Clinical Trial/Experimental Study

Medicine®

OPEN

Correlation between real-time heart rate and fatigue in chest compression providers during cardiopulmonary resuscitation

A simulation-based interventional study

Go Eun Bae, MD[a], Arom Choi, MD[a], Jin Ho Beom, MD, PhD[a], Min Joung Kim, MD, PhD[a], Hyun Soo Chung, MD, PhD[a], In Kyung Min, MS[b], Sung Phil Chung, MD, PhD[a], Ji Hoon Kim, MD, MPH[a,*]

Abstract

Background: The American Heart Association guidelines recommend switching chest compression providers at least every 2 min depending on their fatigue during cardiopulmonary resuscitation (CPR). Although the provider's heart rate is widely used as an objective indicator for detecting fatigue, the accuracy of this measure is debatable.

Objectives: This study was designed to determine whether real-time heart rate is a measure of fatigue in compression providers.

Study design: A simulation-based prospective interventional study including 110 participants.

Methods: Participants performed chest compressions in pairs for four cycles using advanced cardiovascular life support simulation. Each participant's heart rate was measured using wearable healthcare devices, and qualitative variables regarding individual compressions were obtained from computerized devices. The primary outcome was correct depth of chest compressions. The main exposure was the change in heart rate, defined as the difference between the participant's heart rate during individual compressions and that before the simulation was initiated.

Results: With a constant compression duration for one cycle, the overall accuracy of compression depth significantly decreased with increasing heart rate. Female participants displayed significantly decreased accuracy of compression depth with increasing heart rate (odds ratio [OR]: 0.97; 95% confidence interval [CI]: 0.95–0.98; $P < .001$). Conversely, male participants displayed significantly improved accuracy with increasing heart rate (OR: 1.03; 95% CI: 1.02–1.04; $P < .001$).

Conclusion: Increasing heart rate could reflect fatigue in providers performing chest compressions with a constant duration for one cycle. Thus, provider rotation should be considered according to objectively measured fatigue during CPR.

Abbreviations: ACLS = Advanced cardiovascular life support, AHA = American Heart Association, BMI = body mass index, CI = confidence interval, CPR = cardiopulmonary resuscitation, IPAQ = International physical activity questionnaire, IQR = interquartile range, OR = odds ratio, TDC = time-dependent covariates, VAS = visual analog scale.

Keywords: cardiopulmonary resuscitation, chest compression quality, provider's fatigue, wearable device

Editor: Johannes Mayr.

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

The authors have no conflicts of interest to disclose.

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

[a] Department of Emergency Medicine, [b] Department of Research Affairs, Biostatistics Collaboration Unit, Yonsei University College of Medicine, Seodaemun-gu, Seoul, South Korea.

[*] Correspondence: Ji Hoon Kim, Department of Emergency Medicine, Yonsei University College of Medicine, 50 Yonsei-ro, Seodaemun-gu, Seoul 03722, South Korea (e-mail: jichoon81@yuhs.ac).

Copyright © 2021 the Author(s). Published by Wolters Kluwer Health, Inc. This is an open access article distributed under the terms of the Creative Commons Attribution-Non Commercial License 4.0 (CCBY-NC), where it is permissible to download, share, remix, transform, and buildup the work provided it is properly cited. The work cannot be used commercially without permission from the journal.

How to cite this article: Bae GE, Choi A, Beom JH, Kim MJ, Chung HS, Min IK, Chung SP, Kim JH. Correlation between real-time heart rate and fatigue in chest compression providers during cardiopulmonary resuscitation: A simulation-based interventional study. Medicine 2021;100:16(e25425).

Received: 29 November 2020 / Received in final form: 21 February 2021 / Accepted: 26 February 2021

http://dx.doi.org/10.1097/MD.0000000000025425

1. Introduction

Providing high-quality chest compressions during cardiopulmonary resuscitation (CPR) is crucial for improving the outcomes of patients with cardiac arrest.[1,2] According to the guidelines of the American Heart Association (AHA), rescuers should switch every 2 min to prevent fatigue, or sooner if they become fatigued while performing advanced cardiovascular life support (ACLS).[1] However, it is difficult to measure fatigue quantitatively and incorporate this information into the rotation of providers.[3]

Up-to-date, various studies have attempted to measure fatigue in providers while performing CPR.[4–15] Some of these studies revealed associations of fatigue with CPR quality by measuring fatigue with subjective indicators, such as visual analog scale (VAS) scores[6,10–12]; however, subjective indicators can be unreliable in evaluating fatigue. Therefore, several studies have attempted to quantitatively measure a provider's fatigue using vital signs.[5,8,9,13–15] Among them, heart rate is widely used as an objective indicator of fatigue in providers performing CPR. Several studies have reported that changes in heart rate are associated with the quality of CPR.[13,14] In contrast, other studies have reported that heart rate did not reflect the provider's actual fatigue during CPR.[4,5,9] Notably, as these previous

studies were not designed to measure the heart rate of the providers in real-time, they were incapable of determining whether it could be used as a quantitative measure of fatigue.[4,5,9,13,14]

Recently, wearable devices that can measure a person's vital signs in real-time have become popular in clinical research.[16–18] Therefore, this study aimed to determine if real-time changes in the heart rate of providers wearing smart watches could reflect fatigue, and whether fatigue affects the quality of chest compressions in ACLS simulations.

2. Methods

2.1. Study design and participants

The present study was a prospective, simulation-based trial in which mannequins and wristband-type devices were used. Volunteer senior medical students from the Yonsei University College of Medicine were recruited between March 2019 and July 2019. The purpose of the study was explained to the participants, and written informed consent was obtained. A total of 110 medical students were included in this study after excluding students who did not wish to participate or who had physical problems that prevented them from performing CPR. This study was approved by the Yonsei University Institutional Review Board (approval number: 4–2018-1082) and was conducted in accordance with the Declaration of Helsinki. The study was conducted and findings reported based on established guidelines for simulation-based research.[19,20]

2.2. Study protocol

All participants had completed 2 weeks of clinical clerkship in emergency medicine. The curriculum included three lectures, one simulation session, and 10 h of practical training in the emergency department according to the 2015 AHA guidelines. The observations required for this study were performed every 2 weeks, on the last day of the clerkship. Before the simulations, the participants received 30 min of instructions on how to perform the simulation with the mannequin while wearing a wristband device. Subsequently, teams of two participants each performed the simulation one after the other in a separate room. The pairs were determined randomly with computer-generated random sequences. The scenario of the simulation was set up for two rescuers to perform ACLS when an intubated patient suffers cardiac arrest in the emergency department. They were asked to perform chest compressions on the mannequin for four cycles while switching every 2 min. During CPR, ventilation was performed by a researcher who did not participate in the study.

2.3. Data collection

Data on baseline characteristics, including age, sex, body mass index (BMI), International Physical Activity Questionnaire, and actual CPR experience, were collected before the simulations. Before and after the simulations, the participant's fatigue was assessed using VAS scores and blood pressure, as measured by a designated researcher. The participants wore a wristband healthcare device, Fitbit charge 2 (Fitbit, Inc, San Francisco, CA), during the simulation. This device can show the real-time heart rate of the wearer. Variables regarding the quality of chest compressions were collected through the data program of the CPR mannequin using Resusci Anne QCPR with SimPad Plus and Laerdal PC Skill Reporting System (Laerdal Medical, Stavanger, Norway). The device is designed to provide real-time measurements of the depth, recoil depth, and rate of individual chest compressions. We transferred the real-time data from both devices to an assigned laptop and simultaneously collected the participant's heart rate and indicators of chest compressions (Fig. 1).

2.4. Outcomes

The primary outcome of this study was the correct depth of chest compressions. Incorrect depth of compression was defined as a depth of >61 or <50 mm. The secondary outcome was the correct rate of chest compressions. Correct compression rate was defined as a rate of 100 to 120 compressions per minute. The main exposure was the change in the participant's heart rate. This variable was defined as the difference between the participant's heart rate during individual compressions and that before beginning the simulation.

2.5. Statistical analysis

Categorical variables are presented as counts and percentages, while continuous variables are presented as mean and standard deviation for normally distributed variables and as median and interquartile range for non-normally distributed variables. Statistical significance was set at $P < .05$. The data in the present study had a hierarchical structure because chest compressions were repeatedly measured during a cycle, and two consecutive cycles were observed for each participant. To account for within-cluster similarity, the generalized linear mixed effects model with random intercepts for cycle and subject was used.[21] Logit was used as a link function. Additionally, the baseline heart rate, baseline characteristics of the participants, and duration within one cycle were included in the model as fixed effects. The changes in the participants' heart rate were regarded as time-dependent covariates (TDCs). These covariates change in a given individual across the order of chest compressions and can also vary between participants.[22] Additionally, we were interested in the within-subject variations in TDCs. Therefore, the generalized linear mixed effects model with decomposition of TDCs was used. We focused on the association between the changes in each subject's heart rate and the quality of compressions. The analyses were performed using SAS v8.1 (SAS Institute Inc, Cary, NC).

3. Results

Of 118 eligible participants, eight refused to enroll in the study. The remaining 110 participants were divided into 55 teams. Three participants were excluded due to network issues with the devices, and one participant was excluded for physical reasons during the simulation (Fig. 2). All 47,764 chest compressions performed by the 106 participants were individually analyzed. The baseline characteristics of the participants are summarized in Table 1. The participants included 78 (73.58%) men and 28 (26.42%) women. The BMI and ratio of correct chest compressions among the male participants were significantly higher than those among the female participants (all $P < .01$). Table 2 summarizes the data regarding the association between the changes in heart rate and outcomes. Correct depth of compression tended to significantly decrease with increasing duration within one cycle (odds ratio [OR]: 0.977; 95%

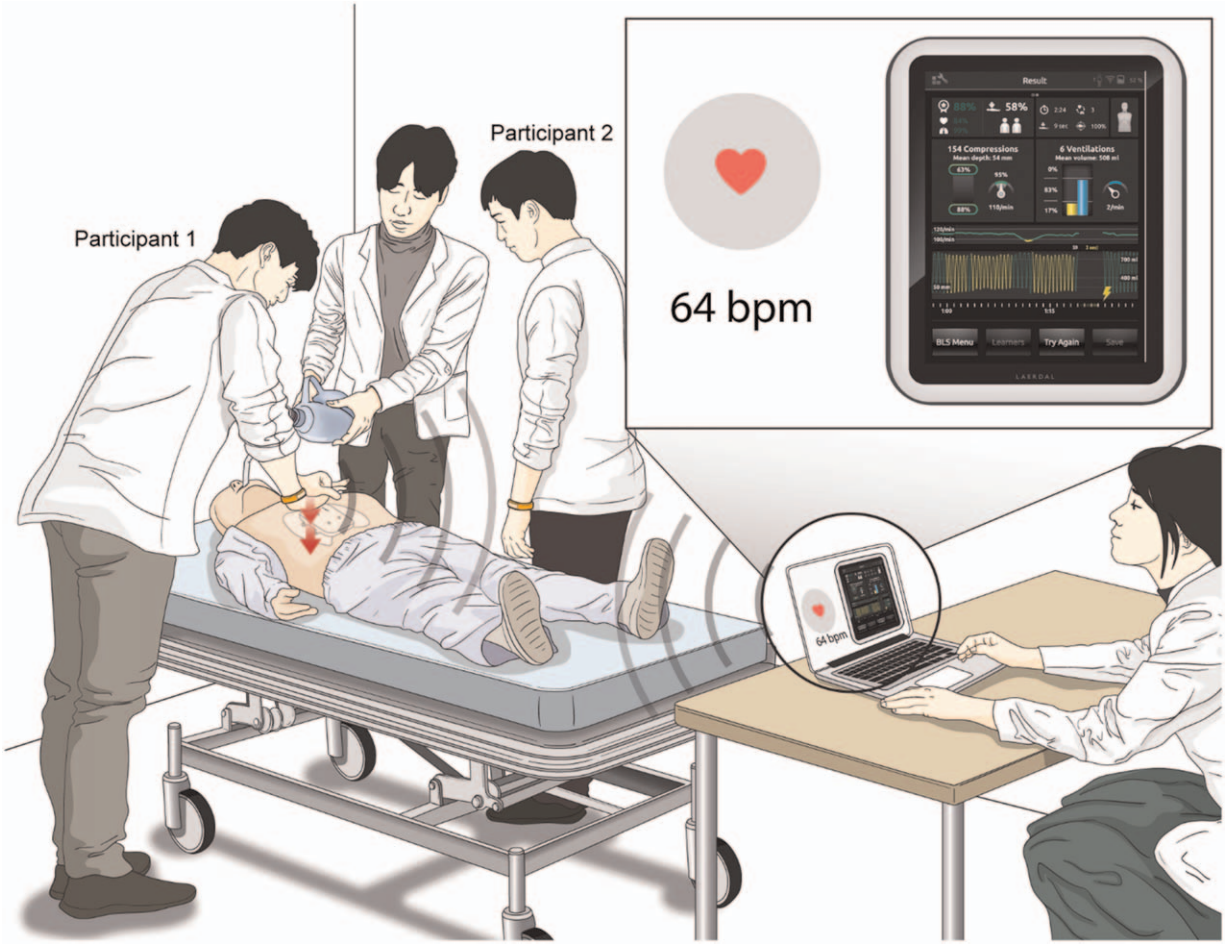

Figure 1. Schematic of the simulation for data collection.

confidence interval [CI]: 0.976–0.978; $P < .001$), while it significantly increased with increasing change in the heart rate (OR: 1.009; 95% CI: 1.004–1.014; $P < .001$). Furthermore, the accuracy of compression depth was significantly higher in male participants than in female participants (OR: 7.195; 95% CI: 1.069–48.405; $P < .043$). Correct compression rate tended to decrease significantly with increasing duration within one cycle (OR: 0.998; 95% CI: 0.997–0.998; $P < .001$) but did not have an association with the changes in the participants' heart rate (OR: 1.000; 95% CI: 0.996–1.004; $P < .96$).

The duration within one cycle and sex were confirmed to affect the correct depth of compressions in addition to the change in heart rate, which was the main exposure in our models; therefore, we performed subgroup analyses based on these factors. The results of the subgroup analyses on the duration within one cycle are summarized in Table 3. Furthermore, we divided the duration within one cycle into four sections and investigated the association between the correct compression depth and the change in heart rate in these sections. Unlike the results of the overall model, compression depth was statistically incorrect as the change in the heart rate increased in all the sections. Table 4 summarizes the findings of the subgroup analyses based on sex. Irrespective of sex, as the duration within one cycle increased, the participants were less likely to perform chest compressions within the correct depth (all $P < .001$). In male participants, as the changes in the heart rate increased, the adequacy of compression depth significantly increased (OR: 1.029; 95% CI: 1.022–1.036; $P < .001$). In contrast, in female participants, as the changes in the heart rate increased, the adequacy of compression depth significantly decreased (OR: 0.967; 95% CI: 0.954–0.980; $P < .001$).

4. Discussion

Interestingly, the overall statistical model of the present study demonstrated that the depth of chest compression tended to be appropriate when the provider's heart rate was higher than that at baseline. However, when a subgroup analysis was performed on the duration within one cycle, which is the effect modifier between the changes in the heart rate and correct compression depth, an increasing change in the heart rate and incorrect compression depth were found to be significantly correlated in all subgroups as opposed to the results of the overall model.

The provider's fatigue is expected to increase over time. The guidelines state that the criterion for the rotation of providers is based on the duration of chest compressions.[1,2] This is consistent with the current findings that the duration within one cycle strongly affected correct compression depth. Therefore,

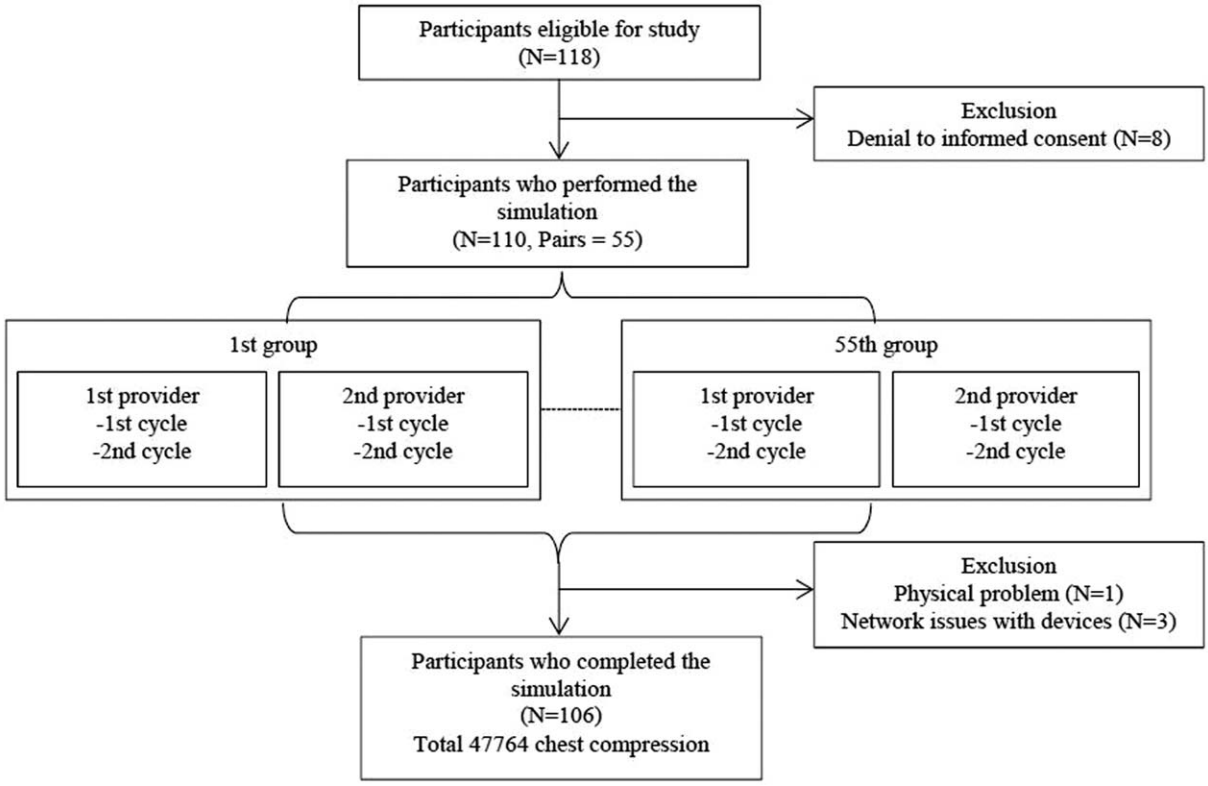

Figure 2. Participant flow chart.

we performed additional analyses by dividing the duration within one cycle into four sections to accurately determine the pure effects of changes in the heart rate on correct compression depth.[4,5,8,9,13,14] Consequently, the association between the exposure and primary outcome was reversed in both the overall model and the subgroup model. Furthermore, the subgroup analysis based on sex, which is another effect modifier between the exposure and the primary outcome, demonstrated that the direction of the association was different in males and females. Zhang et al reported that male providers can maintain chest compression depth more accurately than female providers,[12] while other studies have reported that providers in physically

Table 1

Baseline characteristics of the participants.

	Total (n = 106)	Female participants (n = 28)	Male participants (n = 78)	*P*
Age, years	25.00 (23.00, 26.00)	25.00 (24.00, 26.00)	24.00 (23.00, 26.00)	.488
BMI, kg/m^2	21.85 (19.99, 23.61)	19.20 (18.63, 19.98)	22.59 (21.45, 24.25)	<.001
IPAQ				.262
High	20 (18.87%)	4 (14.29%)	16 (20.51%)	
Moderate	43 (40.57%)	15 (53.57%)	28 (35.9%)	
Low	43 (40.57%)	9 (32.14%)	34 (43.59%)	
Sequence in simulation				.594
First provider	56 (52.83%)	16 (57.14%)	40 (51.28%)	
Second provider	50 (47.17%)	12 (42.86%)	38 (48.72%)	
Actual CPR experience				.893
Yes	73 (68.87%)	19 (67.86%)	54 (69.23%)	
No	33 (31.13%)	9 (32.14%)	24 (30.77%)	
Mean blood pressure difference	4.80 ± 8.22	2.26 ± 8.79	5.71 ± 7.86	.057
VAS difference	4.00 (2.00, 5.00)	4.00 (2.00, 5.00)	4.00 (2.00, 5.00)	.831
Chest compression quality				
Depth	56.54 (52.18, 59.15)	52.14 (50.10, 54.59)	57.98 (53.96, 59.49)	<.001
Accuracy of depth	0.93 (0.63, 1.00)	0.72 (0.55, 0.88)	0.98 (0.71, 1.00)	.001
Rate	112.12 (106.99, 116.84)	107.72 (103.52, 112.70)	113.20 (108.62, 117.07)	.010
Accuracy of rate	0.89 (0.55, 0.99)	0.87 (0.45, 0.98)	0.91 (0.69, 0.99)	.491

Values are shown as the mean ± standard deviation, median with interquartile range, or number (%).

BMI = body mass index, CPR = cardiopulmonary resuscitation, IPAQ = international physical activity questionnaire, VAS = visual analog scale.

Table 2

Three-level generalized linear mixed effects model for chest compression quality.

	OR (95% CI)	P
For correct compression depth		
Change in heart rate	1.009 (1.004–1.014)	.001
Duration within one cycle	0.977 (0.976–0.978)	<.001
Male (vs female [ref level])	7.195 (1.069–48.405)	.043
BMI	1.280 (0.900–1.820)	.167
For correct compression rate		
Change in heart rate	1.000 (0.996–1.004)	.963
Duration within one cycle	0.998 (0.997–0.998)	<.001
Male (vs female ([ref level])	3.095 (0.458–20.910)	.244
BMI	0.947 (0.666–1.346)	.759

BMI = body mass index, CI = confidence interval, OR = odds ratio, ref = reference.

superior groups are better able to maintain chest compression quality.[9,23–25] Therefore, in the present study, the effect of increased heart rate of the participants on the adequacy of compression depth could be explained by the fact that male providers typically have better physical requirements to maintain chest compression quality.

Our results demonstrate that increasing the provider's heart rate decreases the compression depth accuracy in all the segmented durations in a cycle. Several qualitative aspects of exercise, such as intensity and duration, have a certain complex effect on the changes in the heart rate.[26] Heart rate variability has been used in many studies as a useful marker for monitoring autonomic activity,[27–29] and most studies regarding fatigue focus on heart rate variability because of its measurability. In accordance with our results, heart rate may be a useful variable that reflects provider fatigue with a constant duration since changes in the heart rate are known to be more sensitive to the intensity than to the duration of exercise.[26]

In the present study, we developed a three-level generalized linear mixed effects model by assuming the main exposure (change in heart rate) to be a TDC. Previous studies have similarly analyzed the quality of chest compressions according to

Table 3

Subgroup analysis according to the duration for correct compression depth.

	OR (95% CI)	P
1st quartile of duration within one cycle		
Change in heart rate	0.980 (0.964–0.997)	.020
Male (vs female [ref level])	0.966 (0.178–5.235)	.968
BMI	1.125 (0.824–1.537)	.455
2nd quartile of duration within one cycle		
Change in heart rate	0.920 (0.892–0.949)	<.001
Male (vs female [ref level])	2.290 (0.299–17.553)	.422
BMI	1.371 (0.933–2.014)	.107
3rd quartile of duration within one cycle		
Change in heart rate	0.956 (0.935–0.977)	<.001
Male (vs female [ref level])	5.202 (0.635–42.651)	.123
BMI	1.506 (1.013–2.240)	.043
4th quartile of duration within one cycle		
Change in heart rate	0.952 (0.926–0.980)	.001
Male (vs female [ref level])	15.043 (1.520–148.875)	.021
BMI	1.405 (0.918–2.148)	.116

BMI = body mass index, CI = confidence interval, OR = odds ratio; ref = reference.

Table 4

Subgroup analysis according to sex for correct compression depth.

	OR (95% CI)	P
Male participants		
Change in heart rate	1.029 (1.022–1.036)	<.001
Duration within one cycle	0.983 (0.982–0.984)	<.001
BMI	1.139 (0.787–10.647)	.485
Female participants		
Change in heart rate	0.967 (0.954–0.980)	<.001
Duration within one cycle	0.959 (0.957–0.961)	<.001
BMI	3.668 (1.114–12.074)	.034

BMI = body mass index, CI = confidence interval, OR = odds ratio.

participant cohorts.[5,8,9,13–15] However, considering the practical relevance, the quality of chest compression should be analyzed for individual participants. Thus, to interpret the associations of correct compression quality in a participant, the provider's heart rate was assumed to be a TDC.[21,22]

Recently, studies have used advanced technology to collect and utilize real-time information that was not possible in the past.[30,31] To the best of our knowledge, none of the previous studies on the association between chest compression quality and fatigue have attempted to measure the provider's heart rate in real-time for each compression.[3,8,9,11,13,14] In contrast, the participants in the present study used wearable devices and a simulator that could collect real-time data on the compression quality to investigate if real-time changes in the heart rate could reflect a provider's fatigue. In addition to the current subjective guidelines of switching providers before 2 min have passed if a provider is tired, the findings of the present study could be used to suggest provider rotation more accurately by objectively analyzing provider fatigue.

Our study has several limitations. As the present results were obtained using simulations, the same should be verified in clinical practice. In particular, the association of correct compression depth and changes in the heart rate has not yet been confirmed in any randomized controlled trial. However, it is almost impossible to artificially control the changes in a provider's heart rate in clinical trials; therefore, the design of our study could be considered as an effective alternative option. Furthermore, uneven sex distribution of participants in the analyses may have interfered with the identification of the precise association in the overall model. Finally, the change in the heart rate may not be the best indicator of provider fatigue, and the use of electromyography to measure muscle fatigue directly may better reflect provider fatigue.[15] However, electromyography in real-time during CPR is not possible, and hence, an indicator that can easily identify real-time changes in provider fatigue will be more useful and clinically relevant.

In conclusion, the findings of the present study confirmed that real-time increases in the heart rate can reflect fatigue in providers while performing chest compressions with a constant duration within one cycle. The results and methodology of this study can act as a guide for the rotation of providers during CPR based on objectively measured fatigue in individual providers.

Acknowledgments

The authors thank Medical Illustration and Design, part of the Medical Research Support Services of Yonsei University College of Medicine, for all artistic support related to this work.

Author contributions

Conceptualization: Go Eun Bae, Min Joung Kim, Ji Hoon Kim.
Data curation: Go Eun Bae.
Investigation: Hyun Soo Chung.
Methodology: In Kyung Min, Ji Hoon Kim.
Project administration: Ji Hoon Kim.
Resources: Hyun Soo Chung.
Software: In Kyung Min.
Supervision: Min Joung Kim, Sung Phil Chung.
Visualization: Arom Choi, Jin Ho Beom.
Writing – original draft: Go Eun Bae, Arom Choi, Jin Ho Beom.
Writing – review & editing: In Kyung Min, Ji Hoon Kim.

References

[1] Link MS, Berkow LC, Kudenchuk PJ, et al. Part 7: adult advanced cardiovascular life support: 2015 American Heart Association Guidelines Update for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. Circulation 2015;132(18 Suppl 2):S444–464.
[2] Nolan JP, Soar J, Cariou A, et al. European Resuscitation Council and European Society of Intensive Care Medicine Guidelines for Post-resuscitation Care 2015: Section 5 of the European Resuscitation Council Guidelines for Resuscitation 2015. Resuscitation 2015;95:202–22.
[3] Liu S, Vaillancourt C, Kasaboski A, et al. Bystander fatigue and CPR quality by older bystanders: a randomized crossover trial comparing continuous chest compressions and 30:2 compressions to ventilations. CJEM 2016;18:461–8.
[4] Riera SQ, Gonzalez BS, Alvarez JT, et al. The physiological effect on rescuers of doing 2 min of uninterrupted chest compressions. Resuscitation 2007;74:108–12.
[5] Haque IU, Udassi JP, Udassi S, et al. Chest compression quality and rescuer fatigue with increased compression to ventilation ratio during single rescuer pediatric CPR. Resuscitation 2008;79:82–9.
[6] Manders S, Geijsel FE. Alternating providers during continuous chest compressions for cardiac arrest: every minute or every two minutes? Resuscitation 2009;80:1015–8.
[7] Sugerman NT, Edelson DP, Leary M, et al. Rescuer fatigue during actual in-hospital cardiopulmonary resuscitation with audiovisual feedback: a prospective multicenter study. Resuscitation 2009;80:981–4.
[8] Ock SM, Kim YM, Chung J, et al. Influence of physical fitness on the performance of 5-minute continuous chest compression. Eur J Emerg Med 2011;18:251–6.
[9] Hansen D, Vranckx P, Broekmans T, et al. Physical fitness affects the quality of single operator cardiocerebral resuscitation in healthcare professionals. Eur J Emerg Med 2012;19:28–34.
[10] McDonald CH, Heggie J, Jones CM, et al. Rescuer fatigue under the 2010 ERC guidelines, and its effect on cardiopulmonary resuscitation (CPR) performance. Emerg Med J 2013;30:623–7.
[11] Min MK, Yeom SR, Ryu JH, et al. A 10-s rest improves chest compression quality during hands-only cardiopulmonary resuscitation: a prospective, randomized crossover study using a manikin model. Resuscitation 2013;84:1279–84.
[12] Zhang FL, Yan L, Huang SF, et al. Correlations between quality indexes of chest compression. World J Emerg Med 2013;4:54–8.
[13] Shin J, Hwang SY, Lee HJ, et al. Comparison of CPR quality and rescuer fatigue between standard 30:2 CPR and chest compression-only CPR: a randomized crossover manikin trial. Scand J Trauma Resusc Emerg Med 2014;22:59.
[14] Kwak SJ, Kim YM, Baek HJ, et al. Chest compression quality, exercise intensity, and energy expenditure during cardiopulmonary resuscitation using compression-to-ventilation ratios of 15:1 or 30:2 or chest compression only: a randomized, crossover manikin study. Clin Exp Emerg Med 2016;3:148–57.
[15] Abelairas-Gomez C, Rey E, Gonzalez-Salvado V, et al. Acute muscle fatigue and CPR quality assisted by visual feedback devices: a randomized-crossover simulation trial. PLoS One 2018;13:e0203576.
[16] Ahn C, Lee J, Oh J, et al. Effectiveness of feedback with a smartwatch for high-quality chest compressions during adult cardiac arrest: a randomized controlled simulation study. PLoS One 2017;12:e0169046.
[17] Weenk M, van Goor H, van Acht M, et al. A smart all-in-one device to measure vital signs in admitted patients. PLoS One 2018;13:e0190138.
[18] Weenk M, Koeneman M, van de Belt TH, et al. Wireless and continuous monitoring of vital signs in patients at the general ward. Resuscitation 2019;136:47–53.
[19] Cheng A, Auerbach M, Hunt EA, et al. Designing and conducting simulation-based research. Pediatrics 2014;133:1091–101.
[20] Cheng A, Kessler D, Mackinnon R, et al. Reporting guidelines for Health Care Simulation Research: extensions to the CONSORT and STROBE statements. Simul Healthc 2016;11:238–48.
[21] Cho A, Kim MJ, You JS, et al. Postcontrast acute kidney injury after computed tomography pulmonary angiography for acute pulmonary embolism. J Emerg Med 2019;57:798–804.
[22] Kim EN, Kim MJ, You JS, et al. Effects of an emergency transfer coordination center on secondary overtriage in an emergency department. Am J Emerg Med 2019;37:395–400.
[23] Hasegawa T, Daikoku R, Saito S, et al. Relationship between weight of rescuer and quality of chest compression during cardiopulmonary resuscitation. J Physiol Anthropol 2014;33:16.
[24] Ogata H, Fujimaru I, Kondo T. Degree of exercise intensity during continuous chest compression in upper-body-trained individuals. J Physiol Anthropol 2015;34:43.
[25] Hong DY, Park SO, Lee KR, et al. A different rescuer changing strategy between 30:2 cardiopulmonary resuscitation and hands-only cardiopulmonary resuscitation that considers rescuer factors: a randomised crossover simulation study with a time-dependent analysis. Resuscitation 2012;83:353–9.
[26] Michael S, Graham KS, Davis GMO. Cardiac autonomic responses during exercise and post-exercise recovery using heart rate variability and systolic time intervals—a review. Front Physiol 2017;8:301.
[27] Nelesen R, Dar Y, Thomas K, et al. The relationship between fatigue and cardiac functioning. Arch Intern Med 2008;168:943–9.
[28] Stanley J, Peake JM, Buchheit M. Cardiac parasympathetic reactivation following exercise: implications for training prescription. Sports Med 2013;43:1259–77.
[29] D'Agosto T, Pecanha T, Bartels R, et al. Cardiac autonomic responses at onset of exercise: effects of aerobic fitness. Int J Sports Med 2014;35:879–85.
[30] Lu TC, Chang YT, Ho TW, et al. Using a smartwatch with real-time feedback improves the delivery of high-quality cardiopulmonary resuscitation by healthcare professionals. Resuscitation 2019;140:16–22.
[31] Perez MV, Mahaffey KW, Hedlin H, et al. Large-scale assessment of a smartwatch to identify atrial fibrillation. N Engl J Med 2019;381:1909–17.