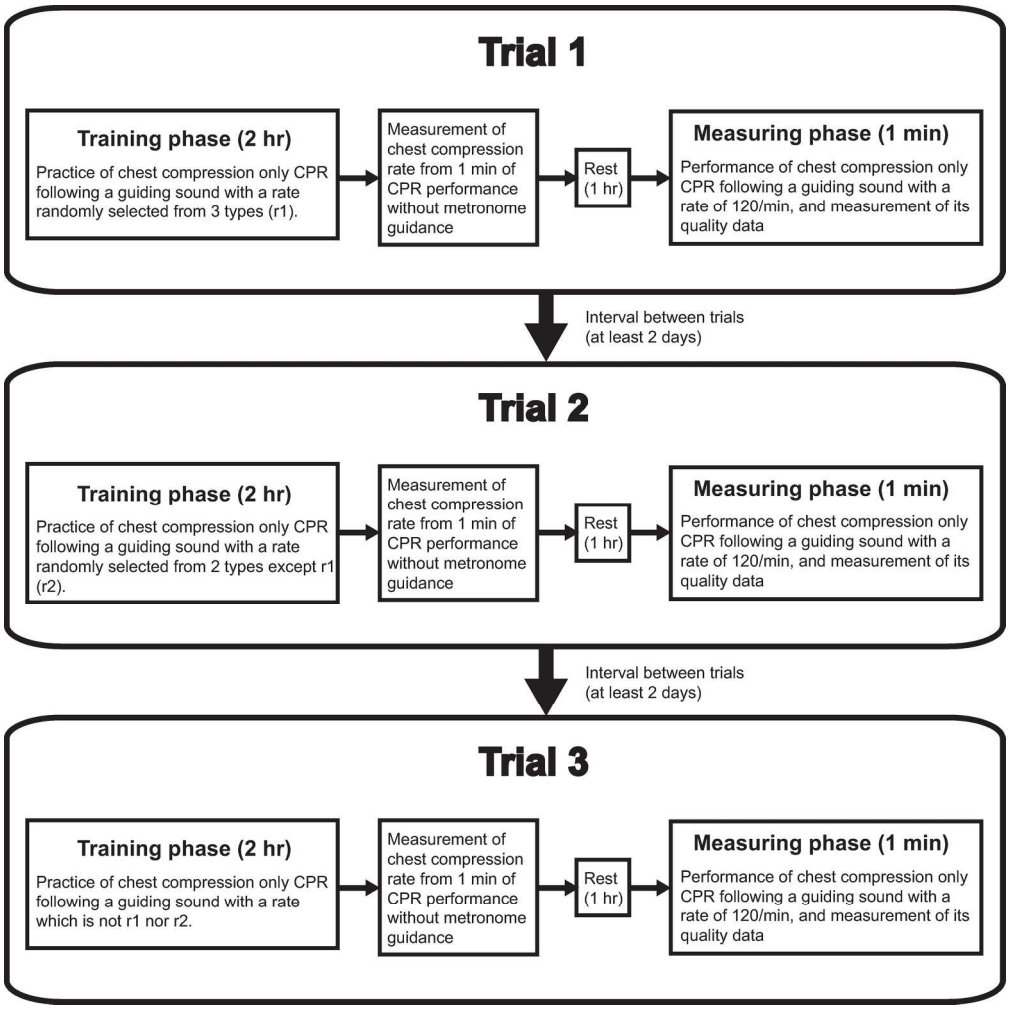
FIGURE LEGENDS

Figure 1 Flow diagram of the experimental procedure.

Figure 2 (A) Parallel coordinates plot of average compression depths according to the rate of chest compressions used in training. Red X symbol represents a median of average compression depths in each trial. P value was calculated from a Friedman test. t100: the trials with a rate of 100 compressions/min used in training, t120: the trials with a rate of 120 compressions/min used in training, t140: the trials with a rate of 140 compressions/min used in training. (B) Box plot of the between-group difference in average compression depths according to the rate of chest compressions used in training. P values were calculated from Wilcoxon signed rank tests. Significant level of p value was adjusted to below 0.017 after Bonferroni correction.

Figure 3 (A) Parallel coordinates plot of duty cycles according to the rate of chest compressions used in training. Red X symbol represents a median of duty cycles in each trial. P value was calculated from a Friedman test. t100: the trials with a rate of 100 compressions/min used in training, t120: the trials with a rate of 120 compressions/min used in training, t140: the trials with a rate of 140

compressions/min used in training. (B) Box plot of the between-group difference in duty cycles according to the rate of chest compressions used in training. P values were calculated from Wilcoxon signed rank tests. Significant level of p value was adjusted to below 0.017 after Bonferroni correction.



Flow diagram of the experimental procedure.
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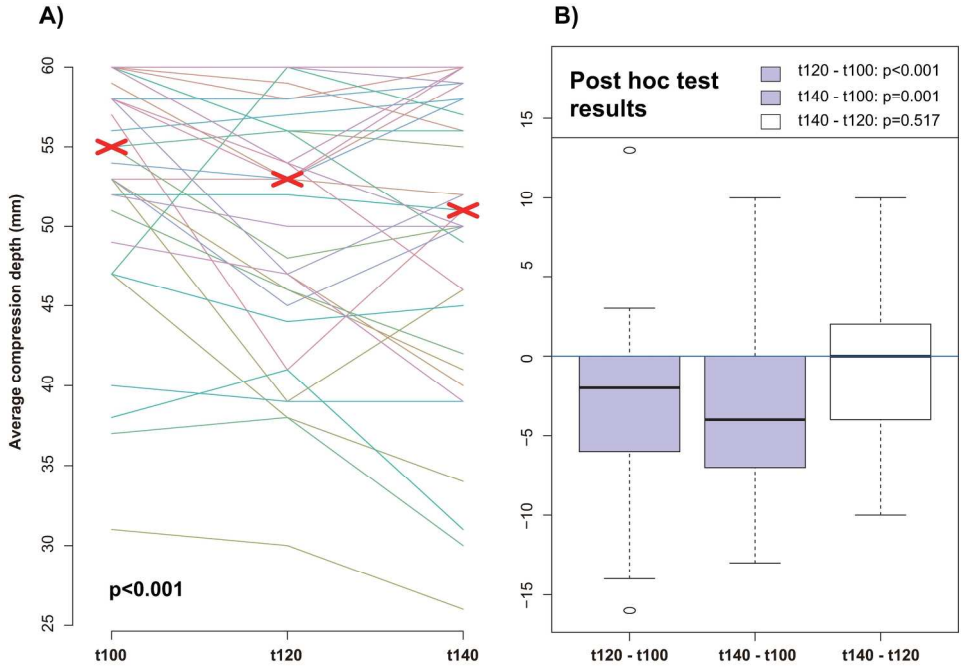

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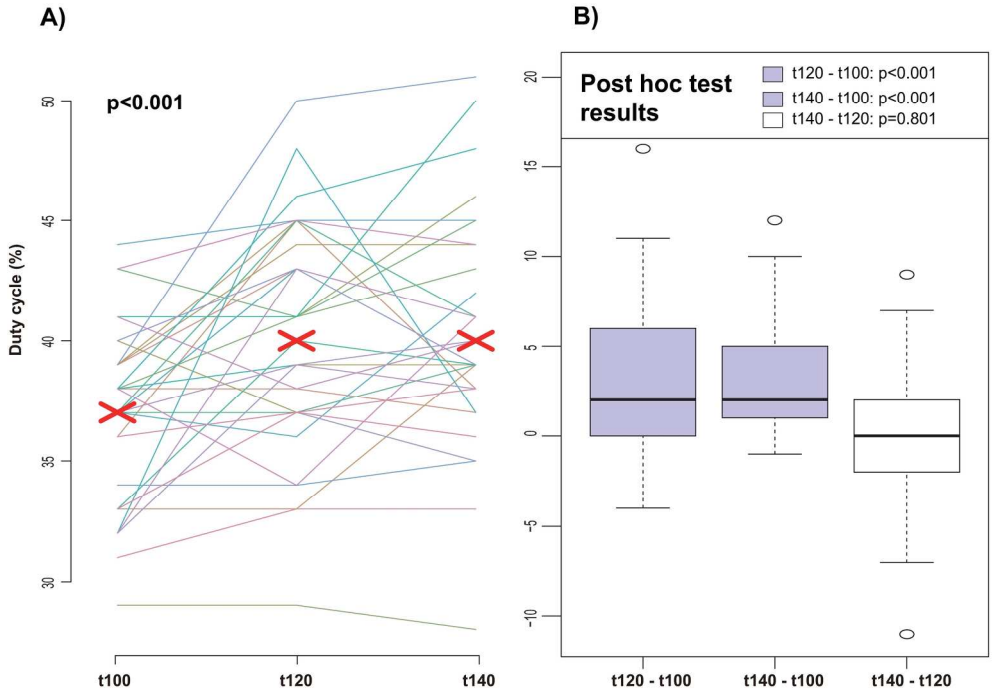

(A) Parallel coordinates plot of duty cycles according to the rate of chest compressions used in training. Red X symbol represents a median of duty cycles in each trial. P value was calculated from a Friedman test. t100: the trials with a rate of 100 compressions/min used in training, t120: the trials with a rate of 120 compressions/min used in training, t140: the trials with a rate of 140 compressions/min used in training. (B) Box plot of the between-group difference in duty cycles according to the rate of chest compressions used in training. P values were calculated from Wilcoxon signed rank tests. Significant level of p value was adjusted to below 0.017 after Bonferroni correction.
207x142mm (300 x 300 DPI)

TREND Statement Checklist

Paper Section/ Topic	Item No	Descriptor	Reported? ✓	Reported? Pg #
Title and Abstract				
Title and Abstract	1	• Information on how unit were allocated to interventions	√	2
		• Structured abstract recommended	√	2
		• Information on target population or study sample	√	2
Introduction				
Background	2	• Scientific background and explanation of rationale	√	3
		• Theories used in designing behavioral interventions	√	3
Methods				
Participants	3	• Eligibility criteria for participants, including criteria at different levels in recruitment/sampling plan (e.g., cities, clinics, subjects)	√	4
		• Method of recruitment (e.g., referral, self-selection), including the sampling method if a systematic sampling plan was implemented	√	4
		• Recruitment setting	√	4
		• Settings and locations where the data were collected	√	4
Interventions	4	• Details of the interventions intended for each study condition and how and when they were actually administered, specifically including:	√	4
		○ Content: what was given?	√	4
		○ Delivery method: how was the content given?	√	4
		○ Unit of delivery: how were the subjects grouped during delivery?	√	4
		○ Deliverer: who delivered the intervention?	√	4
		○ Setting: where was the intervention delivered?	√	4
		○ Exposure quantity and duration: how many sessions or episodes or events were intended to be delivered? How long were they intended to last?	√	4
		○ Time span: how long was it intended to take to deliver the intervention to each unit?	√	4
		○ Activities to increase compliance or adherence (e.g., incentives)	√	4
Objectives	5	• Specific objectives and hypotheses	√	3
Outcomes	6	• Clearly defined primary and secondary outcome measures	√	5
		• Methods used to collect data and any methods used to enhance the quality of measurements	√	5
		• Information on validated instruments such as psychometric and biometric properties	√	5
Sample Size	7	• How sample size was determined and, when applicable, explanation of any interim analyses and stopping rules	√	5
Assignment Method	8	• Unit of assignment (the unit being assigned to study condition, e.g., individual, group, community)	√	4
		• Method used to assign units to study conditions, including details of any restriction (e.g., blocking, stratification, minimization)		
		• Inclusion of aspects employed to help minimize potential bias induced due to non-randomization (e.g., matching)	√	4

TREND Statement Checklist

Blinding (masking)	9	• Whether or not participants, those administering the interventions, and those assessing the outcomes were blinded to study condition assignment; if so, statement regarding how the blinding was accomplished and how it was assessed.		
Unit of Analysis	10	• Description of the smallest unit that is being analyzed to assess intervention effects (e.g., individual, group, or community)	✓	5
		• If the unit of analysis differs from the unit of assignment, the analytical method used to account for this (e.g., adjusting the standard error estimates by the design effect or using multilevel analysis)		
Statistical Methods	11	• Statistical methods used to compare study groups for primary methods outcome(s), including complex methods of correlated data	✓	5
		• Statistical methods used for additional analyses, such as a subgroup analyses and adjusted analysis	✓	5
		• Methods for imputing missing data, if used		
		• Statistical software or programs used	✓	5
Results				
Participant flow	12	• Flow of participants through each stage of the study: enrollment, assignment, allocation, and intervention exposure, follow-up, analysis (a diagram is strongly recommended)	✓	5
		○ Enrollment: the numbers of participants screened for eligibility, found to be eligible or not eligible, declined to be enrolled, and enrolled in the study	✓	5
		○ Assignment: the numbers of participants assigned to a study condition	✓	5
		○ Allocation and intervention exposure: the number of participants assigned to each study condition and the number of participants who received each intervention	✓	5
		○ Follow-up: the number of participants who completed the follow-up or did not complete the follow-up (i.e., lost to follow-up), by study condition		
		○ Analysis: the number of participants included in or excluded from the main analysis, by study condition	✓	5
		• Description of protocol deviations from study as planned, along with reasons		
Recruitment	13	• Dates defining the periods of recruitment and follow-up		
Baseline Data	14	• Baseline demographic and clinical characteristics of participants in each study condition	✓	6
		• Baseline characteristics for each study condition relevant to specific disease prevention research		
		• Baseline comparisons of those lost to follow-up and those retained, overall and by study condition		
		• Comparison between study population at baseline and target population of interest		
Baseline equivalence	15	• Data on study group equivalence at baseline and statistical methods used to control for baseline differences	✓	6

TREND Statement Checklist

Numbers analyzed	16	• Number of participants (denominator) included in each analysis for each study condition, particularly when the denominators change for different outcomes; statement of the results in absolute numbers when feasible	√	5
		• Indication of whether the analysis strategy was "intention to treat" or, if not, description of how non-compliers were treated in the analyses		
Outcomes and estimation	17	• For each primary and secondary outcome, a summary of results for each estimation study condition, and the estimated effect size and a confidence interval to indicate the precision	√	6
		• Inclusion of null and negative findings	√	6
		• Inclusion of results from testing pre-specified causal pathways through which the intervention was intended to operate, if any		
Ancillary analyses	18	• Summary of other analyses performed, including subgroup or restricted analyses, indicating which are pre-specified or exploratory	√	6
Adverse events	19	• Summary of all important adverse events or unintended effects in each study condition (including summary measures, effect size estimates, and confidence intervals)	√	6
DISCUSSION				
Interpretation	20	• Interpretation of the results, taking into account study hypotheses, sources of potential bias, imprecision of measures, multiplicative analyses, and other limitations or weaknesses of the study	√	7
		• Discussion of results taking into account the mechanism by which the intervention was intended to work (causal pathways) or alternative mechanisms or explanations	√	7
		• Discussion of the success of and barriers to implementing the intervention, fidelity of implementation	√	8
		• Discussion of research, programmatic, or policy implications	√	8
Generalizability	21	• Generalizability (external validity) of the trial findings, taking into account the study population, the characteristics of the intervention, length of follow-up, incentives, compliance rates, specific sites/settings involved in the study, and other contextual issues	√	8
Overall Evidence	22	• General interpretation of the results in the context of current evidence and current theory	√	9

From: Des Jarlais, D. C., Lyles, C., Crepaz, N., & the Trend Group (2004). Improving the reporting quality of nonrandomized evaluations of behavioral and public health interventions: The TREND statement. *American Journal of Public Health*, 94, 361-366. For more information, visit: http://www.cdc.gov/trendstatement/

BMJ Open

Effect of the rate of chest compression familiarized in previous training on the depth of chest compression during metronome-guided cardiopulmonary resuscitation: a randomized crossover trial.

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Objectives: To assess how the quality of metronome-guided cardiopulmonary resuscitation (CPR) was affected by the chest compression rate familiarized by training before the performance and to determine a possible mechanism for any effect shown.

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Intervention: Senior medical and paramedic student performed 1 min of metronome-guided cardiopulmonary resuscitation (CPR) with chest compressions only at a speed of 120 compressions/min after training for chest compression with three different rates (100, 120, and 140 compressions/min). Friedman's test was used to compare average compression depths based on the different rates used during training.

Results: Average compression depths were significantly different according to the rate used in training ($p < 0.001$). A post hoc analysis showed that average compression depths were significantly different between trials after training at a speed of 100 compressions/min and those at speeds of 120 and 140 compressions/min (both $p < 0.001$).

Conclusion: The depth of chest compression during metronome-guided CPR is affected by the relative difference between the rate of metronome guidance and the chest compression rate practiced in previous training.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- This is the first study to assess directly how the rate of chest compression used in previous training affects the quality of metronome-guided CPR.
- Our study suggests the necessity for considering the training status of rescuers regarding chest compression rate before planning metronome-guided CPR.
- Our results provide a clue to explain the discordance in the results of prior research assessing the effect of the rate of guiding sound on the quality of metronome-guided CPR
- Our results were derived from a simulated trial of chest compression only CPR, which may not represent all aspects of real clinical setting.

INTRODUCTION

Results of recent clinical studies which showed a significant relationship between chest compression rate and survival after out-of-hospital cardiac arrest suggested the necessity for keeping the rate of chest compressions between 100 and 120 /min.[1 2] Metronome-guidance may be a good assistance to keep chest compression rate at this relatively narrow target range, considering the prior evidences which showed its efficacy in keeping chest compression rate without compromising other quality components of cardiopulmonary resuscitation (CPR).[3-6]

Performance of chest compression following metronome-guidance at a certain rate may be a slow-down of chest compression for a rescuer who is familiarized with faster chest compression by training,

while it may be a speedup of chest compression for a rescuer who is familiarized with slower chest compression. Limitation of chest compression speed may limit its depth, considering the linear correlation of chest compression rate and depth shown in a prior study performed under an experimental condition which the effect of rescuer-fatigue could relatively be excluded.[7] However, none of the prior researches studying the usefulness of metronome for assisting CPR specifically assessed how a baseline training status regarding chest compression rate affected the quality of metronome-guided CPR. We hypothesized that induction of chest compression at a certain rate during metronome-guided CPR would decrease its depth if a rescuer was familiarized with faster chest compression in previous training, while it would increase the depth if he (or she) was familiarized with slower chest compression. To test the hypothesis, we aimed to assess how the quality of metronome-guided CPR was affected by the change of chest compression rate used in training. We also aimed to determine a possible mechanism for any such difference regarding critical quality factors such as the depth of chest compression.

METHODS

This study was performed under the approval of the CHA University Bundang Medical Center Institutional Review Board (IRB approval # BD2014-019, Feb 2 2014). This was a single-blinded, randomized, prospective, cross-over trial of simulated, one-person, chest-compression-only CPR.

The study was performed at CHA University Bundang Medical Center, Gyeonggi-Do, Korea, from Mar 2014 to Feb 2015. We enrolled senior students of a medical school (CHA University) and two paramedic schools (Seojeong College, and Eulji University) who, within the previous year, had finished two sessions of regular CPR training courses based on the American Heart Association (AHA)

Basic Life Support course according to the 2010 AHA guidelines for CPR and emergency cardiovascular care.[8] Any student who declined to participate in the study for any reason was excluded. Written informed consent was obtained from every participant.

A ResusciAnne® manikin with a PC skill-reporting system (Laerdal, Stavanger, Norway) was used to measure and record CPR data. Chest compression guiding sounds at speeds of 100, 120, and 140 compressions/min were synthesized using Reason® audio synthesis software (Propellerhead, Stockholm, Sweden).

The experimental procedure consisted of three trials with two phases: a training phase for the participants to become accustomed to a certain chest compression rate, and a measuring phase to measure the quality of chest compressions while performing CPR following metronome guidance at a conventional rate of chest compression (120/min). The participants practiced chest-compression-only CPR following the metronome-guided sound at a rate randomly selected from 100, 120, or 140 compressions/min for 2 hours as a training phase. Randomized selection of a rate was based on a random number table generated by Microsoft® Office Excel 2010 (Redmond, WA, USA). The rate and the depth of chest compression without metronome guidance were measured for 1 min shortly after the practice. After 1 hour of rest, the participants performed chest compression-only CPR for 1 min following the metronome-guided sound at a rate of 120 compressions/min, and their quality was measured. This was the first trial. As the training phase for the second trial, the participants again performed chest compression-only CPR following the metronome-guided sound at a rate randomly selected between the two not selected in the first trial. Then, the rest of the trial was repeated. For the third trial, a training phase was performed using the guiding sound at the rate unselected in the prior two trials. The duration of the interval between each trial was guaranteed to be least 2 days to prevent a possible interaction of different chest compression rates practiced in each training phase (Fig 1). Only one participant was included at a time in each trial. The rate of metronome guidance used in every trial was blinded to the participants.

The sex, age, body weight, and height of the participants were collected. Average compression depth (ACD, mm), average compression rate (ACR, counts/min), duty cycle (%), and the fractions of chest compressions with incomplete release and incorrect hand position (%) were measured and

recorded during the measuring phase of the procedure using the PC skill-reporting system.

The data following a normal distribution were described as mean ± standard deviation, and non-parametric data were described as median (interquartile range). A repeated measures analysis of variance (ANOVA) was conducted to compare normally distributed variables, and a paired t-test with a Bonferroni correction was performed as a post hoc test. A Friedman test was used to compare non-normally distributed variables, and a Wilcoxon signed rank test with Bonferroni correction was performed as a post hoc test. Statistical significance was set at $p < 0.05$, which was calculated from two-sided test, if applicable. A sample size of 32 was required to have sufficient power to detect a significant difference in the ACD of each trial using repeated measure ANOVA (effect size f=0.25, power=0.80). Microsoft® Office Excel 2010 was used to record and analyse data, and IBM® SPSS® Statistics 21.0 (IBM Corp., Armonk, NY, USA) was used for statistical calculations. R 3.1.3 (R-project, http://www.r-project.org) was used to build a parallel-coordinates plot and a box plot of the between-group difference for visualizing the results of Friedman's test. G*Power 3.1 (Heinlich-Heine Universität, Düsseldorf, Germany) was used to calculate the sample size.[9]

RESULTS

A total of 42 senior medical and paramedic students enrolled in the study. Five participants dropped out during the performance due to physical restraint in training phase, so data from 37 students were included in the analysis. The baseline data of the participants are summarized in Table 1.

Table 1. Characteristics of the participants

Age (year)		26 (24-28)
Sex (count, %)	Male	19, 51.4
	Female	18, 41.6
Background (count, %)	Medical	26, 70.3
	Paramedic	11, 29.7
Weight (Kg)		59.4 ± 11.6
Height (cm)		168.0 ± 7.7

Age was described median (interquartile range). Weight and height were described as mean ± standard deviation.

There was a significant difference of ACD in the measuring phase according to the rate of chest compression used in a training phase which was 100, 120, or 140/min [ACD = 55.0 (50.0-60.0), 53.0 (45.5-57.5), and 51.0 (43.5-59.0), mm, respectively] ($p < 0.001$) (Fig 2a). Post hoc analysis revealed the differences between the trials with a rate of 100/min used in a training phase (t100) and those with a rate of 120/min (t120) ($p< 0.001$), and between t100 and those with a rate of 140/min (t140) ($p = 0.001$). There was no significant difference between t120 and t140 ($p = 0.517$) (Fig 2b).

There was also a significant difference of duty cycle among t100, t120, and t140 [duty cycle = 37.0 (33.5-39.0), 40.0 (37.0-43.5), and 40.0 (38.0-42.5), %, respectively] ($p < 0.001$) (Fig 3a). Post hoc analysis revealed differences between t100 and t120 ($p<0.001$) and between t100 and t140 ($p < 0.001$). There was no significant difference between t120 and t140 ($p = 0.801$) (Fig 3b).

The rate of chest compression measured shortly after the training phase was significantly different according to the rate of metronome guidance used (rate = 96.9±8.3, 125.7 ± 9.6, and 142.4 ± 7.4 compressions/min, respectively) ($p < 0.001$), with significant post-hoc test results ($p < 0.001$ for all comparisons), while there was no significant difference in the depth [ACD = 55.0 (49.5-59.0), 55.0 (43.5-59.0), and 53.0 (43.5-59.0), mm, respectively] ($p = 0.063$). There was not any significant difference of the ratio of incomplete release or improper hand position in the measuring phase according to the rate used in the training phase (both $p = 0.232$ and 0.368).

DISCUSSION

This is the first study to assess directly how the rate of chest compression used in previous training affects the quality of metronome-guided CPR. Our results suggest that the relative difference in the rate of chest compression familiarized in practice affects the depth of chest compression when CPR is performed following metronome guidance at a certain rate.

We observed a significant difference of ACD in the measuring phase according to the rate practiced in the training phase and showed that the depth of chest compression, which is one of the most important quality factors of CPR, can differ based on the rate of chest compression trained in practice, even under the guidance of identical metronome sound. Moreover, the results of our post hoc analysis showed that deeper chest compression was induced when the rate of metronome-guided sound was faster than in training phase. This finding, which is that limitation of chest compression speed at a rate equal to or below that familiarized by training may limit its depth, supports our hypothesis, and suggests that the consideration for training status of rescuers regarding chest compression rate is quite necessary before planning metronome-guided CPR. This may also provide a clue to explain the discordance in the results of prior research assessing the effect of the rate of guiding sound on the quality of metronome-guided CPR.[7 10 11] Difference in the trained status of the studied population regarding the practiced rate of chest compression may be a cause of the discordance, because none of those researches had considered it.

The duty cycle in the measuring phase was significantly shorter when the rate of chest compression in the training phase was slower than the rate of metronome guidance in the measuring phase. This trend regarding duty cycle is similar but in opposite direction to those regarding ACD, suggesting that

the difference of chest compression depth according to the pre-trained rate, shown in our experiment, might be related with duty cycle of chest compression. We think that limitation of chest compression speed also causes a longer duty cycle, resulting in a lower depth, based on a prior study that showed an inverse correlation of compression fraction and chest compression depth.[12] This effect of the training status regarding the rate of chest compression on the depth may be more critical if CPR is performed by a female or light-weight rescuer, considering the results of another study which showed that the inverse correlation of duty cycle and ACD was more prominent in those groups.[13]

The results of our analysis of chest compression rates measured just after the training phase showed that our experimental intervention to make the participants accustomed to a certain rate of chest compression worked successfully. Additionally, the results regarding the ratios of incomplete release or improper hand position showed that alteration of the rate of chest compression in training phase did not affect the error rate of chest compression performance in measuring phase. These results confirmed that our experiment was performed as intended.

According to our results, deeper chest compression is induced during metronome-guided CPR if the rate of metronome-guidance is faster than in practice. This may be interpreted as that the use of slower chest compression rate in training, even than that recommended in the guidelines for CPR, is better to acquire higher chest compression depth in the real practice of metronome-guided CPR, which is expected to use the rate recommended in the guidelines. However, great caution is necessary to translate our results in this manner, because our experiment was only designed to assess how the baseline training status of the participants regarding chest compression rate affects the quality of metronome-guided CPR. Rather, the results would better be understood as that metronome-guided CPR without any consideration for trained chest compression rate of rescuers can be useless according to circumstances.

Our study had a few limitations. First, our results were based on data measured from simulated chest compression-only CPR. Furthermore, we adopted some experimental conditions which might be different from real practice. Hence, great caution is needed before implementing our results in clinical settings. Second, our study was designed as a crossover trial. Subsequently, there could be an interaction caused by the different rate of chest compression trained in each trial. However, we

tried to overcome this limitation by placing enough intervals (more than 2 days) between each trial and full randomization of the sequence of the trials. Moreover, we performed the analysis of chest compression rate data measured just after the training phase without metronome-guidance to rule out the possibility of that interaction. Third, we did not consider the rate of chest compression used in previous CPR training courses which were requisite for enrollment to the study. Intervals between those courses and the study performances were not considered either, which might be different from each other. These facts could cause bias of the results. However, the effects were thought to be minimal, if there had been any, considering the result from the comparison of chest compression quality data acquired shortly after the training phase. Furthermore, this was an important reason why we chose crossover design, which makes baseline conditions other than intended intervention equal for each comparing group.

CONCLUSION

The depth of chest compression during metronome-guided CPR is affected by the relative difference between the rate of metronome guidance and chest compression rate practiced in training. Limiting chest compression rate equal to or below that familiarized in training may lower chest compression depth during metronome-guided CPR.

CONFLICT OF INTERESTS

The authors have no commercial associations or sources of support that might pose a conflict of interest.

Contributor statement

All three authors have made substantial contributions to all of the following: (1) the conception and design of the study, or acquisition of data, or analysis and interpretation of data, (2) drafting the article or revising it critically for important intellectual content, (3) final approval of the version to be submitted. In detail: JB – acquisition of data, analysis and interpretation of data, drafting of the manuscript, final approval given; TNC – conception, design, analysis and interpretation of data, drafting of the manuscript, final approval given; SMJ – acquisition of data, critical revision of manuscript, final approval given.

Data sharing

There is no unpublished data to be shared from the current study.

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FIGURE LEGENDS

Figure 1 Flow diagram of the experimental procedure.

Figure 2 (A) Parallel coordinates plot of average compression depths according to the rate of chest compressions used in training. Red X symbol represents a median of average compression depths in each trial. P value was calculated from a Friedman test. t100: the trials with a rate of 100 compressions/min used in training, t120: the trials with a rate of 120 compressions/min used in training, t140: the trials with a rate of 140 compressions/min used in training. (B) Box plot of the between-group difference in average compression depths according to the rate of chest compressions used in training. P values were calculated from Wilcoxon signed rank tests. Significant level of p value was adjusted to below 0.017 after Bonferroni correction.

Figure 3 (A) Parallel coordinates plot of duty cycles according to the rate of chest compressions

used in training. Red X symbol represents a median of duty cycles in each trial. P value was calculated from a Friedman test. t100: the trials with a rate of 100 compressions/min used in training, t120: the trials with a rate of 120 compressions/min used in training, t140: the trials with a rate of 140 compressions/min used in training. (B) Box plot of the between-group difference in duty cycles according to the rate of chest compressions used in training. P values were calculated from Wilcoxon signed rank tests. Significant level of p value was adjusted to below 0.017 after Bonferroni correction.

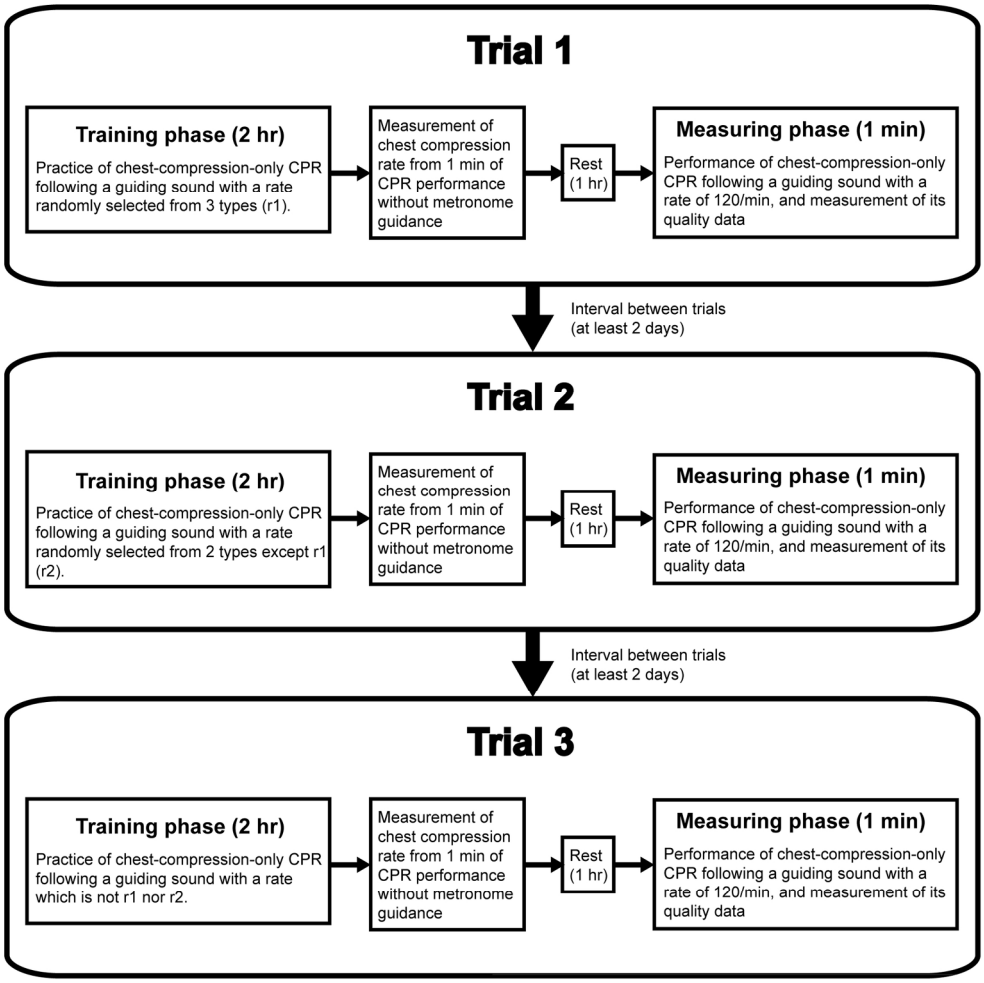

Figure 1. Flow diagram of the experimental procedure.
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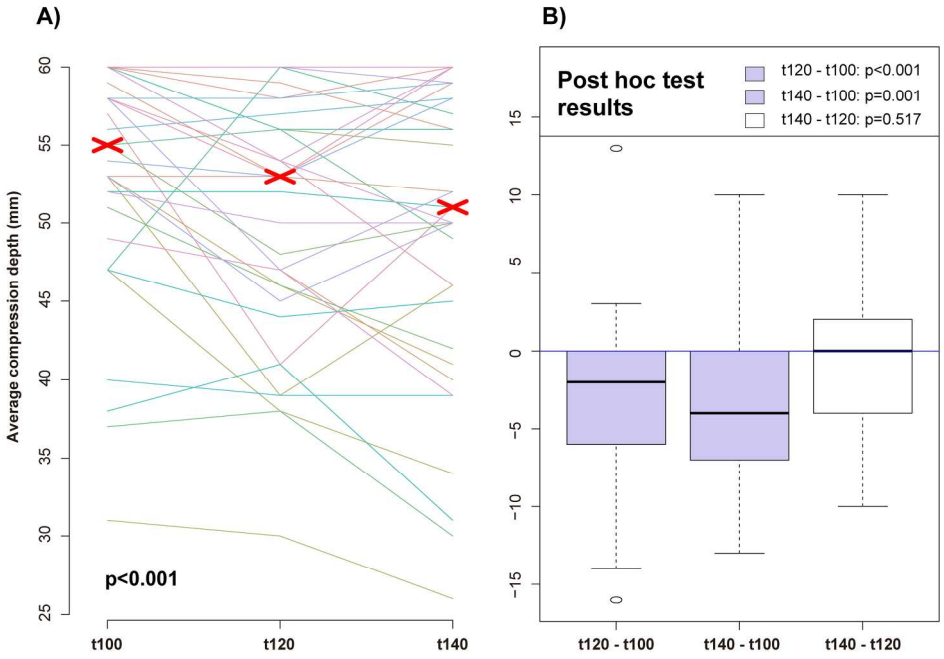

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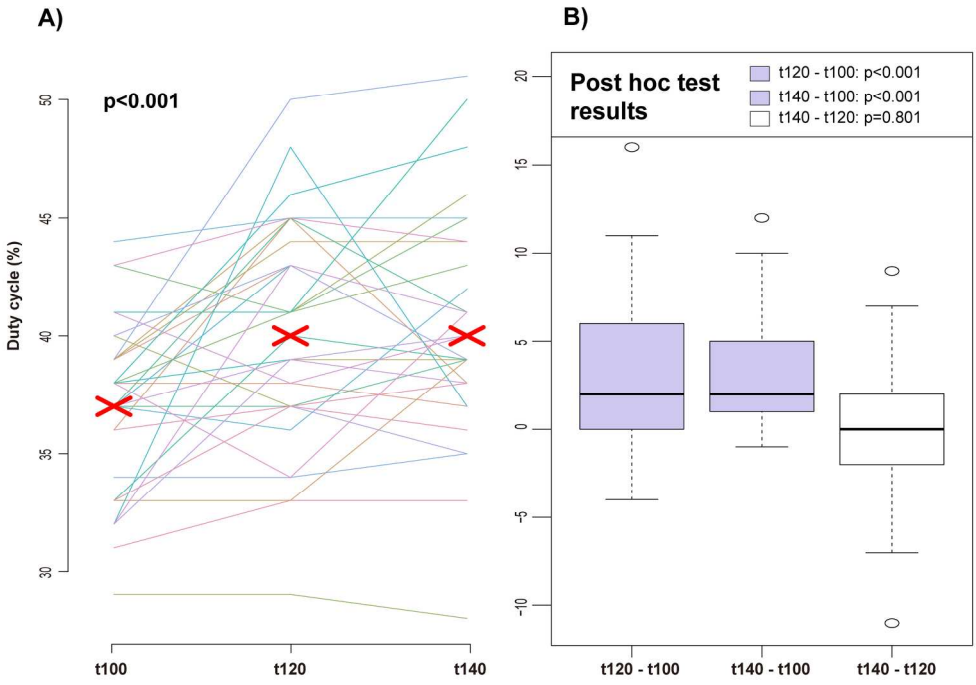

Figure 3. (A) Parallel coordinates plot of duty cycles according to the rate of chest compressions used in training. Red X symbol represents a median of duty cycles in each trial. P value was calculated from a Friedman test. t100: the trials with a rate of 100 compressions/min used in training, t120: the trials with a rate of 120 compressions/min used in training, t140: the trials with a rate of 140 compressions/min used in training. (B) Box plot of the between-group difference in duty cycles according to the rate of chest compressions used in training. P values were calculated from Wilcoxon signed rank tests. Significant level of p value was adjusted to below 0.017 after Bonferroni correction.
212x146mm (300 x 300 DPI)

TREND Statement Checklist

Paper Section/ Topic	Item No	Descriptor	Reported? ✓	Reported? Pg #
Title and Abstract				
Title and Abstract	1	• Information on how unit were allocated to interventions	✓	2
		• Structured abstract recommended	✓	2
		• Information on target population or study sample	✓	2
Introduction				
Background	2	• Scientific background and explanation of rationale	✓	3
		• Theories used in designing behavioral interventions	✓	3
Methods				
Participants	3	• Eligibility criteria for participants, including criteria at different levels in recruitment/sampling plan (e.g., cities, clinics, subjects)	✓	4
		• Method of recruitment (e.g., referral, self-selection), including the sampling method if a systematic sampling plan was implemented	✓	4
		• Recruitment setting	✓	4
		• Settings and locations where the data were collected	✓	4
Interventions	4	• Details of the interventions intended for each study condition and how and when they were actually administered, specifically including:	✓	4
		○ Content: what was given?	✓	4
		○ Delivery method: how was the content given?	✓	4
		○ Unit of delivery: how were the subjects grouped during delivery?	✓	4
		○ Deliverer: who delivered the intervention?	✓	4
		○ Setting: where was the intervention delivered?	✓	4
		○ Exposure quantity and duration: how many sessions or episodes or events were intended to be delivered? How long were they intended to last?	✓	4
		○ Time span: how long was it intended to take to deliver the intervention to each unit?	✓	4
		○ Activities to increase compliance or adherence (e.g., incentives)	✓	4
Objectives	5	• Specific objectives and hypotheses	✓	3
Outcomes	6	• Clearly defined primary and secondary outcome measures	✓	5
		• Methods used to collect data and any methods used to enhance the quality of measurements	✓	5
		• Information on validated instruments such as psychometric and biometric properties	✓	5
Sample Size	7	• How sample size was determined and, when applicable, explanation of any interim analyses and stopping rules	✓	5
Assignment Method	8	• Unit of assignment (the unit being assigned to study condition, e.g., individual, group, community)	✓	4
		• Method used to assign units to study conditions, including details of any restriction (e.g., blocking, stratification, minimization)		
		• Inclusion of aspects employed to help minimize potential bias induced due to non-randomization (e.g., matching)	✓	4

TREND Statement Checklist

Blinding (masking)	9	• Whether or not participants, those administering the interventions, and those assessing the outcomes were blinded to study condition assignment; if so, statement regarding how the blinding was accomplished and how it was assessed.		
Unit of Analysis	10	• Description of the smallest unit that is being analyzed to assess intervention effects (e.g., individual, group, or community)	✓	5
		• If the unit of analysis differs from the unit of assignment, the analytical method used to account for this (e.g., adjusting the standard error estimates by the design effect or using multilevel analysis)		
Statistical Methods	11	• Statistical methods used to compare study groups for primary methods outcome(s), including complex methods of correlated data	✓	5
		• Statistical methods used for additional analyses, such as a subgroup analyses and adjusted analysis	✓	5
		• Methods for imputing missing data, if used		
		• Statistical software or programs used	✓	5
Results				
Participant flow	12	• Flow of participants through each stage of the study: enrollment, assignment, allocation, and intervention exposure, follow-up, analysis (a diagram is strongly recommended)	✓	5
		○ Enrollment: the numbers of participants screened for eligibility, found to be eligible or not eligible, declined to be enrolled, and enrolled in the study	✓	5
		○ Assignment: the numbers of participants assigned to a study condition	✓	5
		○ Allocation and intervention exposure: the number of participants assigned to each study condition and the number of participants who received each intervention	✓	5
		○ Follow-up: the number of participants who completed the follow-up or did not complete the follow-up (i.e., lost to follow-up), by study condition		
		○ Analysis: the number of participants included in or excluded from the main analysis, by study condition	✓	5
		• Description of protocol deviations from study as planned, along with reasons		
Recruitment	13	• Dates defining the periods of recruitment and follow-up		
Baseline Data	14	• Baseline demographic and clinical characteristics of participants in each study condition	✓	6
		• Baseline characteristics for each study condition relevant to specific disease prevention research		
		• Baseline comparisons of those lost to follow-up and those retained, overall and by study condition		
		• Comparison between study population at baseline and target population of interest		
Baseline equivalence	15	• Data on study group equivalence at baseline and statistical methods used to control for baseline differences	✓	6

TREND Statement Checklist

Numbers analyzed	16	• Number of participants (denominator) included in each analysis for each study condition, particularly when the denominators change for different outcomes; statement of the results in absolute numbers when feasible	√	5
		• Indication of whether the analysis strategy was "intention to treat" or, if not, description of how non-compliers were treated in the analyses		
Outcomes and estimation	17	• For each primary and secondary outcome, a summary of results for each estimation study condition, and the estimated effect size and a confidence interval to indicate the precision	√	6
		• Inclusion of null and negative findings	√	6
		• Inclusion of results from testing pre-specified causal pathways through which the intervention was intended to operate, if any		
Ancillary analyses	18	• Summary of other analyses performed, including subgroup or restricted analyses, indicating which are pre-specified or exploratory	√	6
Adverse events	19	• Summary of all important adverse events or unintended effects in each study condition (including summary measures, effect size estimates, and confidence intervals)	√	6
DISCUSSION				
Interpretation	20	• Interpretation of the results, taking into account study hypotheses, sources of potential bias, imprecision of measures, multiplicative analyses, and other limitations or weaknesses of the study	√	7
		• Discussion of results taking into account the mechanism by which the intervention was intended to work (causal pathways) or alternative mechanisms or explanations	√	7
		• Discussion of the success of and barriers to implementing the intervention, fidelity of implementation	√	8
		• Discussion of research, programmatic, or policy implications	√	8
Generalizability	21	• Generalizability (external validity) of the trial findings, taking into account the study population, the characteristics of the intervention, length of follow-up, incentives, compliance rates, specific sites/settings involved in the study, and other contextual issues	√	8
Overall Evidence	22	• General interpretation of the results in the context of current evidence and current theory	√	9

From: Des Jarlais, D. C., Lyles, C., Crepaz, N., & the Trend Group (2004). Improving the reporting quality of nonrandomized evaluations of behavioral and public health interventions: The TREND statement. *American Journal of Public Health*, 94, 361-366. For more information, visit: http://www.cdc.gov/trendstatement/