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Bystander Cardiopulmonary Resuscitation: Training, Delivery, And Measurement Error

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Abstract

Bystander-delivered cardiopulmonary resuscitation (B-CPR) is an essential treatment for sudden cardiac arrest (SCA), yet less than one-third of victims receive B-CPR. Few studies have examined disparities in either layperson CPR training or B-CPR delivery. Furthermore, the association between CPR training and B-CPR delivery, and the potential impact of Dispatch-assisted CPR (D-CPR), has been inadequately quantified, partially due to limited observational datasets. We performed a nationally representative survey to measure estimated CPR training prevalence in the United States. We acquired clinical SCA and B-CPR data from the Resuscitation Outcomes Consortium (ROC) national registry and from Seattle King County (SKC) Emergency Medical Services (EMS) to enable inquiry into D-CPR and missing data within ROC. We assessed the differences in estimated CPR training prevalence, disparities in B-CPR, the association of community-level CPR training and B-CPR, and the impact of missing data. Aim 1: Between 09/2015-11/2015, 9,022 individuals completed the national CPR training survey; 18% reported current training in CPR, and 65% reported prior training. Aim 2: In the ROC cohort, 19,331 out-of-hospital cardiac arrests were assessed. In public locations, 39% (272/694) of females and 45% (1,170/2,600) of males received B-CPR ($p<0.01$), whereas in private settings, 35% (2,198/6,328) of females and 36% (3,364/9,449) of males received B-CPR (p=ns). Aim 3: From survey and ROC data analysis (n=17,883), increased community CPR training was associated with B-CPR delivery (OR: 1.21(95% CI: 1.04-1.39)), but this relationship was modified by site (p=ns). Aim 4: The ROC D-CPR variable had 80% missingness; multiple imputation (MI) was used and provided comparable results to the complete SKC dataset on the association of D-CPR on B-CPR (ROC MI RR: 3.84 (95% CI: 2.97-4.98) vs EMS complete case RR: 3.51 (95% CI: 3.22-3.83)). MI was verified in Missing Completely at Random and Missing at Random simulated datasets. In conclusion, rates of public CPR training and B-CPR delivery were low in the US. Males were more likely to receive B-CPR in public locations. The association of community-level CPR training on B-CPR delivery was modified by site. Future work is required to understand the role of D-CPR in encouraging CPR delivery.

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BYSTANDER CARDIOPULMONARY RESUSCITATION: TRAINING, DELIVERY,

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BYSTANDER CARDIOPULMONARY RESUSCITATION: TRAINING, DELIVERY, AND MEASUREMENT ERROR

This work is dedicated to my husband; I have accomplished so much through his constant support, dedication and faith in me. I also dedicate this work to my parents; they taught me to dream big and strive for more in all aspects of life.

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ABSTRACT

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Bystander-delivered cardiopulmonary resuscitation (B-CPR) is an essential treatment for sudden cardiac arrest (SCA), yet less than one-third of victims receive B-CPR. Few studies have examined disparities in either layperson CPR training or B-CPR delivery. Furthermore, the association between CPR training and B-CPR delivery, and the potential impact of Dispatch-assisted CPR (D-CPR), has been inadequately quantified, partially due to limited observational datasets. We performed a nationally representative survey to measure estimated CPR training prevalence in the United States. We acquired clinical SCA and B-CPR data from the Resuscitation Outcomes Consortium (ROC) national registry and from Seattle King County (SKC) Emergency Medical Services (EMS) to enable inquiry into D-CPR and missing data within ROC. We assessed the differences in estimated CPR training prevalence, disparities in B-CPR, the association of community-level CPR training and B-CPR, and the impact of missing data. *Aim 1:* Between 09/2015-11/2015, 9,022 individuals completed the national CPR training survey; 18% reported current training in CPR, and 65% reported prior training. *Aim 2:* In the ROC cohort, 19,331 out-of-hospital cardiac arrests were assessed. In public locations, 39% (272/694) of females and 45% (1,170/2,600) of males received B-CPR ($p<0.01$), whereas in private settings, 35% (2,198/6,328) of females and 36% (3,364/9,449) of males received B-CPR (p=ns). *Aim 3:* From survey and ROC data analysis (n=17,883), increased community CPR training was associated with B-CPR delivery (OR: 1.21(95% CI: 1.04-1.39)), but this relationship was modified by site (p=ns). *Aim 4:* The ROC D-CPR variable had 80% missingness; multiple imputation (MI) was used and provided comparable results to the complete SKC dataset on the association of D-

CPR on B-CPR (ROC MI RR: 3.84 (95% CI: 2.97-4.98) vs EMS complete case RR: 3.51 (95% CI: 3.22-3.83)). MI was verified in Missing Completely at Random and Missing at Random simulated datasets. In conclusion, rates of public CPR training and B-CPR delivery were low in the US. Males were more likely to receive B-CPR in public locations. The association of community-level CPR training on B-CPR delivery was modified by site. Future work is required to understand the role of D-CPR in encouraging CPR delivery.

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CHAPTER 1: BACKGROUND AND SIGNIFICANCE

Sudden cardiac arrest (SCA) is a leading cause of death in the US, with over 350,000 individuals experiencing out-of-hospital SCA annually and less than 20% surviving to hospital discharge (Chan, McNally et al. 2014, Benjamin, Virani et al. 2018, Zive, Schmicker et al. 2018). There is great potential to improve SCA survival with existing therapies that are poorly disseminated;(Rea, Helbock et al. 2006, Bradley, Gabriel et al. 2010) specifically, survival from SCA depends on prompt delivery of CPR (defined as performance of chest compressions and rescue breaths) (Hasselqvist-Ax, Herlitz et al. 2015, Malta Hansen, Kragholm et al. 2015, Goto, Funada et al. 2016). For every minute without treatment, survival falls by 7-10% (Cobb, Fahrenbruch et al. 1999, Holmberg, Holmberg et al. 2000, Iwami, Kawamura et al. 2007). Unfortunately, over 70% of SCA victims do not receive CPR until the arrival of professional rescuers; this delay greatly contributes to mortality (Nichol, Thomas et al. 2008). Specifically, the provision of CPR by a layperson who witnesses a SCA (known as bystander CPR, or B-CPR) is provided to less than one-third of victims in many US communities (Nichol, Thomas et al. 2008, McNally, Robb et al. 2011, Chan, McNally et al. 2014).

There are several methods to improve prevalence of B-CPR delivery thereby increasing survival from SCA. One approach is training laypersons in CPR, which is thought to increase the layperson’s self-efficacy and willingness to act in emergency situations where B-CPR is needed. Another means of increasing B-CPR is provision of community dispatch-assisted telephone CPR (D-CPR), also known as tele communicator-assisted CPR, where a 9-1-1 dispatcher provides CPR instruction over the telephone to bystanders who may need prompting or encouragement.

While studies have examined methods to improve B-CPR training and delivery rates independently (Sasson, Haukoos et al. 2013, Sasson, Haukoos et al. 2015), no investigations have assessed the prevalence of individuals in the US trained in CPR nationally. Furthermore, the association between CPR training and delivery rates is poorly quantified. Little work has been done to assess the impact of dispatch-assisted telephone CPR (D-CPR) on increasing B-CPR provision or survival from SCA. Few studies have robustly investigated D-CPR partially due to poor data collection or data capture of D-CPR prospectively in national registries. This chapter will provide an overview of the literature and potential research gaps in the areas of national CPR training, B-CPR delivery, D-CPR, and implications of missing data in resuscitation studies and observational, retrospective inquiries.

National CPR training prevalence and associated disparities remain unquantified

Despite longstanding efforts to increase CPR training, little is known regarding CPR training prevalence rates or associated disparities among geographic regions, race, and socioeconomic status (SES) in the US. One of the few studies addressing this issue quantified the incidence of CPR certification card distribution, mapped to CPR training center locations and found that the overall incidence of CPR training was 2.4% nationally (25^{th}-75^{th} percentiles, 0.9%-5.3%)(Anderson, Cox et al. 2014). Additionally, the investigation sought to quantify CPR training variation by geography and grouped the county incidence rate by tertile, finding that the Southern region of the US had the most counties in the lowest tertile (median, 0.5%, range 0.0% to less than 1.3%)(Anderson, Cox et al. 2014). While this study provided an initial estimate of CPR training, there were important limitations including the inability to account for trainee demographics, health care provider recertification, and more granular geographic location of the trainee. Additionally, the study was unable to account for alternative methods of CPR training aside from certification, such as the use of brief validated, educational methods that do not result in certification, video-self instruction and other abbreviated training approaches (Bobrow, Vadeboncoeur et al. 2011, Blewer, Putt et al. 2016). Current studies have not measured the prevalence of CPR training through these innovative educational methods. A public survey instrument remains the most straightforward approach to assessing CPR training prevalence, individual demographics, and time since previous training.

Quantifying CPR training status via a self-reported survey

Several countries have approached quantifying the number of individuals trained in CPR using a self-reported survey, where participants indicate if or when they are trained in CPR. A recent publication in Scotland surveyed the barriers and facilitators to public attitudes of CPR and found that 52% of the respondents had been trained in CPR (Dobbie, MacKintosh et al. 2018). Using the National Korean Community Health Survey, Ro et al found that 32.4% of Koreans were trained in CPR, and self-efficacy in performing bystander CPR was correlated with recent CPR training (Ro, Shin et al. 2016). A recent study from Canada investigated Canadian's willingness to provide chest-compression-only CPR and found gaps in knowledge with bystander's willingness to act in an out-of-hospital cardiac arrest (OHCA) (Cheskes, Morrison et al. 2016). To our knowledge, no survey study has quantified the prevalence of CPR training nationally or investigated demographic variation by current CPR training in the United States. Knowledge of CPR training and associated demographic variation could help inform future training efforts and development of tailored CPR training approaches.

Bystander CPR delivery: individual and neighborhood-level characteristics

Studies have examined regional, community, and individual-level variation in survival from OHCA (Wang, Devlin et al. 2012, Bagai, McNally et al. 2013, Morrison, Schmicker et al. 2016). While B-CPR is a critical link in the chain of survival, few studies have examined regional, community, and individual-level variation in B-CPR delivery, specifically layperson B-CPR delivery. Furthermore, few, if any, studies have specifically examined layperson B-CPR delivery, or B-CPR by a non-healthcare professional or first responder; this is another critical aspect in the chain of survival. Of note, studies have examined individual-level characteristics associated with B-CPR delivery while examining variation in survival (Weisfeldt, Everson-Stewart et al. 2011, Malta Hansen, Kragholm et al. 2015). For example, the study by Malta-Hansen et al assessed bystander response, but as a secondary examination of a larger bystander and first responder intervention and subsequent impact on survival (Survival increased: 7.1% to 9.7% post larger bystander intervention) (Malta

Hansen, Kragholm et al. 2015). Further, studies have examined variation in community-level characteristics and survival; (Nichol, Thomas et al. 2008, Reinier, Thomas et al. 2011, Sasson, Magid et al. 2012, Fosbol, Dupre et al. 2014). Of investigations that have examined B-CPR delivery, the studies have examined neighborhood characteristics and variation in race and socioeconomic status and subsequent association with B-CPR delivery (Sasson, Magid et al. 2012, Fosbol, Dupre et al. 2014). For example, a recent study conducted in North Carolina demonstrated that low B-CPR rates were associated with neighborhoods characterized by higher percentages of black residents and persons living in poverty (Black: OR, 3.73; 95% CI, 2.00-6.97, Poverty: OR 1.77, 1.16-2.71) (Fosbol, Dupre et al. 2014). Little work have examined variation in individual, patient-level characteristics, such as gender, and receipt of layperson B-CPR. This is important as it may shed light on potential individual-level biases and that may affect community response and B-CPR. For instance, investigations have suggested that men are more likely to receive assistance in public emergency response situations (El-Menyar, El-Hennawy et al. 2014, Forrester, Forrester et al. 2017). No study has examined receipt of B-CPR and variation by patient-level gender.

Association of increased community-level CPR training and bystander CPR delivery

While many studies have examined survival from OHCA and B-CPR delivery, few investigations have examined the association of increased community-level CPR training with B-CPR delivery. A recent study from Australia sought to examine whether there was regional variation in rates of CPR training and willingness to perform B-CPR in Victoria, Australia (Bray, Straney et al. 2017). Using survey data to quantify the rates of CPR training, the study team found lower rates of CPR training and lower survival in regions with lower rates of B-CPR (Bray, Straney et al. 2017). Additionally, a recent study from Korea demonstrated that higher reported CPR training rates on a community level was associated with more frequent B-CPR and survival from OHCA (Ro, Shin et al. 2016). Both studies examined this association using a city-level, ecological study design. No study has modeled this association as a semi-ecological study design (or semi-individual, using partial individual data) or examined whether increased community-level CPR training influences individual-level B-CPR delivery. Knowledge of this may aid our understanding of the association between CPR training and B-CPR delivery, critical links in the chain of the survival.

Importance of quantifying dispatch-assisted telephone CPR

Studies have suggested that increasing the availability of D-CPR may improve B-CPR rates (Rea, Eisenberg et al. 2001, Bobrow, Panczyk et al. 2012, Hasselqvist-Ax, Herlitz et al. 2015). While this approach is promising, D-CPR is not uniformly available across the US and its impact on B-CPR delivery when bystanders are untrained remains unclear (Blewer and Abella 2018).

D-CPR or the provision of CPR instructions by dispatchers when individuals call 9-1-1, has been encouraged by programs such as the Resuscitation Academy, a nation-wide effort to train prehospital providers to improve survival from cardiac arrest. Initiatives such as these assist communities and dispatch organizations, by providing resources to improve the delivery of D-CPR. Research has focused on methods to improve D-CPR delivery by identifying challenges to effective D-CPR during actual cardiac arrest events and in simulated settings (Hauff, Rea et al. 2003, Birkenes, Myklebust et al. 2014). Examples of challenges or barriers to D-CPR include inability to calm callers, callers not being with the victim, and hesitancy of callers to follow D-CPR instructions (Hauff, Rea et al. 2003, Dami, Carron et al. 2010).

City-wide, epidemiologic data suggest that independently training more individuals in CPR and increasing effective D-CPR improves rates of CPR delivery and cardiac arrest survival (Rea, Eisenberg et al. 2001). Further, a recent publication from Arizona demonstrated that D-CPR was independently associated with improved survival (1.64 (95% CI: 1.61-2.30)) (Wu, Panczyk et al. 2018). Despite this, few studies have examined the effect of D-CPR on B-CPR delivery and survival on an individual level. Furthermore, surprisingly little work has examined the interaction between D-CPR and layperson CPR training. This may be partially due to incomplete capture of the D-CPR variable in prospectively collected, observational, patient-level datasets.

Missing data and the effect on observational data

Missing data are common in observational, epidemiologic studies, and the missingness may lead to substantial bias and misleading inference if handled inadequately by the investigator (Molenberghs, Fitzmaurice et al. 2015). The reduction in precision is related to the amount of missing data and is influenced, to a certain extent, by the method of analysis (Molenberghs, Fitzmaurice et al. 2015). When there are missing data, the validity of any method of analysis will require that certain assumptions about the reasons why missing values occur be tenable. The assumptions, whether the data are Missing Completely at Random (MCAR), Missing at Random (MAR), and Missing Not at Random (MNAR), are often referred to as the missing data mechanism. MCAR refers to when the probability of missingness is unrelated to the value or the missing data or any of the variables in the dataset. Data are considered MAR when the probability of missingness is unrelated to the missing data after controlling for observed covariate data. When data are MNAR, the probability of missingness is related to a systematic, uncollected difference that is not observed in the dataset.(Molenberghs, Fitzmaurice et al. 2015) Many clinical research studies address missing data by using complete case analysis (using the complete cases to assess the effect of the exposure on the outcome). This method assumes the data are MCAR and may lead to potential biases and imprecise measures of association. Multiple imputation is gaining traction as a method to handle missing data in clinical studies and performs robustly under the assumption that the data are MAR. No study has examined the effect of missing data on associations conducted using observational datasets in the resuscitation community. Bringing awareness to the degree of bias introduced by missing data, impact of the validity of the results, and describing methods to handle missing data may greatly benefit the resuscitation community.

Conclusion

In summary, there is a crucial need in the resuscitation community to quantify the national CPR training prevalence and associated individual-level disparities. Further, it is important to explore and shed light on patient-level disparities in receipt of B-CPR. Assessing the association between community-level CPR training and B-CPR delivery has yet to be explored and needs to be quantified. Lastly, little has been done to explore the implications of missing data when examining observational resuscitation outcomes datasets. These areas of inquiry will be addressed in the next four chapters of this monograph.

CHAPTER 2: PUBLIC CPR TRAINING

In the introductory chapter, the important role of B-CPR and key research gaps were discussed. In this chapter, we will focus on the specific topic of layperson CPR training prevalence, and efforts to answer the fundamental question: how many adults in the United States are trained in CPR?

The prompt delivery of B-CPR increases the probability of survival from SCA by over two-fold, yet less than one-third of SCA victims receive B-CPR in the United States (Iwami, Kawamura et al. 2007, Weisfeldt, Everson-Stewart et al. 2011, Chan, McNally et al. 2014, Hasselqvist-Ax, Herlitz et al. 2015, Malta Hansen, Kragholm et al. 2015). Recent work has demonstrated an association between increased public CPR training and B-CPR delivery (Moller Nielsen, Lou Isbye et al. 2012, Wissenberg, Lippert et al. 2013, Hasselqvist-Ax, Herlitz et al. 2015). Despite growing efforts to promote CPR education of the public, little is known regarding the national prevalence of CPR training or the association of training status with individual-level demographic characteristics.

A recent investigation sought to quantify national CPR training activity by measuring the distribution of CPR certification cards and found that 2.4% of the adult U.S. population received CPR education within a one year period through certification programs (Anderson, Cox et al. 2014). While this study provided an initial estimate of CPR training incidence, there were important limitations to the investigation including the lack of individual-level trainee demographic data and the prevalence of prior training. Understanding demographic associations with training prevalence could aid with targeted CPR training initiatives to maximize CPR education efforts.

We implemented a telephone-based, prospective, nationally representative survey to determine CPR training prevalence and its relationship with demographic variables and prior training experiences. We hypothesized that increased age and lower socioeconomic status (SES), independently, would be associated with a lower likelihood of CPR training.

Methods

Study design and population

This cross-sectional investigation was designed to estimate the association between individual-level demographic variation and CPR training status. From 9/2015-11/2015, survey data were collected via random digit dial (RDD) telephone methodology in collaboration with an established social sciences research organization (SSRS, Media, PA). Participants were queried as part of an ongoing omnibus survey, through both landline and mobile telephone modalities. Results from the omnibus survey have been used in prior peer-reviewed biomedical investigations (Blendon, Benson et al. 2012, Blendon, Benson et al. 2014, Lang, Alexander et al. 2015).

Individuals in the US ages 18 and older were eligible to be survey respondents. After determining eligibility, participants were given a series of questions designed to assess individual-level demographic characteristics and CPR training status. The study protocol was deemed exempt by the University of Pennsylvania Institutional Review Board.

Survey questionnaire development

Questions were developed and extensively pilot tested among adult laypersons by study personnel (Appendix Table 1). The wording was designed to capture individual's training status. Once finalized, the questions were introduced on a regional health survey in Southeastern Pennsylvania. Responses from this regional survey were used to establish CPR training content and construct validity. Data from this regional survey in Pennsylvania have been presented elsewhere.

Survey methodology

The survey approach was designed to represent the adult US population via a stratified RDD sample of landline residential as well as mobile telephone numbers. Telephone numbers were computer generated and loaded into on-line sample files accessed directly by the computer-assisted telephone interviewing system via well-established survey methods (Blendon, Benson et al. 2012, Blendon, Benson et al. 2014, Lang, Alexander et al. 2015). Area-code specific quotas were also set to ensure adequate geographic representation, and interviews were conducted in either English or Spanish to ensure representation of the Spanish-speaking population. Survey weights, accounting for selection bias and non-response bias by household, telephone, and key demographics such as age, race, gender, and education, were used to provide nationally representative estimates of the adult population 18 years of age and older (Appendix Data Supplemental File 1).

Variable definitions

We defined an individual who is CPR trained as anyone who had reported receiving a CPR certification card, or was trained via a non-certification CPR educational program, similar to the methodology of Anderson et al (Anderson, Cox et al. 2014). We queried individuals if they reported receiving CPR training within the past 2 years, 3-5 years, 6-10 years, or greater than 10 years. We defined those who were currently trained as anyone who reported receiving training in the past 2 years (compliant with current CPR certification standards), and defined those who were ever trained as anyone who reported receiving CPR training at any point in time (Appendix Table 1).

We captured respondent’s age, race/ethnicity, gender, education, and income. Since socioeconomic status (SES) is a multi-dimensional construct and not well defined by a single unit of measure, we used education and income variables to characterize SES, consistent with prior work (Oakes and Rossi 2003, Braveman, Cubbin et al. 2005).

Descriptive comparison of training and SCA data

Prior studies have demonstrated that B-CPR rates are lower in the private residential environment compared to the public setting. Spouses (generally of comparable ages) may be the first responders to SCA events in these environments. Age distribution within our CPR training survey data was compared to that of SCA clinical events in a portion of the U.S. during a similar time period (2011-2015), using data from the Resuscitation Outcomes Consortium (ROC). ROC is an NIH-funded clinical trial network focused on pre-hospital SCA and severe traumatic injury. Details of the ROC registry will be described in detail in Chapter 3.

Statistical analysis

Data were analyzed using a statistical software package (STATA 14 with the svy suite of commands, Statacorp, College Station, TX). The dataset were missing 17% of the covariates of interest; we analyzed differences in the covariates by missingness and assessed the final model using complete-case analysis. As a sensitivity analysis, we used multiple imputation to impute the missing covariates of interest. The estimates from the imputed data sets were similar to the observed data set (data not shown).

Using survey-weighted logistic regression modeling, we analyzed whether there were differences between CPR training prevalence by age, education, and income. We explored this association with CPR training status using the data in a binary (yes/no CPR training) fashion and defined CPR training as currently trained (within previous two years) and ever trained (without time boundary). Age was examined continuously (increasing in years) and categorically (by age deciles). Individuals indicated their highest education level achieved and were either categorized as less than high school educated, high school graduate, some college, graduate of college, or graduate school or more. Total household income categories included less than $15,000, $15,000-$29,999, $30,000-$49,999, $50,000-$74,999, $75,000-$99,999, and $100,000 or more. The final regression model included age, education, income, gender, and race, which were statistically significantly associated with CPR training based on a univariate analysis ($p<0.05$). The geographic variable was modeled and tested as a fixed effect in the final regression equation. We used residuals to examine final regression model fit and ran the predictive margins of age, education, and income.

Results

CPR training prevalence

From 9/2015-11/2015, 9,022 individuals completed the survey, with data weighted to represent the adult U.S. population (based on the U.S. Census American Community Survey 2014, reflecting a U.S. adult population (18 years of age or older) of 245,201,076 (2014); 4,497 interviews were completed through mobile telephones and 4,525 were completed via landlines. Of those eligible, 17% declined to conduct the survey, 29% halted participation partially through the interview process and 44% of the phone calls went to voicemail or an answering machine, while 10% completed the entire interview (n=9,022). Of those surveyed, 18% of respondents were currently trained in CPR, 65% were trained at some point previously (ever trained), and 35% had never been trained. Population characteristics are detailed in Table 1. The mean age of all the surveyed population was 48 (95% CI: 47-49) years, and 51% of the population were female. Of all participants, 65% were White, 12% were Black, while 15% were Hispanic; 30% were high school graduates, and 15% had a household income of less than $15,000 a year.

Among those that were currently trained, the mean age was 42 (95% CI: 41-43), while the mean age of those ever trained was 46 (95% CI: 47-49), compared to 48 (95% CI: 6-51) of those never trained. In contrast, the mean age of SCA victims in the U.S. population within the ROC cohort was 63.8±19.8 (Figure 1). Further, we examined the association of B-CPR delivery during SCA events by victim age and found a statistically significant association of decreased B-CPR delivery with increased age with events that occurred in the home environment (Figure 2), in a fashion that mirrored the age-dependent nature of CPR training demonstrated in our survey work. This association of decreased B-CPR with victim age was not found among SCA events in the public setting.

Demographic characteristics associated with training

Of those who were currently trained, increased age was associated with a lower likelihood of being currently CPR trained (OR for each year of increased age: 0.98, 95% CI: 0.97-0.99, p-value: <0.01) (Table 2). When age was examined categorically by increased decades (global p-value: 0.04), those who were 70-79 years were 0.15 (95% CI: 0.10-0.23) times less likely to be currently trained (p<0.01) and 60-69 years old were 0.29 (95% CI: 0.20-0.42) times less likely to be currently trained compared to 18-29 year olds (p<0.01) (Table 3 and Figure 3). Increased education level was associated with a significant increase in likelihood of current CPR training (p<0.02). Specifically, those who were graduate school educated or more, had a 3.36 (95% CI: 1.60-7.09) increased likelihood of being currently CPR trained compared to those who had less than a high school education (p<0.01). Further, increased income was associated with an increase in an individual's likelihood of current CPR training (p=0.03). There was a significant difference in the global distribution of race and current CPR training (p=0.03), but the individual associations were not significant. Gender was not associated with likelihood of current CPR training (p=ns) (Table 3).

Similar demographic associations were seen between those that had ever received training compared to those who never received CPR training. Of those who were ever trained, increased age was associated with CPR training (OR for each year of increased age: 0.99, 95% CI: 0.98-0.99, p=0.04). When age was examined categorically (global p-value: 0.04), those who were 80 years or older were 0.34 (95% CI: 0.22-0.52) times less likely to be ever CPR trained compared to those who were 18-29 years old (p<0.01); those who were 70-79 years were 0.58 (95% CI: 0.43-0.77) times less likely to be ever trained (p<0.01) and 60-69 years old were 0.86 (95% CI: 0.71-1.05) times less likely to be currently trained compared to 18-30 year olds (p=ns) (Table 3).

Discussion

In a nationally-representative telephone survey, we found that the overall prevalence of current CPR training was 18%, while 65% of the population identified being trained at some point in their lifetime. We identified an independent association between both older age and lower SES with a decreased likelihood of CPR training. To our knowledge, this is the first study to estimate the national CPR training prevalence within the U.S. population.

Age and CPR training status

Our work found a striking association with older age and decreased likelihood of CPR training. This is especially important since the mean age of SCA victims in the U.S. is approximately 64 years of age. Previous studies have demonstrated that B-CPR rates are lower in the private residential environment compared to the public setting (Nichol, Thomas et al. 2008, Weisfeldt, Everson-Stewart et al. 2011). It is possible that spouses (generally of comparable ages) may be the first responders to SCA events in these environments. While our findings suggest that many older individuals have been trained at some point, the prevalence of current training in the highest risk population is very low. Furthermore, our findings suggest that a victim’s chance of receiving B-CPR in the home environment decreases by age, further affirming the need to consider targeted training in the older population. It may be the spouses or close loved ones of older individuals who are most likely to need to act during SCA events in the home environment. Future initiatives should consider targeted methods to train this population, which may be at higher risk of witnessing SCA events, especially in the home setting where few others may be available to provide prompt care.

SES and CPR training status

Previous studies have suggested an association with SES and B-CPR delivery (Sasson, Keirns et al. 2011, Sasson, Magid et al. 2012, Root, Gonzales et al. 2013, Fosbol, Dupre et al. 2014).

Specifically, a recent study found that individuals living in low-income African-American neighborhoods were much less likely to receive B-CPR compared to the national population (odds ratio 0.49, 95% CI 0.41-0.58) (Sasson, Magid et al. 2012). Additionally, the work of Anderson et al demonstrated aggregate geographic, racial, and SES disparities with B-CPR training (Anderson, Cox et al. 2014). The current work has confirmed and extended these findings, allowing for individual-level linkage of CPR training status with self-reported SES demographic data. We found an association with lower educational attainment and household income and decreased likelihood of CPR training. Future training initiatives should address barriers that may prevent lower SES individuals from receiving CPR training.

Dispatch CPR as an alternative to broad CPR training

Recent studies have highlighted the importance of D-CPR as another method to increase B-CPR delivery (Rea, Eisenberg et al. 2001, White, Rogers et al. 2010, Lewis, Stubbs et al. 2013). However, the relationship between D-CPR and CPR training is unknown; it is possible that CPR training improves the bystander response to D-CPR instructions, and that lack of CPR training may limit willingness to accept instructions from the dispatchers. In a recent investigation, even when D-CPR instructions were optimized, the change in the B-CPR rate was modest (61.8% before D-CPR and 66.8% after D-CPR bundled intervention, p=0.006)(Bobrow, Spaite et al. 2016), suggesting the role of additional factors that affect the actual provision of CPR following dispatch instructions. Further studies will be required to assess the interplay between D-CPR, layperson CPR training, and actual delivery.

Importance of targeted CPR training

Organizations such as the American Heart Association (AHA) have expended broad efforts to increase public CPR training, yet little is known as to which individuals should be targeted for training to maximize the public health benefit. The National Academy of Medicine (NAM, formerly the Institute of Medicine) has selected SCA, CPR delivery and resuscitation outcomes as foci of a national report (“Strategies to Improve Cardiac Arrest Survival: A Time to Act”), underscoring the public health importance of this topic(2015). Specifically, the NAM report called for educating and engaging the public stating that “all can play a role in the effort to promote and facilitate CPR training”(2015). Furthermore, scientific advisories and consensus statements from the AHA have emphasized the importance of addressing barriers to CPR education (Abella, Aufderheide et al. 2008, Sayre, Berg et al. 2008, Sasson, Meischke et al. 2013, Morley, Lang et al. 2015). Understanding individual-level disparities in CPR training status could help inform future targeted educational initiatives and increase rates of B-CPR delivery. Developing effective interventions based on our understanding of these relationships has the potential to greatly influence CPR education programs and inform future public health initiatives, to maximize the lay public response to SCA and improve survival.

The current work has limitations inherent in telephone survey methodology. While our survey has a low response rate, it is similar to other nationally-representative telephone surveys(Lang, Alexander et al. 2015). While this is a limitation of the methodology, the RDD approach is more cost-effective than mail or door-to-door surveys. Further, we acknowledge that survey methodology is subject to both recall and social desirability bias. We are encouraged that our findings regarding CPR training prevalence are similar to that from our Health Household Survey implemented in Southeastern Pennsylvania, which found an 18% prevalence of current CPR training and 61% prevalence of training overall.

Conclusions

In conclusion, the national prevalence of those currently trained in CPR was low. Our data suggest that many individuals obtain CPR training at some point in time, but few maintain current training. Further, older individuals are less likely to be CPR trained, and lower SES is also associated with a decreased likelihood of CPR training. These findings suggest the need for focused CPR training efforts to address these disparities and maximize public health benefit (Blewer, Putt et al. 2016).

Having established the estimated prevalence of CPR training in the US and explored disparities of CPR training, we then sought to address the question of disparities in CPR provision, or layperson B-CPR. This will be described in depth through the subsequent chapter.

Chapter 2 Acknowledgement

This paper was reproduced with permission by my graduate group chair, dissertation committee, and the *Journal of the American Heart Association.* The exact citation is: Blewer AL, Ibrahim SA, Leary M, et al. Cardiopulmonary Resuscitation Training Disparities in the United States. *Journal of the American Heart Association.* 2017; 6(5): e006124.

CHAPTER 3: DISPARITIES IN BYSTANDER CPR DELIVERY

In this next chapter, we will describe our work that quantified B-CPR initiated by laypersons and gender disparities among individuals that receive layperson B-CPR. A better understanding of layperson B-CPR is critical to informing future CPR training dissemination strategies and ultimately helping to improve outcomes from SCA.

Recent investigations have affirmed that prompt delivery of B-CPR increases survival from OHCA, yet B-CPR rates remain low in many U.S. communities (Wissenberg, Lippert et al. 2013, Hasselqvist-Ax, Herlitz et al. 2015, Malta Hansen, Kragholm et al. 2015, Kragholm, Wissenberg et al. 2017). Epidemiologic studies have demonstrated disparities in B-CPR rates by neighborhood-level characteristics, such as racial composition or socioeconomic status (Becker, Han et al. 1993, Brookoff, Kellermann et al. 1994, Galea, Blaney et al. 2007, Sasson, Magid et al. 2012). For example, a recent study conducted in North Carolina demonstrated that low B-CPR rates were associated with neighborhoods characterized by higher percentages of black residents and persons living in poverty (Black: OR, 3.73; 95% CI, 2.00-6.97, Poverty: OR 1.77, 1.16-2.71) (Fosbol, Dupre et al. 2014). Improving B-CPR training and delivery have been highlighted as crucial national objectives in statements from the National Academy of Medicine the American Heart Association (Abella, Aufderheide et al. 2008, Sasson, Meischke et al. 2013, 2015), with the goal of increasing survival from OHCA, an abrupt condition that strikes over 400,000 victims each year in the U.S (Benjamin, Virani et al. 2018).

There is evidence that gender disparities persist when examining treatment for other forms of cardiovascular disease such as percutaneous coronary intervention for ST segment elevation myocardial infarction (Gan, Beaver et al. 2000, Pelletier, Humphries et al. 2014, Khera, Kolte et al. 2015, De Luca, Marini et al. 2016). Further, studies suggest that men are more likely then women to receive treatment in other time-sensitive medical conditions, alluding to a potential gender bias in emergent responses (El-Menyar, El-Hennawy et al. 2014, Forrester, Forrester et al. 2017). While studies suggest gender differences exist among arrest victims with regard to chance of survival (Bray, Stub et al. 2013, Wissenberg, Hansen et al. 2014, Bosson, Kaji et al. 2016), little work has primarily examined layperson B-CPR delivery or this relationship in the public and home environment. Understanding whether B-CPR gender variation persists in these two environments may present important considerations for future training and public messaging around layperson CPR, a critical and potentially modifiable link in the cardiac arrest chain of survival (Cummins, Ornato et al. 1991).

We conducted a retrospective cohort study to assess whether there is variation in layperson B-CPR rates by gender for OHCA in both the home and public environments. We hypothesized that females would be less likely than males to receive B-CPR in the public environment. We then sought to measure whether B-CPR variation was associated with differences in clinical outcomes, hypothesizing that females have lower survival to hospital discharge.

Methods

Study design

We conducted a retrospective cohort study, examining differences in B-CPR rates based on victim's gender among adult, non-traumatic cardiac arrest events that occurred in the out-of-hospital setting. To assess this, we used data collected prospectively for several clinical trials by the U.S. sites of the Resuscitation Outcomes Consortium (ROC) from April, 2011-June, 2015, including Alabama, Dallas, Milwaukee, San Diego, Pittsburgh, Portland, and Seattle-King County. The study protocol was determined to be exempt from review by the University of Pennsylvania Institutional Review Board.

Data sources

ROC represented an NIH-funded clinical trial network focused on OHCA and traumatic injury, ending in 2015. Since 2006, ROC collected data from 11 municipal regions in the US and Canada. All participating EMS agencies within ROC sites prospectively collected patient-level data on persons treated for OHCA. Detailed methods for EMS data collection have been previously described (Davis, Garberson et al. 2007). Collected variables at the patient level included B-CPR and other time sensitive OHCA data elements. ROC epidemiologic data have been reported in various clinical trial publications previously (Nichol, Leroux et al. 2015, Kudenchuk, Daya et al. 2016) (Weisfeldt, Everson-Stewart et al. 2011).

Patient-level variables

We defined a victim who received B-CPR as anyone who received B-CPR from a layperson excluding those from police, healthcare workers, Emergency Medical Services (EMS) or other first responders. We excluded pediatric victims (age<18) and those who experienced OHCA from traumatic injury. We also excluded arrest events that occurred in a residential institution (e.g. skilled nursing facility) or healthcare center and those that were witnessed by EMS. Gender was defined as male or female. To avoid collinearity, race and ethnicity were combined as a categorical variable defined as White non-hispanic, Black non-hispanic, Hispanic, and Other race, similar to methods conducted previously in the literature (Sugarman, Sitlani et al. 2009, Blewer, Ibrahim et al. 2017). Age was modelled both continuously and as a categorical variable (by age deciles). Location of cardiac arrest included whether the event occurred in the home, street/highway, public building, place of recreation, other public location, and other non-public environment. Public location was then defined as a street/highway, public building, place of recreation, or other public location. Event time of day was grouped based on assumed daily activity similar to previous studies from our group (6:00am-8:59am, 9:00am-3:59pm, 4:00pm-6:59pm, 7:00pm-10:59pm, 11:00pm-5:59am) (Wallace, Abella et al. 2013). We calculated the duration of time to arrival of EMS in minutes from the time that a dispatch center received the 9-1-1 call to when the first EMS dispatched unit arrived on scene.

Statistical analysis

The data, analytics methods, and study materials will be made available to other researchers for the purposes of reproducing the results or replicating the procedure. Data were analyzed using a statistical software package (STATA 14, Statacorp, College Station, TX). The dataset was missing 3.8% of the primary outcome, and variation of the dependent variables from 0-3.9% with the exception of race which is missing 41.2%, which is consistent with prior ROC studies where ascertainment of race is difficult;(Reinier, Thomas et al. 2011) we analyzed differences in the covariates by missingness and assessed the final model including the missing variables for race as an unknown category. As a sensitivity analysis we used multiple imputation to impute the missing covariates of interest. To conduct the sensitivity analysis, we imputed the data using multiple imputation with 20 imputations and a multivariate normal regression algorithm. Once imputed we estimated the logistic regression with the imputed dataset. Our final primary hypothesis of interest, patient-level gender and likelihood of receipt of B-CPR in the public did not change with imputation of the datasets (data not shown).

Using logistic regression modeling, we analyzed whether there were differences in layperson B-CPR rates by gender. We built models for the likelihood of overall B-CPR delivery and examined the likelihood of B-CPR delivery in the home and public locations. Covariates were assessed in a univariate analysis with admission into the larger model based on a cut off of $p<0.15$. The final regression model included layperson B-CPR, site, time of event, location of event, patient demographics (age, race/ethnicity, gender), EMS time to arrival, and whether the event was witnessed. Since we were primarily concerned with controlling for site differences, site was modeled and tested as a fixed effect in the final regression equation. Site A was arbitrarily selected as the reference group. We used post-estimation methods including goodness of fit tests and predicted probability figures to examine final regression model fit.

Results

Characteristics of OHCA events

From 2011-2015, there were 19,331 adult, non-traumatic OHCA events in the seven US ROC sites that did not occur in an institutional or healthcare facility and were not EMS witnessed. Of these, 17% (3,297/19,331) occurred in a public location, while 82% (15,788/19,331) occurred in private environments (e.g., patient homes). Mean victim age was 64±17 years. Overall, 63% (12,225/19,331) of the arrest victims were male (Table 4).

Unadjusted analysis of B-CPR delivery

Among the total cohort, 37% (7,096/19,331) of the population received B-CPR, while 44% (1,444/3,297) received B-CPR in the public and 35% (5,564/15,788) received B-CPR in private settings. Among all events, 35% (2,487/7,086) of females and 38% (4,605/12,225) of males received B-CPR (p<0.01), while 35% (2,198/6,328) of females and 36% (3,364/9,449) of males received B-CPR in private (p=ns). In contrast, 39% (272/694) of females and 45% (1,170/2,600) of males received B-CPR in public locations (p<0.01).

Multivariable logistic regression of B-CPR and gender

We examined all arrest events in a multivariable logistic regression controlling for site, time of day of the event, age, race/ethnicity, witnessed status, and time to arrival of EMS (Table 5). This relationship varied, when assessing B-CPR delivery in a multivariable logistic regression by gender in the public environment with males having a significant association with receiving B-CPR delivery compared to females OR: 1.27 (95% CI: 1.05-1.53, p=0.01) (Table 5). In contrast, this difference was not found when evaluating B-CPR delivery in the home environment (OR: 0.93 (95% CI: 0.87-1.01), p=ns) (Table 5).

Patient-level survival

Examining all arrest events regardless of arrest location in a logistic regression model including gender, receiving B-CPR was significantly associated with survival to hospital discharge OR: 2.03 (95% CI: 1.86-2.22, $p<0.01$); in the same model, male gender was significantly associated with survival compared to females OR: 1.33 (95% CI: 1.21-1.46, $p<0.01$). While controlling for site, age and race in a multivariable logistic regression model, B-CPR was associated with a 1.69 (95% CI: 1.54-1.85) increased odds of survival to hospital discharge ($p<0.01$); males had a 1.29 (95% CI: 1.17-1.42) increased chance of survival compared to females ($p<0.01$).

Discussion

In this investigation of B-CPR delivery for non-traumatic OHCA within the U.S., males had a significantly increased likelihood of receiving B-CPR compared to females among arrests that occurred in public locations. Furthermore, survival was greater among those that received B-CPR and among males compared to females. Interestingly, this gender disparity of B-CPR delivery was not found in the home environment, where lay responders are more likely to be family members. To our knowledge, this is the first demonstration of national gender disparities in B-CPR delivery. It is estimated that over 100,000 individuals suffer OHCA in public locations each year in the U.S (Benjamin, Virani et al. 2018). When taken together with the large effect size of B-CPR on survival to hospital discharge, this suggests an important gender disparity with broad clinical impact for resuscitation care and patient outcomes (Hasselqvist-Ax, Herlitz et al. 2015, Kragholm, Wissenberg et al. 2017).

Our work extends the findings of prior investigations that demonstrated disparities of B-CPR delivery by neighborhood-level characteristics such as race and socioeconomic status. For example, studies have examined geographic and racial differences in survival from OHCA, and suggested a correlation with these variables and B-CPR delivery rates (Sasson, Rogers et al. 2010, Moon, Bobrow et al. 2014, Nassel, Root et al. 2014, Girotra, van Diepen et al. 2016). Other investigations measuring B-CPR delivery have found disparities related to geography, socioeconomic status (SES), and racial composition (Sasson, Keirns et al. 2011, Sasson, Magid et al. 2012, Root, Gonzales et al. 2013). Specifically, a recent study found that individuals living in low-income Black neighborhoods were much less likely to receive B-CPR compared to the national population (OR 0.49, 95% CI 0.41-0.58) (Sasson, Magid et al. 2012). While other works have suggested OHCA survival differences by gender (Wigginton, Pepe et al. 2002, Herlitz, Engdahl et al. 2004, Adielsson, Hollenberg et al. 2011). B-CPR delivery and its association to victim gender was not characterized in these studies.

Past studies have examined survival differences by gender and the effect of estrogen on outcomes from sudden cardiac arrest (Bray, Stub et al. 2013, Wissenberg, Hansen et al. 2014, Bosson, Kaji et al. 2016). Understanding survival differences is complicated, however, by the confluence of both biologic factors (estrogen and gender differences in ischemia-reperfusion response) and responder factors (delivery of CPR, other chain-of-survival metrics). In this analysis, we primarily examined the likelihood of receiving layperson B-CPR delivery based on victim's gender to better understand responder factors that might influence survival by gender. The B-CPR differences found in our work, specifically in the public location compared to the home, may speak to different types of responders and motivation of the lay responders in the public compared to the home. It is highly probable that individuals that respond in the home are family members of the victim, where as those that are responding in the public may represent unrelated members of the general public. Since B-CPR rates were higher among men then women in the public setting, it may suggest inherent barriers to B-CPR delivery or other biases among the responder population that remain to be elucidated. Few studies have characterized laypersons who performed B-CPR or laypersons who witnessed OHCA events but failed to do so;(Swor, Khan et al. 2006) further work to characterize lay responders and barriers to B-CPR delivery is needed.

Since B-CPR was more prevalent among male victims in the public environment, this finding also presents an opportunity to improve messaging of CPR from emergency dispatchers. Dispatchers are often trained to offer guidance to encourage B-CPR during an arrest event (often termed “dispatch-assisted” or “telecommunicator-assisted” CPR). In most cases, the dispatch instructions follow a uniform script, but do not address physical characteristics or gender-related issues pertaining to either rescuer or victim. It is unknown through this analysis whether dispatch-assisted CPR was more prevalent among victims of one gender or the other. The findings of gender disparity in B-CPR may present an actionable opportunity for OHCA in public settings, to allow for scripting and additional interventions around targeting and improving B-CPR rates to address OHCA victim gender.

Overall, these findings highlight an important knowledge gap in resuscitation science: understanding of layperson response to OHCA events. In our work, the gender of rescuers was unreported, as is common in most investigations of OHCA care. In addition, few studies have evaluated motivational factors among laypersons and barriers to actual performance, nor have investigations characterized the quality of layperson response. Few studies, for example, have evaluated CPR quality during layperson B-CPR. Given the significant impact of B-CPR on eventual outcome, further work to measure layperson B-CPR delivery, and the quality of rescuer performance, represents a crucial priority. Next steps may include designing a study that understands bystander motivation and, more generally, layperson CPR quality.

There are limitations inherent in this retrospective cohort analysis. Confounders of the relationship of B-CPR and victim gender may have influenced our findings. For example, we were unable to control for socioeconomic status in this analysis, as the individual-level socioeconomic information was not present in our dataset. Despite this, measures were taken to minimize bias by analyzing the data as a multivariable analysis, although there may be unmeasured confounding since this was not the primary outcome of interest for the set of ROC investigations.

Further, as described above, this dataset did not include rescuer demographic data, such as age or gender, and therefore it is unknown if male or female rescuers are more likely to perform B-CPR. Finally, it is unknown whether the results from layperson response within the ROC consortium sites adequately represent the wider landscape of OHCA in the U.S.; however, other findings from our investigation such as patient demographic data and survival rates are consistent with national reports,(Benjamin, Virani et al. 2018) suggesting that our work is likely generalizable.

In conclusion, males had a significantly increased likelihood of receiving B-CPR compared to females in public locations. Survival was associated with B-CPR delivery and was higher among males compared to females. It is possible that these measured disparities reflect inherent biases among the responder population that delivered B-CPR. These findings could inform future messaging to lay responders, health care providers and dispatchers regarding public B-CPR delivery through targeted messages addressing potential biases.

Chapters 2 and 3 focused on quantifying estimated public CPR training, B-CPR delivery, and associated disparities. The next chapter of this monograph will use this work to assess whether increased community CPR training is associated with layperson B-CPR delivery.

Chapter 3 Acknowledgement

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CHAPTER 4: COMMUNITY CPR TRAINING AND BYSTANDER CPR DELIVERY

The prior chapter explored disparities in layperson B-CPR delivery. This next chapter will use the methodology for quantifying estimated CPR training prevalence from Chapter 2 and the regression created in Chapter 3, to examine community CPR training and the association with layperson B-CPR delivery to answer the question: does higher community CPR training increase B-CPR delivery?

Prompt delivery of B-CPR may double the chance of survival from OHCA, yet less than one-third of victims receive B-CPR in many US communities (Nichol, Thomas et al. 2008, Girotra, van Diepen et al. 2016). To address this, there have been various initiatives to improve B-CPR delivery including implementing D-CPR protocols and mass CPR training programs (Bobrow, Panczyk et al. 2012, Garcia del Aguila, Lopez-Rebollo et al. 2014). Despite broad efforts to train individuals in CPR, it is unknown whether there is an association between increased community-level CPR training and B-CPR delivery rates in the US.

Increasing layperson CPR training may have an important impact on OHCA outcomes by increasing the number of trained bystanders who subsequently deliver B-CPR; however, the association between public CPR training and B-CPR delivery is poorly quantified, and it is unknown whether the strength of this association varies depending on community factors. One of the few studies that has sought to quantify this, is a study which examined self-reported CPR training from a survey conducted in Victoria, Australia. The investigators categorized CPR training and regional B-CPR by high and low training, and examined regional variation by high and low CPR training and B-CPR (Bray, Straney et al. 2017). The investigators found that rates of lower CPR training were associated with lower rates of B-CPR (Bray, Straney et al. 2017). To our knowledge, no study as assessed this association in the US. Understanding these relationships may have the potential to greatly influence CPR education programs and inform future public health initiatives, to maximize the lay public response to OHCA and improve survival.

We assessed whether there is an association between higher community-level public CPR training and increased B-CPR delivery. We hypothesized that the likelihood of receiving individual-level B-CPR delivery will be higher in communities with increased public community CPR training.

Methods

Study design and data sources

This is a semi-ecologic study, meaning the study was designed to combine individual-level data with community-level survey data. By doing so, this may further causal inference and reduce the potential for ecologic bias. Specifically, we used individual-level patient data and aggregated community-level CPR training to assess whether higher public CPR training increases the likelihood of B-CPR among adult, non-traumatic cardiac arrest events that occurred in the out-of-hospital setting.

To examine B-CPR delivery, we used individual-level data collected by the U.S. ROC sites from April, 2011-June, 2015, including Alabama, Dallas, Milwaukee, San Diego, Pittsburgh, Portland, and Seattle-King County. Additional details of the ROC dataset were described in depth in Chapter 3 and a recent publication by Blewer et al in *Circulation: Cardiovascular Quality and Outcome* (Blewer, McGovern et al. 2018).

In addition, from 2/2016-12/2016, we conducted a survey to measure community-level CPR training in these same ROC communities; survey data were collected via random digit dial (RDD) telephone methodology in collaboration with an established social sciences research organization

(SSRS, Media, PA) at the U.S. ROC sites. A randomly selected adult cohort (age>18 years old) was queried as part of an ongoing omnibus survey, through both landline and mobile telephone modalities. After determining eligibility, participants were given a series of questions designed to assess individual-level demographic characteristics and CPR training status. Methodology from this CPR training survey has been published elsewhere and is described in detail in Chapter 2 and a recent publication by Blewer et al in the *Journal of the American Heart Association* (Blewer, Ibrahim et al. 2017).

To account for neighborhood characteristics, we used census-level estimates from the 2014 American Community Survey (ACS) conducted by the U.S. Census Bureau (2014). The ACS provides small area estimates, in this case census tract, of areas formally surveyed via the decennial long-form census survey. Variables collected include, but are not limited to, census tract-level gender, age, and SES.

The study protocol was determined to be exempt from review by the University of Pennsylvania Institutional Review Board.

Patient and neighborhood-level variables

We used the same patient-level variables from the ROC dataset described in detail in Chapter 3. From the ACS, we included characteristics that geographically matched data on census tract from the ROC dataset. We included the following neighborhood characteristics: 1) percent of the census tract that identified as female, 2) census-tract median age, 3) percent of the census tract that is high school educated, and 4) percent that identify as White, non-Hispanic.

CPR training variable

We surveyed adults living within the ROC sites defined by ROC census tracts (n=4365 interviews). The responses allowed us to make inferences both between and within ROC sites regarding current CPR training prevalence (trained within 2 years). Detailed discussion of measurement and quantification of the CPR training variable is discussed in detail in Chapter 2. As previously discussed, we used the individual-level, OHCA, B-CPR delivery data described in detail in Chapter 3. We added B-CPR training as an aggregated covariate to assess the relationship of community-level CPR training on B-CPR delivery in a multivariable logistic regression model. In this model, we accounted for location type, time of day, initial rhythm, race, gender, age, D-CPR, and neighborhood characteristics (SES, race, and age).

Rationale for the aggregated unit of analysis and buffer definitions

To help define the aggregated unit of analysis, we used prior research definitions of egocentric neighborhoods, a technique used to define a neighborhood as a radius around a particular location. Many studies have commented on the importance of accurately defining and selecting a community when analyzing community studies (Browning and Soller 2014, Duncan, Kawachi et al. 2014, Mooney, Richards et al. 2014). Specifically, the use of zip codes or mailing addresses may incorrectly describe an individual's neighborhood or community (Browning and Soller 2014, Duncan, Kawachi et al. 2014, Mooney, Richards et al. 2014). A recent manuscript in the *American Journal of Epidemiology* suggesting the use of egocentric buffers to define neighborhoods, since it crosses typical zip code, county and city-level boundaries (Duncan, Kawachi et al. 2014). In this publication, Duncan et al illustrated the use of these buffers by examining youth's access to alcohol outlets by using a 400 meter circular buffer, 800 meter circular buffer, 400 meter street network buffer, and 800 meter street network buffer (Duncan, Kawachi et al. 2014). Rationale for these buffer sizes are ease of access through ArcGis, version 10.5 (Environmental Systems Research Institute, Redlands, California). No study has used egocentric buffer definitions to create a neighborhood-level exposure from survey data, or used egocentric buffers to define community-level CPR training.

ArcGis buffer development

To create the egocentric buffers, the ROC dataset was geocoded to individual census tract centroids (geometric center, most dense area) using ArcGIS, version 10.5 (Environmental Systems Research Institute, Redlands, California). From the census centroid, spatial buffers of 400 meter circular, 800 meter circular, 400 meter street network, and 800 meter street network were created using the ArcGIS buffer tool and ArcGIS network analysis tool. To calculate the buffer proportion of area within the underlying zip code, the ArcGIS intersect tool was used. Specifically, composition of the community CPR training variable was calculated from where the buffer fell within geographic bounds regardless of zip code or census tract constraints. The final aggregated variable represented the proportion of individuals trained in CPR within the egocentric buffer.

Statistical analysis

Data were analyzed using a statistical software package (STATA 14, Statacorp, College Station, TX). Using logistic regression modeling, we analyzed whether there were differences in layperson B-CPR rates by proportion of community-level CPR training. We built models to assess the likelihood of overall B-CPR delivery and examined the likelihood of B-CPR delivery by public CPR training buffer catchment areas. Patient-level and neighborhood-level variables were assessed in a univariate analysis with admission into the larger model based on $p<0.15$. The final regression model included layperson B-CPR, site, time of event, location of event, patient demographics (age, race/ethnicity, gender), EMS time to arrival, whether the event was witnessed, and census-tract level gender, age, and education. County and census tract were modeled and tested as a fixed effect in the final regression equation. Population density was included to account for neighborhood level population variability. Final analysis were presented as an unadjusted and adjusted model of each buffer (400 meter buffer, census tract, 800 meter buffer, 400 meter street buffer, 800 meter street buffer). The CPR training variable was population weighted when it was aggregated into the final multivariable logistic regression model. We used post-estimation methods to examine final regression model fit.

Results

Characteristics of OHCA events and the CPR survey responders

From 2011-2015, there were 17,883 adult, non-traumatic OHCA events that matched to the CPR training survey and census tracts in the seven US ROC sites. Mean victim age was 64±17 years. Overall, 63% (11,260/17,883) of the arrest victims were male (Table 6). Within this OHCA cohort, 82% (14,644/17,883) occurred in the home. B-CPR was performed in 36% (6,512/17,883) of cases.

Individuals were surveyed from 7 ROC sites representing Alabama, California, Oregon, Pennsylvania, Texas, Washington, and Wisconsin; 19% of the respondents identified being currently trained in CPR (trained within the past 2 years). Of those currently trained, the mean age was 41 (95% CI: 40-43), and 51% of the respondents were female, while 62% of the respondents were White and 13% were Black (Table 7).

Unadjusted analysis of CPR training and B-CPR delivery

In an unadjusted analysis, increased community-level CPR training was associated with an increased likelihood of receiving B-CPR (1.20 (95% CI: 1.05-1.37), $p<0.01$) within the 400 meter buffer. Within census tracts, increased community-level CPR training was associated with an increased odds of receiving B-CPR (1.21 (95% CI: 1.06-1.39), $p<0.01$). Similarly, in the 800 meter buffers, the 400 meter street buffers, and the 800 meter street buffers, increased community-level CPR training was associated with an increased likelihood of victims receiving B-CPR (1.21 (95% CI: 1.06-1.39), $p<0.01$; 1.18(95% CI: 1.04-1.35), $p=0.01$; 1.22(95% CI: 1.07-1.41), $p<0.01$, respectively) (Table 8).

Multivariable logistic regression of CPR training and B-CPR delivery

When controlling for patient-level cardiac arrest episode time in seconds, location of the event, age, victim's gender, and EMS response time, within the 400 meter buffer, increased community-level CPR training was associated with a 1.29 (95% CI: 1.12-1.49) increased likelihood of receiving B-CPR (p<0.01) (Table 9). The positive association between increased CPR training and increased B-CPR delivery was also seen within the census tract (1.29(95% CI: 1.11-1.50), p<0.01) the 800 meter buffer (1.28(95% CI: 1.10-1.48), p<0.01), the 400 meter street buffer (1.23(95% CI: 1.07-1.42), and the 800 meter street buffer (1.26(95% CI: 1.09-1.46), p<0.01 (Table 9). This relationship was similar when taking county into account (Table 10).

When including ROC site, this relationship was no longer significant (p=ns), suggesting that site acts as an effect modifier on the relationship of community-level CPR training and B-CPR delivery (Table 11). Further, we examined the effect of accounting for population density in the relationship, and the effect of site was still seen on the relationship of community-level CPR training and B-CPR delivery (Table 11).

Discussion

This study suggests that the relationship between a higher prevalence community-level CPR training and increased likelihood of receipt of B-CPR delivery was modified by site. Site may act as an effect modifier on the relationship between community-level CPR training and B-CPR delivery, or there may be additional unmeasured confounding variables within site that need to be accounted for when examining the relationship between increased community level CPR training and B-CPR delivery. Further, the lack of variation by aggregated unit of analysis or buffer suggest that there may be limitations in the precision of the survey sample size and data. These findings suggest that future work is needed to understand the modification of site, survey data, and variation within site which may be driving these findings.

Dispatch-assisted telephone CPR

An additional factor which may influence the relationship between CPR training and B-CPR delivery is D-CPR, or receipt of CPR instructions by a dispatcher when a layperson calls 9-1-1. Uptake of D-CPR by communities has been variable, and few studies have robustly examined the epidemiology of D-CPR (Bobrow, Panczyk et al. 2012, Bobrow, Spaite et al. 2016, Blewer and Abella 2018). Further, it is important to consider how CPR training and D-CPR interact; while studies have examined these topics separately, no investigation has examined the interplay between these strategies. A recent investigation found an increase in B-CPR with city-level increased training.(Bobrow, Spaite et al. 2016) Exploring the interactions between D-CPR and layperson CPR training may provide CPR trainers and emergency responders with the knowledge of how to target and improve interventions to advance CPR quality and increase B-CPR rates. While significant additional work is needed to improve the model proposed in this chapter (through accounting for various unmeasured confounders and improved sample size), future studies may use an enhanced version of the logistic regression model created in our study to assess the interaction between D-CPR, community-level CPR training, and B-CPR delivery. Understanding these interactions are critical for the field of resuscitation science and B-CPR delivery, specifically.

Community CPR training initiatives

We assessed whether higher prevalence of community-level CPR training increased the likelihood of individuals delivering CPR. While our study was able to robustly measure individual-level, self-reported CPR training through survey questionnaires, the methods assumed an aggregated level of self-reported, community CPR training. As such, the study did not account for varying levels of community CPR training initiatives by site. Specifically, the study did not account for or track community awareness campaigns or CPR training initiatives which may influence site effect modification. Mass CPR training campaigns may allow for individuals to be reached or made aware of CPR through means unaccounted for through an individual-level survey. Future work may consider methods to quantify community-level CPR training initiatives and methods to measure and integrate this in our own assessment. Furthermore, the interaction of mass CPR training campaigns and the effect on individual-level identified CPR training would present a novel area to research to help our understanding of the relationship between CPR training and B-CPR delivery.

Continual monitoring of CPR training and the effect on B-CPR delivery

This work ultimately highlights the critical need to prospectively monitor and assess the relationship of CPR training in communities and its association with B-CPR. Measuring CPR training rates prospectively and robustly via survey research methods may allow communities to understand the areas to target CPR training interventions and provide insight on how to improve B-CPR delivery. Future initiatives may consider incorporating CPR training questions onto national or community household surveys such as the Behavioral Risk Factor Surveillance System (conducted through the Center for Disease Control) or Southeastern Pennsylvania Household Health Survey (conducted through Public Health Management Corporation). Robust understanding and improvement of the CPR training survey methodology, and development and retooling of our regression analysis through adding additional site-specific confounding variables may allow us to more precisely monitor community CPR training and B-CPR delivery.

Limitations

There are several limitations inherent in this study design. First, the sampling and self-selection inherent in our survey methods may not provide us the ability to examine community CPR training and B-CPR delivery in a robust manner. Future work should involve a more precise survey sample size, and ability to estimate the survey on a level more specific then zip code. Refining this method may be an area for future investigation. Secondly, the survey data were collected via self-report which is subject to selection and social desirability bias. Future work may consider using data obtained through certification card agencies such as the American Heart Association and American Red Cross to supplement the survey. Lastly, defining a neighborhood level of analysis is difficult, and we decided to use the buffer catchment areas to help define our aggregated unit of analysis. While this approach has support from the epidemiologic literature, this definition has limited utility to specifically address and implement CPR training initiatives. Specifically, targeted training initiatives by a buffer may not be easily translatable to public health officials or AHA training centers. Despite this, the work represents a novel investigation of the relationship of community-level CPR training and B-CPR delivery.

Conclusion

In conclusion, increased community-level CPR training was associated with layperson B-CPR delivery; however, site was an effect modifier on the relationship between increased community-level CPR training and layperson B-CPR delivery. Future work is needed to address the limitations with the survey data and sample size. These findings provide insights on the relationship between CPR training, B-CPR delivery, and the effect of site.

In this chapter, we found that site modified the relationship between community CPR training and B-CPR delivery. This may be due to site specific confounding that impacts CPR training prevalence or delivery. One such potential confounding variable is the variable provision of D-CPR at the community level, which is the area of investigation in the next chapter.

CHAPTER 5: MISSING DATA AND DISPATCH-ASSISTED CPR

When a bystander calls 9-1-1, they may receive CPR instruction over the phone by a dispatcher; this is often referred to as D-CPR. D-CPR may confound the relationship between increased community CPR training and B-CPR delivery, but the relationship between D-CPR and CPR training is poorly understood. Unfortunately, the D-CPR variable has been poorly measured in the ROC dataset. While the ROC dataset has been used in many prior publications, the quality of data measurement within ROC has not been rigorously assessed. This monograph provides a unique opportunity to evaluate this, specifically assessing whether missing data, a form of measurement error, might be present in the ROC dataset. We now seek to assess in this chapter the degree of missingness of the ROC D-CPR variable, and to establish methods to address this measurement limitation in the ROC dataset.

Over the years, the resuscitation community has relied on observational datasets (CARES, Get with the Guidelines) to answer various inquiries related to in and out of hospital cardiac arrest (Sasson, Magid et al. 2012, Chan, Berg et al. 2016, Fordyce, Hansen et al. 2017, Starks, Schmicker et al. 2017). Many of these observational datasets may have varying degrees of missing data, specifically with regards to measurement of D-CPR. When analyzing the data, not taking missing data into account introduces bias to estimations that may lead to incorrect conclusion of associations.

There are several conventional approaches to handling missing data including complete case analysis and multiple imputation (MI). With regards to complete case analysis, cases with missing data are excluded from the final estimation. This method may introduce potential biases in the final conclusion if the data are not missing completely at random (Sterne, White et al. 2009). MI is a potentially powerful alternative to complete case analysis and uses information from the observed covariates to predict missing values (Sterne, White et al. 2009). Given that no study in the resuscitation literature has assessed methods to handle missing data in observational datasets, exploring MI and understanding the limitations to this method may benefit the resuscitation community and help inform future analyses by allowing us the opportunity to further explore areas and topics which many have previously been avoided because of missing data.

The objective of this study was to examine the impact of missingness on the relationship of D-CPR on B-CPR delivery. Since the Seattle King County ROC D-CPR data were missing data, we examined the degree of bias introduced by the missing data and the impact on the validity of the results when using MI. To assess this, we compared the ROC findings using MI to a complete dataset (Seattle King County's Emergency Medical Services (EMS) data). Both the ROC and EMS Seattle King County, Washington data were extracted from the same data source. We proposed that if MI was able to adequately address the missing data in the Seattle King County ROC dataset, future work would involve applying this method to the larger ROC dataset to answer larger inquiries related to D-CPR.

Methods

Study design

We conducted a retrospective study to determine the degree of missingness and its impact on differences in B-CPR rates by receipt of D-CPR among non-traumatic OHCA events. To assess this, we used data originally collected prospectively within King County, Washington, through parallel activity by the ROC and EMS agencies from September 2012 to December 2015. Since all patient data were de-identified, the study protocol was determined to be exempt from review by the University of Pennsylvania's Institutional Review Board.

Data sources

Our analysis used two separate data sources from (1) King County's ROC and (2) King County EMS databases. Details of the ROC NIH-funded clinical trial network are described at length in Chapters 3 and 4. For the purposes of this analysis, we used data primarily from King County.

Seattle King County EMS centered in Seattle, Washington operated in partnership with five dispatch centers, five paramedic providers, and twenty-eight fire departments. The EMS regional services consisted of medical direction, effective research, and quality assurance, along with community programs, strategic planning, and management of the regional EMS levy fund. These EMS data have been reported elsewhere in peer-reviewed medical journals (Prekker, Kwok et al. 2014, Calkins, Isaksen et al. 2016).

Patient-level variables

Both the ROC and EMS datasets were extracted and structured to assess if B-CPR was applied to a victim of cardiac arrest and whether the lay bystander received D-CPR. We excluded those that had arrests related to trauma and those that occurred in residential institutions (e.g. skilled nursing facility) or a healthcare center and those that were witnessed by EMS. Both datasets included patient age (as a continuous variable), pre-hospital reported gender, whether the arrest event was witnessed, information on who initiated CPR, whether D-CPR was given, location of the arrest, cardiac arrest time of day, and outcome of the patient (survival to hospital discharge and return of spontaneous circulation). Gender was defined as male or female. Episode time was reported as seconds from midnight. For the purposes of our investigation, B-CPR was defined as anyone who received B-CPR from a layperson excluding those from police, healthcare workers, EMS, or other first responders. Survival to hospital discharge was defined as whether the patient was discharged alive; return of spontaneous circulation was defined as anyone who was alive, died in the hospital after being admitted, died in the emergency department, or left alive in the field. D-CPR was annotated as to whether a professional or citizen received D-CPR instructions and initiated chest compressions.

Matching the ROC and EMS datasets

The de-identified datasets initially varied between ROC (n=4,970) compared to EMS (n=3,021), despite matching data ranges, which suggested that different subjects were included in each dataset. Given the attainable similar variables, we merged the datasets based on cardiac arrest episode time, age, and sex. To perform this, we used a matching process that included matching exactly on age and sex, while allowing for slight deviation from time of cardiac arrest event (deviation higher or lower in seconds). As a sensitivity analysis, we examined the variation in the number of cases matched from ±5 seconds to ±500 seconds (approximately 8 minutes) (Table 12). We chose to proceed with the matched datasets that varied by 3.3 minutes (200 seconds).

Missingness assumptions

We assessed whether the data were Missing Completely at Random (MCAR), Missing at Random (MAR), or Missing Not at Random (MNAR). As described in detail in Chapter 1, MCAR assumes there are no systematic differences between the missing values and observed values, while MAR assumes any systematic differences between the missing values and observed values can be explained by differences in the observed data; MNAR assumes the missing data are missing due to systematic unmeasured differences. Additionally, we assessed the implications of how the data were missing through causal diagrams. We also examined the clinical and patient characteristics and whether variable missingness differed between observed characteristics in the dataset.

Complete case analysis and multiple imputation

As an initial analysis, we assumed the data were MCAR and analyzed our data using complete case analysis.

Next, we assumed the data were MAR and performed MI assessing the MI model fit iteratively (Appendix 3). We generated a list of clinical and patient-level variables thought to inform D-CPR and removed those that were missing data or perfect predictors. We then performed MI with 20, 100, 150, 250, and 500 iterations fitting the model for binary logistic MI. Further, we assessed the MI fit by examining the distributions of the observed and imputed data similar to approaches discussed in previous publications (Gelman, Van Mechelen et al. 2005, Nguyen, Carlin et al. 2017). We also examined how the mean was distributed over imputations. To assess our MI results from the ROC dataset, we performed MI in the EMS dataset under the MCAR and MAR simulated missingness assumptions.

EMS simulated dataset creation

We used the matched EMS dataset and created three simulated datasets under MCAR and MAR assumptions. We patterned the missingness by these assumptions, and created datasets with 10%, 20%, 40%, 60%, and 80% missing. Rationale for these missingness levels are that 10-20% are common missingness ranges in observational data, while increasing missingness by 20% seemed common in the missing data simulation literature (Blankers, Koeter et al. 2010, Marshall, Altman et al. 2010). In order to create the MCAR dataset, we drew a random sample of the missing data at various levels of missingness (10%, 20%, 40%, 60%, and 80%). To simulate the MAR scenario, we perturbed age by randomly sampling cases that were older (>49 yrs of age), and removing their D-CPR information. This MAR simulation approach is similar to other simulation studies (Hardt, Herke et al. 2012, Sullivan, Salter et al. 2015). As a sensitivity analysis, we further perturbed the age MAR assumption, by specifically sampling older individuals with the goal of driving the regression association closer to the null in the complete case analysis.

Statistical analysis

All statistical analyses were conducted in Stata 14 (StataCorp LLC, College Station, TX). Matching was executed using the “nearmrg” command in Stata 14.0, which allowed us to delineate varying deviation limits. Demographic data were displayed using simple frequencies and percentages. To assess differences in clinical and patient-level variables by missing data, descriptive statistics were executed using Pearson's chi-squared and Student's t-test, as appropriate for categorical and continuous data. To conduct the complete case analysis, we analyzed the data using risk ratios examining the likelihood of layperson bystander CPR by dispatch CPR. We reported the data using the risk ratio, since the odds ratio is an imprecise measurement when the exposure is high. We accounted for missing data in the D-CPR variable using logistic regression MI. To estimate the risk ratio, after the data were imputed we used modified Poisson regression with a robust estimator (Zou 2004). We hypothesized that the data were MAR, and we examined this through simulating the "gold standard" EMS dataset, creating missingness assumptions (MCAR and MAR). Once the simulated data were created, we reported the final simulated data using complete case analysis and binary logistic regression MI using modified Poisson regression with a robust estimator. As a post estimation assessment, we examined the mean distribution cuts of the simulated MI imputations in the data.

Results

Characteristics of ROC and EMS datasets

From 2011-2015, there were initially 4,996 subjects in the ROC dataset and 3,021 subjects in the EMS dataset (Figure 4). After matching by age, sex and episode time-of-day in seconds, there were 1,790 subjects that matched exactly by age and sex, and varied by 3 minutes in cardiac arrest episode time (Figure 4 and Table 12). The mean age of both datasets were 63.96±19.59, and 1149/1790 (64%) of the subjects were male. Of those in the ROC dataset, 773/1790 (43%) received bystander CPR, while 747/1790 (42%) received bystander CPR in the EMS dataset (Table 13); 1468/1790 (82%) of the ROC dataset had missing D-CPR variables, while 12/1790 (<1%) were missing in the EMS dataset. When examining missingness by clinical and patient-level variables in the ROC dataset, missingness varied by location type (D-CPR complete, home: 88% vs D-CPR missing, home: 83%) and receipt of B-CPR (D-CPR complete: 72% vs D-CPR missing: 36%) (Table 14).

ROC: Complete case analysis and multiple imputation

When analyzed using complete case analysis within the unmatched ROC dataset (n=911) D-CPR increased layperson B-CPR by (RR: 2.01(95% CI:1.76-2.33)). Examining the matched ROC dataset (n=322), using complete case analysis D-CPR provision was associated with an increased application of layperson B-CPR by (RR: 2.54 (95% CI: 2.00-3.21). In contrast, D-CPR provision was associated with the application of layperson B-CPR in the EMS dataset (n=1778) by (RR: 3.51 (95% CI: 3.22-3.83). Using multiple imputation, the ROC unmatched imputed risk ratio was 1.21 (95% CI: 1.15-1.26), while the ROC matched imputed risk ratio was 3.84 (95% CI: 2.97-4.98) (Table 15).

EMS: Simulation analysis

The risk ratio of D-CPR and the association with layperson B-CPR varied slightly over the complete case analysis when the data were modeled as MCAR. With 10% missing, the risk ratio was 3.47 (95% CI 3.17-3.80), while at 40% missing, the risk ratio was 3.28 (95% CI: 2.95-3.66), and at 80% missing, the risk ratio was 3.58 (95% CI: 2.93-4.37) (Table 16). These risk ratio associations were similar when the datasets were imputed with MI (Table 17).

When modeling the data as MAR, the risk ratio of D-CPR and the association with layperson B-CPR regressed closer towards the null, but was still significant in the complete case analysis as the missingness increased (60% missing: 3.12 (95% CI: 2.75-3.55) and 80% missing: 2.70 (95% CI: 2.32-3.15)). Using MI, the risk ratio point estimates maintained stability as missingness increased while the confidence intervals increased (60% missing: 3.26 (95% CI: 2.92-3.65), 80% missing: 3.34 (95% CI: 2.77-4.05)). As a sensitivity analysis, we further perturbed the MAR assumption and observed a similar pattern with the complete case analysis and MI risk ratios (Table 16 and 17).

Discussion

In this investigation of missing data in the D-CPR variable among OHCA in Seattle King County, use of MI was appropriate. Specifically, use of complete case analysis in the ROC dataset under estimated the association of D-CPR on layperson B-CPR, but MI was able to draw the association closer to the actual risk ratio seen in the EMS dataset. Furthermore, creating simulated MCAR and MAR datasets in the EMS dataset and varying the degree of missingness in the datasets further demonstrated the bias introduced in to the dataset when analyzing the data using complete case analysis. Use of MI in this simulated dataset, demonstrated the effectiveness of MI in drawing the data closer to the true association seen in the EMS dataset.

Epidemiologic studies examining D-CPR

Few studies have assessed the effect of D-CPR on B-CPR or survival from an epidemiologic observational dataset (Rea, Eisenberg et al. 2001, Wu, Panczyk et al. 2018). Specifically, the seminal D-CPR investigation published by Rea et al in *Circulation,* used data from Seattle King County, Washington (Rea, Eisenberg et al. 2001). Additionally, a number of investigations using data from Arizona have shown an increase in survival through bundled city-wide D-CPR protocol implementation (Bobrow, Spaite et al. 2016, Wu, Panczyk et al. 2018), but no study has looked at D-CPR provision on a nationwide level. This may be due to the variability of D-CPR data collection in observational datasets. This project demonstrated the ability to use MI to account for the missing data in the ROC Seattle King County dataset, thus possibly allowing us to use this method to demonstrate the association of D-CPR with SCA outcomes in other sites and throughout the ROC clinical trial network. Next steps involve using MI and the MI model created and fit through this analysis to assess the association of D-CPR on SCA outcomes in other ROC sites and the ROC database nationally. Ultimately, this work may help improve our understanding of D-CPR epidemiologic outcomes nationally.

Caveats with multiple imputation

While this study demonstrated the use of MI to account for a variable with 80% missingness, clinical studies should consider the use of MI for handling data that are MAR, but assess how the imputation model is fit and MI process is executed. Some clinical studies may not use MI possibly due to the perceived complex nature of applying MI. Furthermore, in some cases, use of MI may be conducted inappropriately without correctly fitting the model and selecting the appropriate variables. When applying multiple imputation, it is important to consider the variables being used to inform the imputed variable. Specifically, studies describe the importance of including the outcome variable in the imputation procedure (Sterne, White et al. 2009). Additionally, it is prudent to ensure that the auxiliary variables, or variables that help make estimates on the incomplete data, are not missing data and that the variables provide valuable information to the imputed variable(s) (Sterne, White et al. 2009). Regardless of the possible perceived complex nature of MI, the method is a useful tool for handling missing data and was seen to adequately address the 80% missingness in the D-CPR variable within our ROC dataset.

Methods to reduce missing data

Despite the availability of methods to address missing data, it is also important to consider methods to reduce missing data in future resuscitation studies. One such method may include improving data collection and quality assurance processes. In the example used for this analysis, both the ROC and the EMS databases were extracted from the same EMS run sheet, yet the data were then extracted and housed in different locations or databases. In this case, D-CPR was not the primary variable of interest in the ROC data analyses, which may be the reason for the lack of precise data capture through ROC. To help inform future studies, it may be important to consider checking the quality of all variables collected and ensure rigorous reporting metrics to reduce missing data. Other ways to consider improving data collection are through routine audits and regular training of the data administrators and staff.

Limitations

Since the data were de-identified, we were unable to match the datasets by patient identifiers. Additionally, there is suggestion that the data are MAR through assessment of the D-CPR missing variables and causal diagrams, but we are unable to assess whether the data are MAR. If the data are MNAR, the biases introduced by MI may be larger than analyses from complete case analysis. Unfortunately, it is impossible to determine if the data are truly MNAR, but we assessed the missingness assumptions through a variety of methods including causal diagrams. In addition, when using MI with a mixture of binary and continuous data, unnoticed perfect predictors are possible and most software is not robust to detect this issue (Molenberghs, Fitzmaurice et al. 2015). We fit our model to detect perfect prediction, but acknowledge the possibility that this may be an issue with our binary MI. Additionally, the D-CPR and B-CPR association was limited in that we are unable to account for whether those that did not get any type of B-CPR received D-CPR. Future studies may examine D-CPR outcomes nationally by survival and ROSC in addition to B-CPR.

Conclusion

In conclusion, we demonstrated the use of MI in handling 80% missing data in the D-CPR variable of the ROC dataset. Furthermore, we substantiated these findings through simulations conducted through the EMS dataset. Next steps involve applying these methods to the D-CPR variable in other sites in the ROC dataset to robustly answer questions related to D-CPR using a national dataset.

In this and prior chapters, we described a set of investigations of public CPR training, B-CPR delivery, and D-CPR. The next chapter will summarize our conclusions and discuss next steps and potential future investigations.

CHAPTER 6: CONCLUSIONS AND FUTURE DIRECTIONS

This work represents one of the first of its kind to examine measurement of public CPR training prevalence, B-CPR delivery disparities, and D-CPR in a doctoral thesis. By compiling this work in a single monograph, this represents a collective examination of the landscape of public CPR training, B-CPR delivery, and provides an approach to consider missingness in observational datasets related to OHCA and D-CPR. Each of these lines of investigation contribute separately to the field of resuscitation science while presenting opportunities to explore various lines of inquiries further in the future.

Public CPR training

Through conducting a national survey of the adult US population, we found that the national prevalence of those currently trained in CPR was low. Our data also suggested that while many individuals obtained CPR training at some point in time, few maintained current training. Further, older individuals were less likely to be CPR trained, and lower SES was associated with a decreased likelihood of CPR training. This work highlights several important areas to potentially impact future resuscitation science inquiry or public policy.

Quantifying the national prevalence of CPR training highlights the need for the resuscitation community to longitudinally monitor and track CPR training prevalence nationally, perhaps on an annual basis, to assess the impact of training programs and mass CPR education initiatives. This could be conducted through an academic institution, or through a non-profit organizational body such as the American Heart Association or American Red Cross. Ongoing monitoring of CPR training would allow for robust investigation of training disparities and more rational targeting of training efforts. Further, a more precise measurement of these trainings would allow researchers, public health professionals and CPR trainers to investigate census tracts and examine neighborhood-level CPR training disparities. This could critically inform targeted CPR training initiatives, specifically, targeting neighborhoods for CPR training that have low CPR training prevalence (Blewer and Abella 2014).

Further, this work identifies the need to consider methods to target, train, or retrain the older adult population in CPR. This is clinically relevant, as most OHCA events occur in the home environment where first responders are most likely spouses of similar ages to the victims (6^{th}-7^{th} decade of life). While measures have been taken to hone interventions to train high school students in CPR, few policies have been enacted to consider methods to train or retrain older adults. Studies have investigated targeted training for high-risk adult caregivers; further the American Heart Association noted the need to target training of adult caregivers in the 2015 AHA ECC CPR guidelines (Blewer, Leary et al. 2011, Blewer, Leary et al. 2012, Bhanji, Finn et al. 2015, Blewer, Putt et al. 2016). Future work may investigate implications of enacting policy change to promote CPR training methods that engage older individuals. For example, a future trial may examine the effect of training older adult cardiac caregivers and assess whether equipping them with the CPR skills needed to act in a SCA situation, might help them save the life of their family member or others in the future.

Lastly, as CPR training rates are low in the US, further work may be considered to promote methods to increase awareness around CPR and CPR training more generally. Recognizing this need, the AHA released a recent scientific statement that suggested the use of messaging to improve knowledge translation and implementation around resuscitation education (Cheng, Nadkarni et al. 2018); specifically, the statement authors write that “Psychology and marketing science may decrease stigma or change attitudes to increase individual or community action” (Cheng, Nadkarni et al. 2018). Few studies have examined messaging around CPR and CPR training, highlighting an important area for future investigation.

Bystander CPR delivery

When examining B-CPR delivery and gender disparities, we found that males had a significantly increased likelihood of receiving B-CPR compared to females in public locations. There were additional variations in terms of race and other patient-level variables, but this was the first work that examined gender disparities in receipt of B-CPR delivery. Of note, future work by our team is being conducted examining race, neighborhood characteristics and B-CPR (Blewer, McGovern et al. 2018). By considering gender disparities in the public and private environments, this may shed light on the potential for implicit biases from the responders acting in these particular environments. This work provides an important area for further inquiry, specifically regarding gender bias and B-CPR in the public.

As an applied epidemiologic study, this project identified a disparity with men being more likely than women to receive B-CPR in public locations, but the data and level of inquiry was unable to shed light on the reasons for this particular variation. Our findings may be due to potential gender biases, with individuals being wary of touching an unknown female’s chest, specifically since this phenomenon occurred in public locations. Unfortunately, few studies have truly quantified or characterized the lay responder. While work is potentially underway by various research teams to consider methods to understand the lay responder, few robust datasets allow for such level of inquiry. This may be due to the complex nature of having to find, identify, and interview lay bystanders to gather their perspective; although, understanding this may assist the resuscitation community in a variety of ways including better tailored messaging and training to higher risk populations. Future work may consider methods to characterize lay bystanders to understand the implications and potential biases for this gender disparity and occurrence in the public setting.

Another future line of inquiry may be to create a clinical trial examining the potential gender biases associated with B-CPR delivery. Specifically, a trial could be designed randomizing potential lay bystanders to performing CPR on a male torso or a female torso manikin in a simulated high-fidelity environment. The study could quantify observational, ethnographic attitudes of the bystanders, as well as CPR quality. In regards to CPR quality, it is unknown if the chest compression rate and depth are similar when examining CPR given on a male or female torso manikin. Future work may also consider placing this trial in a virtual reality setting to elicit potential biases of the subject in various simulated environments (eg- public vs the home). Lastly, these trials may allow for capture of the demographics of the lay responder and variation in individual response to a male or female manikin. Future work may consider implementing these trials and potentially impact our understanding of B-CPR delivery and layperson response by victim’s gender.

Community CPR training and bystander CPR delivery

Increased community-level CPR training was associated with layperson B-CPR delivery; however, site was an effect modifier on the relationship between increased community-level CPR training and layperson B-CPR delivery. This finding provides insight on the relationship between CPR training, B-CPR delivery, and reveals the effect of site.

Our work suggests that site is an effect modifier, but, unfortunately, the survey methodology may not be robust enough to truly quantify the within site CPR training variation. This could be due to the limited sample size of the survey methodology. Future work may consider increasing the sample size and precision of the survey sample area estimation while combining the survey data with CPR certification data or other methods to assess CPR training prevalence.

Further, it may be valuable to consider investigating sites using qualitative methods to understand whether there are additional unmeasured drivers to within site CPR training penetration and B-CPR delivery. Specifically, the odds ratio and site effect modification in our work suggest that we may have CPR training measurement error and perhaps unmeasured site level confounding. A qualitative investigation may help shed light on these factors. For example, recent work by Nallamothu and Chan's team used qualitative methods to investigate in-hospital SCA outcome variation (Nallamothu, Guetterman et al. 2018). Specifically, the study team identified top, middle and bottom performing hospitals by survival and performed qualitative in-depth interviews with key stakeholders within the hospitals (Nallamothu, Guetterman et al. 2018). While qualitative methods are not quantitatively scalable, future work may consider using qualitative methods to investigate ROC sites to better understand variation with public CPR training and B-CPR delivery. For example, conversations with key community stakeholders such as CPR trainers and EMS directors may highlight site specific community-level factors that affect the relationship between CPR training and B-CPR delivery.

Site effect modification from this work also highlights the importance of understanding the interaction of D-CPR and CPR training (Figure 5). It is unclear if laypersons respond to D-CPR instructions adequately if they have not received CPR training previously. Furthermore, current CPR training courses do not typically incorporate D-CPR information (or practice with D-CPR), and whether to include such training to improve actual care delivery remains an open question. To investigate this question, it is plausible that one could test randomizing subjects to receiving training or not receiving training prior to receiving D-CPR instructions in a simulation environment. Further elements of the trial could include ensuring that the subjects received the D-CPR instruction simulation 6 months post-CPR training, similar to follow-up work described by our team in *Circulation: Cardiovascular Quality and Outcomes* (Blewer, Putt et al. 2016). Enormous efforts have been placed into both D-CPR and layperson CPR education independently over past decades. The time is ripe to bring these two domains together and understand how these mechanisms interact.

Missing data and D-CPR

We demonstrated the use of MI in handling 80% missing data in the D-CPR variable of the ROC dataset. Furthermore, we substantiated these findings through simulations conducted through the EMS dataset under MCAR and MAR missingness assumptions.

Next steps within this line of inquiry involve applying these methods to the D-CPR variable in other sites within the ROC dataset to robustly answer questions related to D-CPR and B-CPR using the national dataset. We may consider applying this method to one site within the ROC dataset, and if the MI performs robustly, we will apply the method to the full dataset. This will allow us to examine the impact of D-CPR on B-CPR and survival outcomes nationally.

We may also consider crafting a commentary manuscript to the resuscitation community on the importance of minimizing missing data and improving observational data collection for research purposes, as discussed in Chapter 5. While safeguards may be in place to minimize missing data, problems occur in the processes that may impact data collection and affect the final outcomes. A clear, concise paper messaging the importance of minimizing missing data to the resuscitation community may assist with future resuscitation science study designs. Furthermore, recent literature has focused on the importance of MI, potential pitfalls, and considerations when implementing the missing data method. Considering the 80% missingness of the D-CPR variable and the dataset, we may consider an epidemiology methods manuscript focused on the use and performance of MI with 80% missing data in our dataset.

Lastly, appropriate handling of the missing data in the D-CPR variable within the ROC dataset will allow us to answer important questions regarding D-CPR variation and barriers to implementation. Few studies have examined D-CPR on a national epidemiologic level in regards to B-CPR, survival, and ROSC. Within cities, uptake of D-CPR has been variable and outcomes have differed when investigating survival and ROSC (Bobrow, Panczyk et al. 2012, Bobrow, Spaite et al. 2016). Knowledge of D-CPR variation nationally and linkage to SCA outcomes in a robust observational database could provide insight into whether there are areas which D-CPR could be modified. Specifically, D-CPR interventions could be designed to either improve dispatcher's D-CPR training, refine the agency's D-CPR protocol or script, or increase feedback regarding D-CPR through methods such as debriefing (providing critical feedback to dispatchers after an OHCA). Understanding the national D-CPR epidemiologic landscape could provide the resuscitation community with a robust understanding of D-CPR and areas to improve implementation, training, and ultimately B-CPR delivery. This is an area ripe for future inquiry which could potentially change the landscape of resuscitation science and improve outcomes from SCA.

Conclusions

This body of investigations has examined public CPR training, B-CPR delivery, and missing data on D-CPR nationally. Future work may continue to pursue avenues to examine B-CPR and further our understanding of the D-CPR landscape. In conclusion, this monograph has provided significant, meaningful contributions to the field of resuscitation science in the areas of public CPR training, B-CPR delivery, and missing data within D-CPR datasets nationally, critical elements in the resuscitation chain of survival.

Chapter 6 Acknowledgement

Portions of this paper used parts, including a figure from our paper in *Circulation.* Per *Circulation* copyright guidelines, this is permissible. The exact citation is: Blewer AL, Abella, BS. Unmeasured Interface in Emergency Cardiovascular Care: How do Dispatch-Assisted Telephone

Cardiopulmonary Resuscitation and Bystander Training Interact? *Circulation.* 2018; 137(10): 996-998.

TABLES

Table 1. Demographics of 9,002 participant's survey weighted to the US national population 2015

	All participants N=245,201,076	Currently trained N=44,879,865	Ever trained N=160,386,024	Never trained N=84,815,052
Mean age (95% CI), years	48 (95%CI: 47-49)	42 (95% CI: 41-43)	46 (95% CI: 47-49)	48 (95% CI: 46-51)
Female gender, (%)	51%	56%	52%	50%
Race, (%)				
White	65%	65%	71%	55%
Black	12%	13%	11%	12%
Hispanic/Latino	15%	13%	11%	24%
Other	8%	9%	7%	9%
Highest education, (%)				
Less than high school	11%	4%	7%	20%
High school graduate	30%	22%	26%	38%
Some college	27%	32%	30%	22%
Graduated college	20%	26%	23%	13%
Graduate school or more	12%	16%	14%	7%
Household income, n (%)				
Less than $15,000	15%	10%	11%	24%
$15,000-$29,999	20%	14%	17%	27%
$30,000-$49,999	19%	19%	19%	18%
$50,000-$74,999	16%	19%	18%	13%
$75,000-$99,999	12%	14%	14%	8%
$100,000 or more	18%	24%	21%	10%

*Race: missing 2%
*Education: missing 1%
*Income: missing 17%

Table 2. Likelihood of individuals being currently CPR trained or ever CPR trained by individual demographics

	Currently trained	*Global p-value*	*p-value*	Ever Trained	*Global p-value*	*p-value*
Mean age (95% CI), years	0.98 (95% CI: 0.97-0.99)	<0.01		0.99 (95% CI: 0.98-0.99)	0.04	
Female gender, OR (95% CI)	1.34 (95% CI: 0.98-1.83)	0.06		1.16 (95% CI: 0.93-1.43)	0.16	
Race, OR (95% CI)		0.03			<0.01	
White (base)	-			-		
Black	1.33 (95% CI: 0.84-2.10)		0.19	0.92 (95% CI: 0.78-1.08)		0.25
Hispanic/Latino	0.88 (95% CI: 0.67-1.14)		0.29	0.44 (95% CI: 0.37-0.52)		<0.01
Other	1.16 (95% CI: 0.88-1.53)		0.25	0.71 (95% CI: 0.52-0.95)		0.03
Highest education, OR (95% CI)		0.02			<0.01	
Less than high school (base)	-			-		
High school graduate	1.85 (95% CI: 1.35-2.54)		<0.01	1.63 (95% CI: 1.33-1.99)		<0.01
Some college	3.11 (95% CI: 1.89-5.10)		<0.01	2.72 (95% CI: 2.20-3.37)		<0.01
Graduated college	3.24 (95% CI: 1.96-5.36)		<0.01	2.98 (95% CI: 2.40-3.70)		<0.01
Graduate school or more	3.36 (95% CI: 1.60-7.09)		<0.01	3.29 (95% CI: 2.54-4.27)		<0.01
Household income, OR (95%		0.03			<0.01	
CI)	-			-		
Less than $15,000 (base)	0.94 (95% CI: 0.64-1.39)		0.73	1.25 (95% CI: 0.99-1.57)		0.06
$15,000-$29,999	1.36 (95% CI: 1.06-1.75)		0.02	1.62 (95% CI: 1.34-1.95)		<0.01
$30,000-$49,999	1.55 (95% CI: 1.19-2.02)		0.01	2.02 (95% CI: 1.62-2.53)		<0.01
$50,000-$74,999	1.72 (95% CI: 1.38-2.16)		<0.01	2.32 (95% CI: 1.49-3.59)		<0.01
$75,000-$99,999	1.88 (95% CI: 1.26-2.81)		<0.01	2.55 (95% CI: 1.67-3.88)		<0.01
$100,000 or more						

Table 3. Likelihood of individuals being currently CPR trained or ever CPR trained by individual demographics: age categorical

	Currently trained	*Global p-value*	*p-value*	Ever Trained	*Global p-value*	*p-value*
Age (95% CI), years		0.04			0.04	
18-29 (base)	-			-		
30-39	0.75 (95% CI: 0.61-0.93)		0.02	1.15 (95% CI: 1.01-1.30)		0.04
40-49	0.63 (95% CI: 0.52-0.75)		<0.01	1.37 (95% CI: 1.10-1.70)		0.01
50-59	0.56 (95% CI: 0.43-0.73)		<0.01	1.27 (95% CI: 1.05-1.54)		0.02
60-69	0.29 (95% CI: 0.20-0.42)		<0.01	0.86 (95% CI: 0.71-1.05)		0.12
70-79	0.15 (95% CI: 0.10-0.23)		<0.01	0.58 (95% CI: 0.43-0.77)		<0.01
80 and older	0.05 (95% CI: 0.01-0.20)		<0.01	0.34 (95% CI: 0.22-0.52)		<0.01

Table 4. Demographic characteristics of ROC subjects

	All subjects N=19,331	Public B-CPR, yes N=1,444 (44%)	Public B-CPR, no N=1,853 (56%)	Home B-CPR, yes N=5,564 (35%)	Home B-CPR, no N=10,224 (65%)
Male	12,225 (63%)	1,170 (81%)	1,430 (77%)	3,364 (60%)	6,085 (60%)
Site, n (%)					
A	1032 (6%)	52 (3%)	104 (6%)	196 (4%)	660 (6%)
B	5,324 (28%)	310 (22%)	550 (30%)	1,153 (21%)	3,268 (32%)
C	2,604 (13%)	103 (7%)	247 (13%)	302 (5%)	1,914 (19%)
D	1,607 (8%)	146 (10%)	157 (8%)	412 (7%)	880 (8%)
E	2,244 (12%)	196 (14%)	120 (6%)	1,014 (18%)	894 (9%)
F	2,571 (13%)	237 (16%)	271 (15%)	834 (15%)	1,187 (12%)
G	3,949 (20%)	400 (28%)	404 (22%)	1,653 (30%)	1,421 (14%)
Time of Day, n (%)					
11:00pm-5:59am	3,631 (19%)	93 (6%)	219 (12%)	1,201 (22%)	2,084 (21%)
6:00am-8:59am	2,650 (14%)	163 (12%)	204 (11%)	754 (14%)	1,500 (15%)
9:00am-3:59pm	6,601 (34%)	688 (48%)	790 (43%)	1,694 (31%)	3,328 (33%)
4:00pm-6:50pm	2,919 (15%)	276 (19%)	316 (17%)	845 (15%)	1,443 (14%)
7:00pm-10:59pm	3,386 (18%)	214 (15%)	312 (17%)	1,024 (18%)	1,796 (17%)
Location type, n (%)					
Street, highway	892 (4%)	274 (19%)	618 (33%)	-	-
Public building	329 (2%)	149 (10%)	180 (10%)	-	-
Place of recreation	396 (2%)	231 (16%)	165 (9%)	-	-
Home	15,788 (82%)	-	-	5,564 (100%)	10,224 (100%)
Other public	1,680 (9%)	790 (55%)	890 (48%)	-	-
Other nonpublic	150 (1%)	-	-	-	-
Age, years (%)					
18-29	756 (4%)	47 (4%)	80 (5%)	273 (5%)	338 (4%)
30-39	1,099 (6%)	66 (5%)	145 (8%)	334 (6%)	537 (5%)
40-49	1,985 (10%)	186 (13%)	245 (13%)	593 (11%)	926 (9%)
50-59	3,714 (19%)	328 (23%)	470 (25%)	1,075 (19%)	1,781 (17%)
60-69	4,335 (22%)	419 (29%)	487 (26%)	1,195 (22%)	2,185 (21%)
70-79	3,419 (18%)	241 (17%)	240 (13%)	968 (17%)	1,935 (19%)

80+	4,012 (21%)	156 (11%)	185 (10%)	1,125 (20%)	2,520 (25%)
Race, n (%)					
White, non-Hispanic	6,349 (33%)	516 (36%)	557 (30%)	2,035 (37%)	3,164 (31%)
Black, non-Hispanic	3,148 (16%)	108 (7%)	301 (16%)	537 (10%)	2,173 (21%)
Hispanic	872 (5%)	59 (4%)	83 (4%)	194 (3%)	524 (5%)
Other	629 (3%)	38 (3%)	47 (3%)	253 (4%)	283 (3%)
Unknown	8,333 (43%)	723 (50%)	865 (47%)	2,545 (46%)	4,080 (40%)
Not Witnessed	10,419 (57%)	340 (24%)	817 (46%)	2,934 (54%)	6,239 (65%)
Time from initial call, min					
First arrival EMS, min	5.27±2.35	5.18±2.63	4.78±2.34	5.61±2.43	5.20±2.23
First arrival <4 min	5,673 (30%)	480 (34%)	745 (42%)	1,174 (22%)	3,114 (32%)
First EMS compress	7.78±3.43	7.40±3.72	7.60±4.61	7.83±2.98	7.82±3.29
Initial rhythm					
Shockable (VF/pVT)	4,474 (24%)	760 (55%)	691 (38%)	1,297 (23%)	1,647 (16%)
Non-shockable	14,385 (75%)	595 (44%)	1,111 (61%)	4,169 (76%)	8,361 (83%)
(PEA/asystole)	199 (1%)	17 (1%)	17 (1%)	46 (1%)	114 (1%)
Cannot determine					
ROSC present at arrival to ED					
Yes	5,531 (47%)	664 (55%)	629 (43%)	1,752 (54%)	2,397 (42%)
Survival at hospital discharge					
Yes	2,261 (12%)	475 (33%)	374 (20%)	666 (12%)	690 (7%)

B-CPR indicates bystander cardiopulmonary resuscitation; ED, emergency department; EMS, Emergency medical services; PEA, pulseless electrical activity; ROSC, return of spontaneous circulation; and ventricular fibrillation/pulseless ventricular tachycardia.

Table 5. Multivariable logistic regression demonstrating likelihood of receiving B-CPR

	All locations (n=17,560)			Public (n=3,060)			Home (n=14,123)		
	OR (95% CI)	*Global p-value*	*Individual p-value*	OR (95% CI)	*Global p-value*	*Individual p-value*	OR (95% CI)	*Global p-value*	*Individual p-value*
Male	0.97 (0.90-1.04)		0.34	1.27 (1.05-1.53)		0.01	0.93 (0.87-1.01)		
Site, (baseline A)		<0.01			<0.01			<0.01	
B	1.42 (1.16-1.73)		<0.01	1.29 (0.84-1.98)		0.25	1.47 (1.17-1.84)		<0.01
C	0.67 (0.54-0.84)		<0.01	0.88 (0.55-1.41)		0.60	0.61 (0.48-0.79)		<0.01
D	1.72 (1.38-2.14)		<0.01	1.84 (1.15-2.96)		0.01	1.68 (1.30-2.16)		<0.01
E	4.08 (3.30-5.05)		<0.01	3.42 (2.11-5.56)		<0.01	4.23 (3.32-5.40)		<0.01
F	2.70 (2.18-3.33)		<0.01	2.00 (1.27-3.15)		<0.01	2.90 (2.28-3.70)		<0.01
G	3.60 (2.95-4.41)		<0.01	2.07 (1.35-3.20)		<0.01	4.21 (3.33-5.30)		<0.01
Time of Day, (baseline 11:00pm-5:59am)		0.10			<0.01			0.43	
6:00am-8:59am	1.02 (0.91-1.14)		0.76	1.65 (1.16-2.34)		<0.01	0.95 (0.84-1.07)		0.40
9:00am-3:59pm	1.09 (0.99-1.20)		0.08	1.69 (1.27-2.26)		<0.01	1.01 (0.91-1.12)		0.90
4:00pm-6:50pm	1.15 (1.03-1.30)		0.01	1.87 (1.36-2.58)		<0.01	1.07 (0.95-1.22)		0.26
7:00pm-10:59pm	1.05 (0.94-1.17)		0.40	1.40 (1.01-1.94)		0.04	1.04 (0.93-1.17)		0.48
Age, (baseline,18-29)		<0.01			0.32			<0.01	
30-39	0.77 (0.62-0.95)		0.01	0.75 (0.45-1.24)		0.26	0.73 (0.58-0.93)		0.01
40-49	0.81 (0.67-0.98)		0.03	1.00 (0.64-1.57)		0.98	0.73 (0.59-0.90)		<0.01
50-59	0.77 (0.64-0.92)		<0.01	0.91 (0.59-1.38)		0.65	0.67 (0.55-0.82)		<0.01
60-69	0.72 (0.60-0.86)		<0.01	1.05 (0.69-1.59)		0.83	0.59 (0.48-0.72)		<0.01
70-79	0.61 (0.51-0.74)		<0.01	1.10 (0.71-1.72)		0.67	0.50 (0.41-0.61)		<0.01
80+	0.50 (0.42-0.60)		<0.01	0.86 (0.54-1.37)		0.53	0.41 (0.34-0.50)		<0.01
Race, (baseline, White, non-Hispanic)		<0.01			<0.01			<0.01	
Black, non-Hispanic	0.58 (0.51-0.64)		<0.01	0.50 (0.38-0.66)		<0.01	0.59 (0.52-0.67)		<0.01
Hispanic	0.68 (0.58-0.81)		<0.01	0.78 (0.53-1.15)		0.21	0.65 (0.54-0.79)		<0.01
Other	0.99 (0.83-1.19)		0.96	0.91 (0.56-1.47)		0.70	1.03 (0.85-1.26)		0.74
Unknown	0.82 (0.76-0.88)		<0.01	0.81 (0.68-0.96)		0.02	0.84 (0.77-0.91)		<0.01
Not witnessed	0.57 (0.53-0.62)		<0.01	0.37 (0.31-0.44)		<0.01	0.63 (0.59-0.68)		<0.01
Time to first arrival of EMS (min)	1.04 (1.03-1.06)		<0.01	1.06 (1.02-1.09)		<0.01	1.04 (1.02-1.05)		<0.01
Location type	1.05 (1.03-1.07)		<0.01	-	-	-	-	-	-

B-CPR

indicates bystander cardiopulmonary resuscitation; ED, emergency department; EMS, Emergency medical services; PEA, pulseless electrical activity; ROSC, return of spontaneous circulation; and ventricular fibrillation/pulseless ventricular tachycardia.

Table 6. Chapter 4, ROC demographic characteristics

	All individual variables N=17,883
B-CPR, Yes	6,512 (36%)
Male	11,260 (63%)
Site, n (%)	
A	903 (5%)
B	4,763 (27%)
C	2,556 (14%)
D	1,148 (6%)
E	2,203 (12%)
F	2,474 (14%)
G	3,836 (22%)
Time of day, n (%)	
11:00pm-5:59am	3,378 (19%)
6:00am-8:59am	2,467 (14%)
9:00am-3:39pm	6,100 (34%)
4:00pm-6:59pm	2,677 (15%)
7:00pm-10:59pm	3,137 (18%)
Location type, n (%)	
Street, highway	806 (5%)
Public building	296 (2%)
Place of recreation	352 (2%)
Home	14,644 (82%)
Other, public	1,564 (9%)
Other, non-public	136 (0%)
Age, years	64±17
Race	

White, non-Hispanic	5,769 (32%)
Black, non-Hispanic	3,067 (17%)
Hispanic	851 (5%)
Other	603 (3%)
Unknown	7,593 (43%)
Not Witnessed	9,633 (57%)
Time from initial call (min)	5.19±2.24
ROSC present at arrival to ED	
Yes	5,235 (49%)
No	5,458 (51%)
Survival at hospital discharge	
Alive	2,143 (12%)
Dead	15,685 (88%)
Neighborhood characteristics, mean SD	
Median Age	36±7
% Female	51±5
% HS Education	84±14
% White, non-Hispanic	49±30

Missing variables: Time of Day: 159 (0.63%), Location type: 85 (0.48%), Age: 5 (0.03%), Sex: 13 (0.07%), Witnessed: 880 (4.92%), Time from initial call, min: 605 (3.38%), ROSC present at ED: 7,190 (40.21%), Survival at hospital discharge: 55 (0.31%), % female: 28 (0.16%), % median age: 30 (0.17%), % HS Education: 19 (0.11%), % white, non-hispanic: 28 (0.16%). Site: A=Alabama, B=Dallas, C=Milwaukee, D=Pittsburgh, E=Portland, F=San Diego, G=Seattle.

Table 7. Demographic characteristics of ROC survey participants

	All participants	Currently trained
Mean age (95% CI), years	47 (95% CI: 45-49)	41 (95% CI: 40-43)
Female gender, (%)	51%	51%
Race, (%)		
White	62%	62%
Black	12%	13%
Hispanic/Latino	16%	16%
Other	10%	9%
Highest education, (%)		
Less than high school	9%	6%
High school graduate	28%	25%
Some college	26%	25%
Graduated college	22%	25%
Graduate school or more	15%	19%
Site, (%)		
Alabama	7%	7%
California	18%	18%
Oregon	10%	9%
Pennsylvania	14%	13%
Texas	18%	18%
Washington	22%	24%
Wisconsin	11%	10%
Race: missing 2%; Education: missing 1%		

Table 8. Unadjusted analysis of increased community CPR training on receipt of B-CPR delivery

	Odds Ratio (95% CI)	*Standard Error*	*P-value*
400 meter buffer	1.20 (1.05-1.37)	0.08	<0.01
Census tract	1.21 (1.06-1.39)	0.09	<0.01
800 meter buffer	1.21 (1.06-1.39)	0.08	<0.01
400 meter street buffer	1.18 (1.04-1.35)	0.08	0.01
800 meter street buffer	1.22 (1.07-1.41)	0.09	<0.01

Table 9. Multivariable analysis including episode time, location, age, gender, and EMS response time

	Odds Ratio (95% CI)	*Standard Error*	*P-value*
400 meter buffer	1.29 (1.12-1.49)	0.09	<0.01
Census tract	1.29 (1.11-1.50)	0.10	<0.01
800 meter buffer	1.28 (1.10-1.48)	0.10	<0.01
400 meter street buffer	1.23 (1.07-1.42)	0.09	<0.01
800 meter street buffer	1.26 (1.09-1.46)	0.09	<0.01

Table 10. Multivariable analysis including census, county

	Odds Ratio (95% CI)	*Standard Error*	*P-value*
400 meter buffer	1.21 (1.04-1.39)	0.09	0.01
Census tract	1.19 (1.02-1.38)	0.09	0.03
800 meter buffer	1.21 (1.05-1.41)	0.09	0.01
400 meter street buffer	1.17 (1.01-1.35)	0.09	0.03
800 meter street buffer	1.21 (1.04-1.40)	0.09	0.02

Table 11. Multivariable analysis including population density and site

	Odds Ratio (95% CI)	*Standard Error*	*P-value*
400 meter buffer	1.05 (0.90-1.24)	0.09	0.54
Census tract	1.03 (0.87-1.21)	0.09	0.76
800 meter buffer	1.03 (0.88-1.22)	0.09	0.70
400 meter street buffer	1.05 (0.89-1.23)	0.09	0.58
800 meter street buffer	1.04 (0.88-1.23)	0.09	0.64

Table 12. Matched datasets varying sudden cardiac arrest episode time

Matched	*Difference in seconds*	*% Difference in datasets*
4,970	-61467, 41969	76% not exact
1,248	5 +/-	2% not exact
1,371	25 +/-	8% not exact
1,408	50 +/-	12% not exact
1,522	100 +/-	19% not exact
1,604	150 +/- (2.5 min)	25% not exact
1,790	200 +/-	29% not exact
1,870	250 +/-	33% not exact
1,977	300 +/- (5 min)	36% not exact
2,072	350 +/-	40% not exact
2,152	400 +/-	43% not exact
2,224	450 +/-	45% not exact
2,321	500 +/-	47% not exact

Difference in seconds refers to difference in sudden cardiac arrest episode time by seconds

Table 13. Demographic characteristics of ROC and EMS datasets

	ROC N=1790	EMS N=1790
Age (mean ± SD)	63.96±19.59	63.96±19.59
Age, n (%)		
<25	86 (5%)	86 (5%)
26-50	266 (15%)	266 (15%)
51-75	892 (50%)	892 (50%)
76+	546 (30%)	546 (30%)
Female	641 (36%)	641 (36%)
Bystander CPR layperson		
No	1017 (57%)	1043 (58%)
Yes	773 (43%)	747 (42%)
Survival to hospital discharge		
No	1,512 (85%)	1549 (87%)
Yes	272 (15%)	241 (13%)
ROSC		
No	1185 (66%)	1103 (62%)
Yes	605 (34%)	687 (38%)
Dispatch CPR		
No	118 (7%)	1420 (79%)
Yes	204 (11%)	358 (20%)
Missing	1468 (82%)	12 (1%)

ROC-SKC, Survival – missing 6 data points.

Table 14. Examining variables based on whether D-CPR was complete or missing in the ROC dataset

	D-CPR variable complete N=322 (18%)	D-CPR variable missing N=1,468 (82%)	*p-value*
Bystander call, arrival of EMS (min)	5.57 ± 2.11	5.56 ± 2.15	0.92
EMS Rig 1 (secs)	45973.37±22517.73	46781.69±22414.65	0.56
EMS Rig 2 (secs)	46168.86±22462.03	46734.97±22403.14	0.68
EMS Rig 3 (secs)	46244.97±22473.49	46502.82±22451.11	0.86
Call requesting Dispatch	320 (99%)	1466 (99%)	0.10
Dispatch Ordered	318 (99%)	1464 (100%)	0.09
Arrival of Order	298 (93%)	1430 (97%)	0.01
Call for Dispatch	45704.29±22533.39	46772.58±22380.78	0.44
Dispatch Align Time	45771.07±22567.82	46723.60±22376.96	0.49
Arrival of Align Time	46038.55±22513.02	46753.12±22425.86	0.70
Cardiac Arrest Time (sec)	45704.29±22533.39	46772.58±22380.78	0.44
Bystander CPR, layperson	233 (72%)	535 (36%)	0.00
Race			0.03
White, Non-Hispanic	133 (41%)	496 (34%)	
Black, Non-Hispanic	15 (5%)	70 (5%)	
Hispanic	1 (0%)	20 (1%)	
Other	28 (9%)	104 (7%)	
Unknown	145 (45%)	778 (53%)	
Age, years	63.29±21.13	64.10±19.23	0.49
Sex, Male	210 (65%)	939 (64%)	0.67
Witness	142 (44%)	517 (35%)	0.28
Location type -public	40 (12%)	255 (17%)	0.03
-home	282 (88%)	1212 (83%)	
Survival, yes	44 (14%)	228 (16%)	0.38

Continuous variables: mean±SD, categorical variables: frequency and percentage; missing: EMS Rig 1: 6 (0.01%), EMS Rig 2: 26 (1%), EMS Rig 3: 88 (5%), Dispatch Ordered: 1 (0.01%)

Table 15. Layperson D-CPR and B-CPR delivery: complete case analysis and multiple imputation

	ROC unmatched, complete case n=911	*ROC matched, complete case* n=322	*ROC matched, multiple imputation* n=1790	*EMS matched, complete case* n=1778
Layperson D-CPR, Risk Ratio (95% CI)	2.01 (1.76-2.33)	2.54 (2.00-3.21)	3.84 (2.97-4.98)	3.51 (3.22-3.83)

Examination of layperson D-CPR on B-CPR delivery using unadjusted risk ratios. First column displays the unmatched complete case analysis; second column displays the matched complete case analysis; third column uses logistic multiple imputation to address the missing data; fourth column compares these findings with the complete case analysis EMS matched dataset.

Table 16. Complete case analysis with EMS simulated data

	Simulation Dataset 1 Risk Ratio (95% CI)	*Simulation Dataset 2* Risk Ratio (95% CI)	*Simulation Dataset 3* Risk Ratio (95% CI)
<1%	3.51 (3.22-3.83)	3.51 (3.22-3.83)	3.51 (3.22-3.83)
10%	3.47 (3.17-3.80)	3.50 (3.20-3.84)	3.36 (3.09-3.67)
20%	3.55 (3.22-3.92)	3.37 (3.07-3.70)	3.20 (2.93-3.51)
40%	3.28 (2.95-3.66)	3.43 (3.07-3.84)	3.00 (2.71-3.31)
60%	3.52 (3.07-4.03)	3.12 (2.75-3.55)	2.96 (2.63-3.33)
80%	3.58 (2.93-4.37)	2.70 (2.32-3.15)	2.80 (2.39-3.28)

Missingness in the simulated dataset increased to 80% and explored the variation in risk ratio and confidence intervals under different missingness assumptions; Risk ratio examined the association of layperson D-CPR on B-CPR delivery; Complete case analysis was used to handle the missing data; Simulation Dataset 1 assumed the data were missing completely at random, by randomly sampling the data proportionally; Simulation Dataset 2 assumed the data were missing at random and removed individuals that were older; Simulation Dataset 3 further perturbed age and introduced additional bias in the association.

Table 17. Multiple imputation with EMS simulated data

	Simulation Dataset 1 Risk Ratio (95% CI)	*Simulation Dataset 2* Risk Ratio (95% CI)	*Simulation Dataset 3* Risk Ratio (95% CI)
<1%	3.51 (3.22-3.83)	3.51 (3.22-3.83)	3.51 (3.22-3.83)
10%	3.44 (3.16-3.76)	3.47 (3.18-3.79)	3.52 (3.23-3.84)
20%	3.50 (3.19-3.83)	3.46 (3.15-3.78)	3.60 (3.29-3.94)
40%	3.28 (2.99-3.61)	3.51 (3.19-3.88)	3.66 (3.33-4.02)
60%	3.34 (2.99-3.73)	3.26 (2.92-3.65)	3.75 (3.32-4.25)
80%	3.58 (3.03-4.23)	3.34 (2.77-4.05)	3.65 (2.91-4.57)

Missingness in the simulated dataset increased to 80% and explored the variation in risk ratio and confidence intervals under different missingness assumptions; Risk ratio examined the effect of layperson D-CPR on B-CPR delivery; Multiple imputation was used to handle the missing data; Simulation Dataset 1 assumed the data were missing completely at random, by randomly sampling the data proportionally; Simulation Dataset 2 assumed the data were missing at random and removed individuals that were older; Simulation Dataset 3 further perturbed age and introduced additional bias in the association.

FIGURES

Figure 1. Histogram of the distribution of sudden cardiac arrest by age

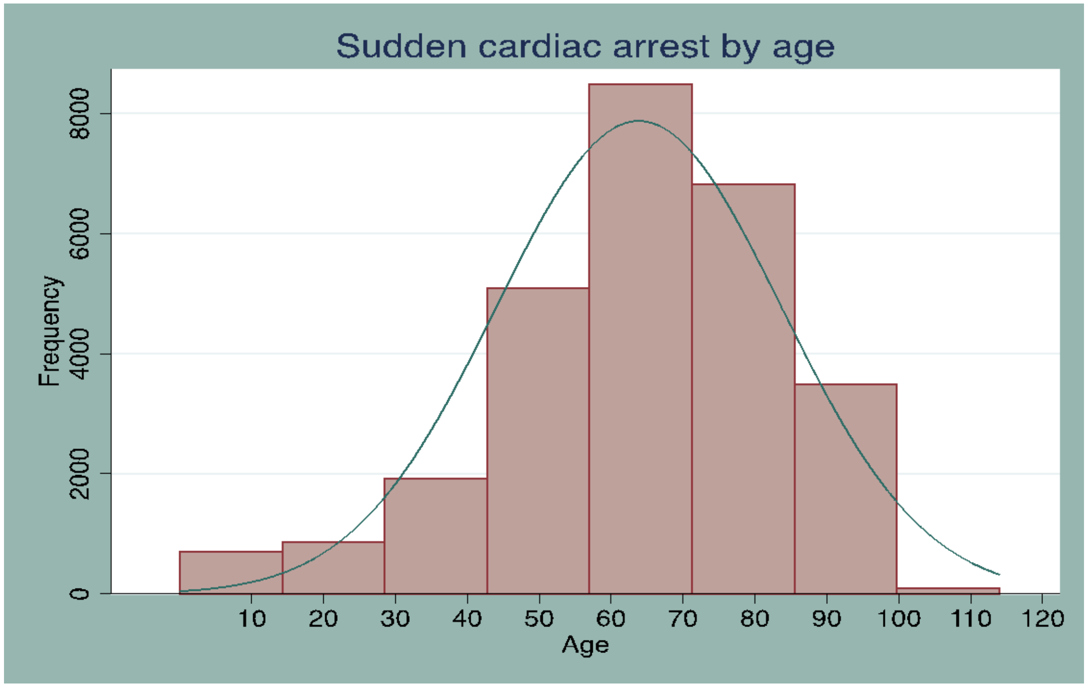


Figure 2. Probability of current CPR in the home and the public

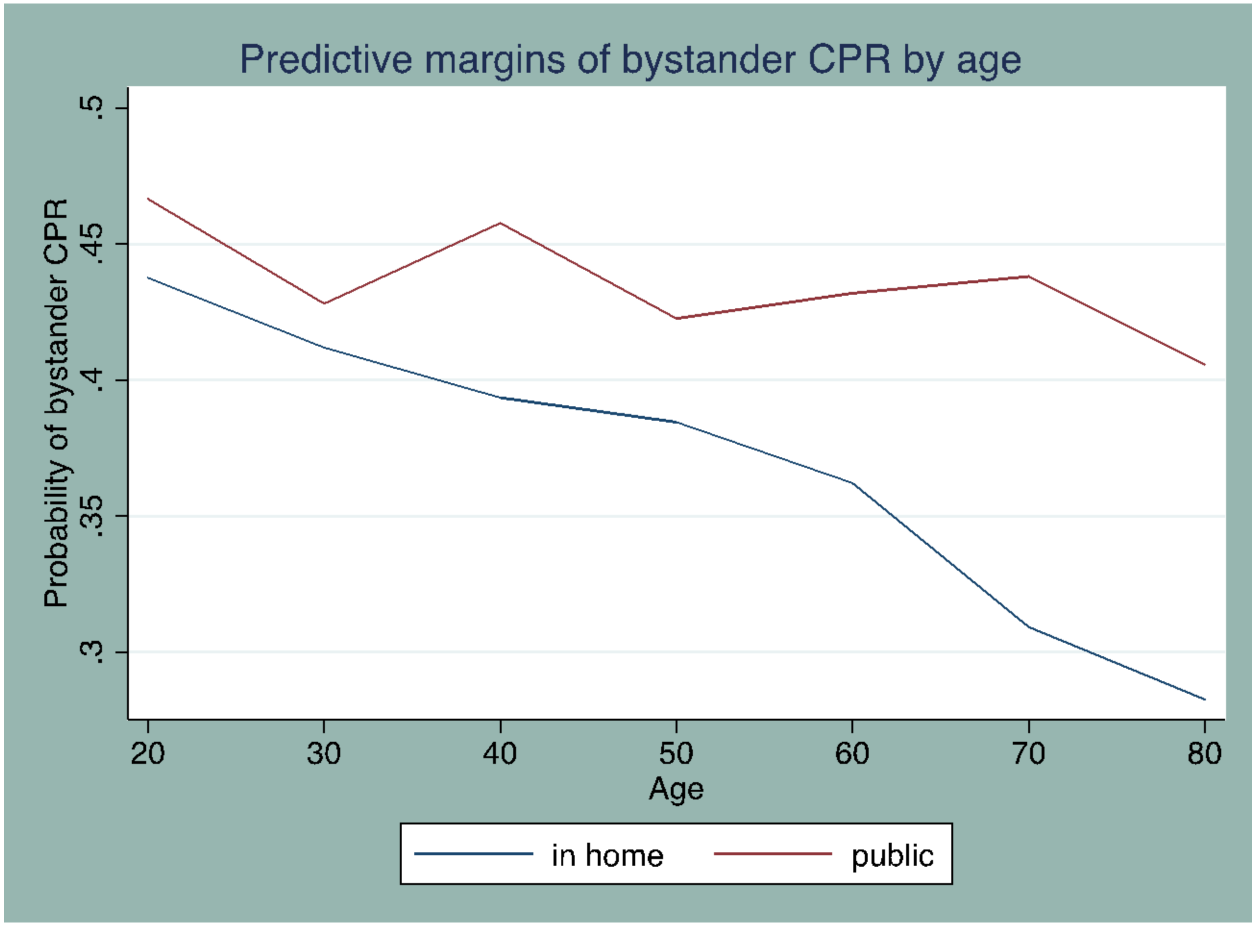


Figure 3. Probability of current CPR training by age

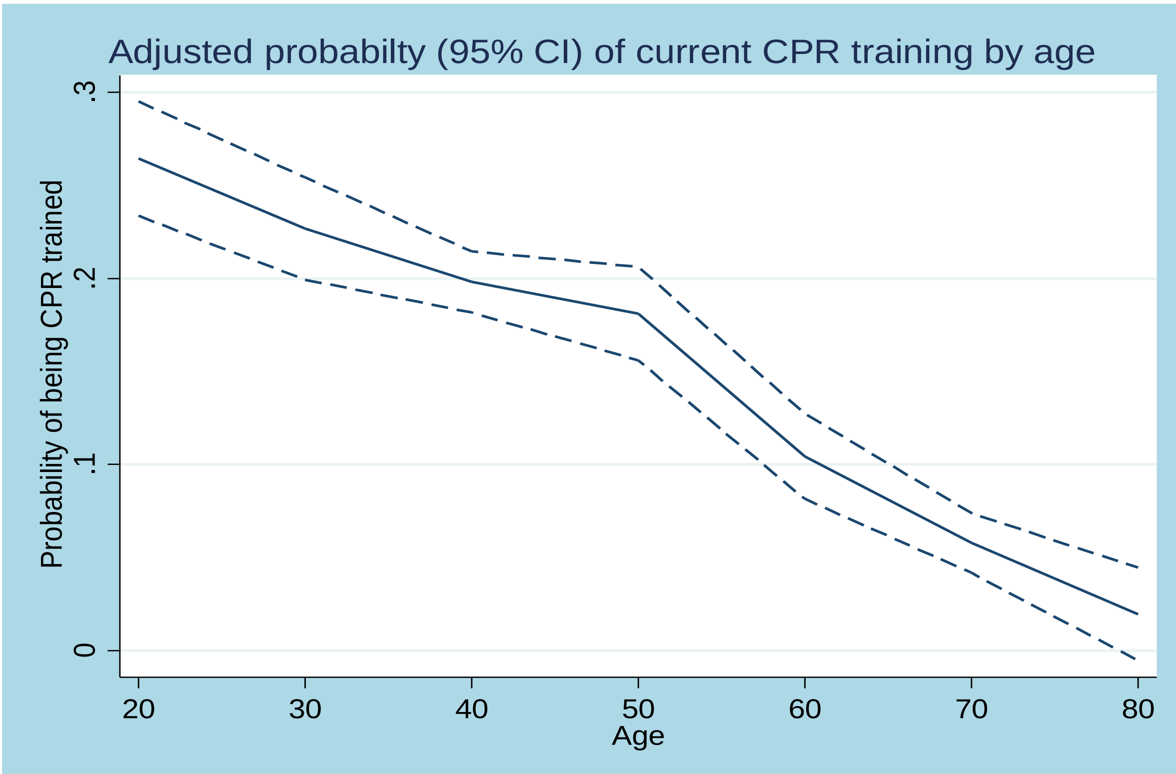


Figure 4. Missing dataset matching and data reduction diagram

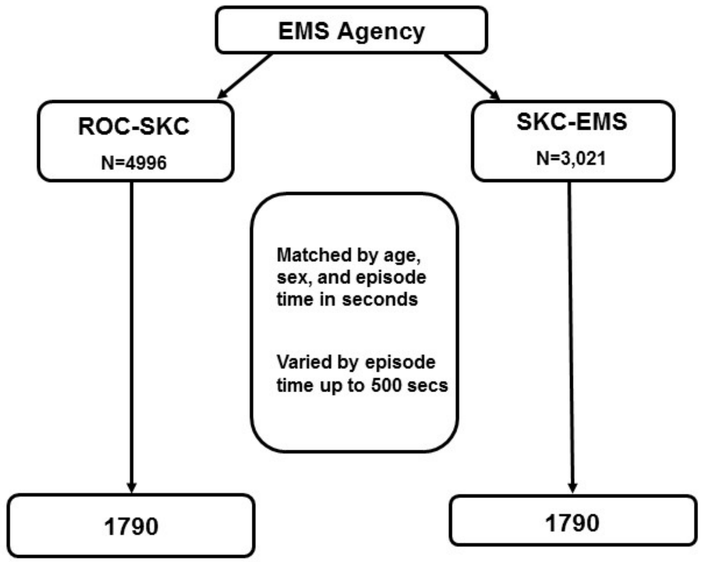
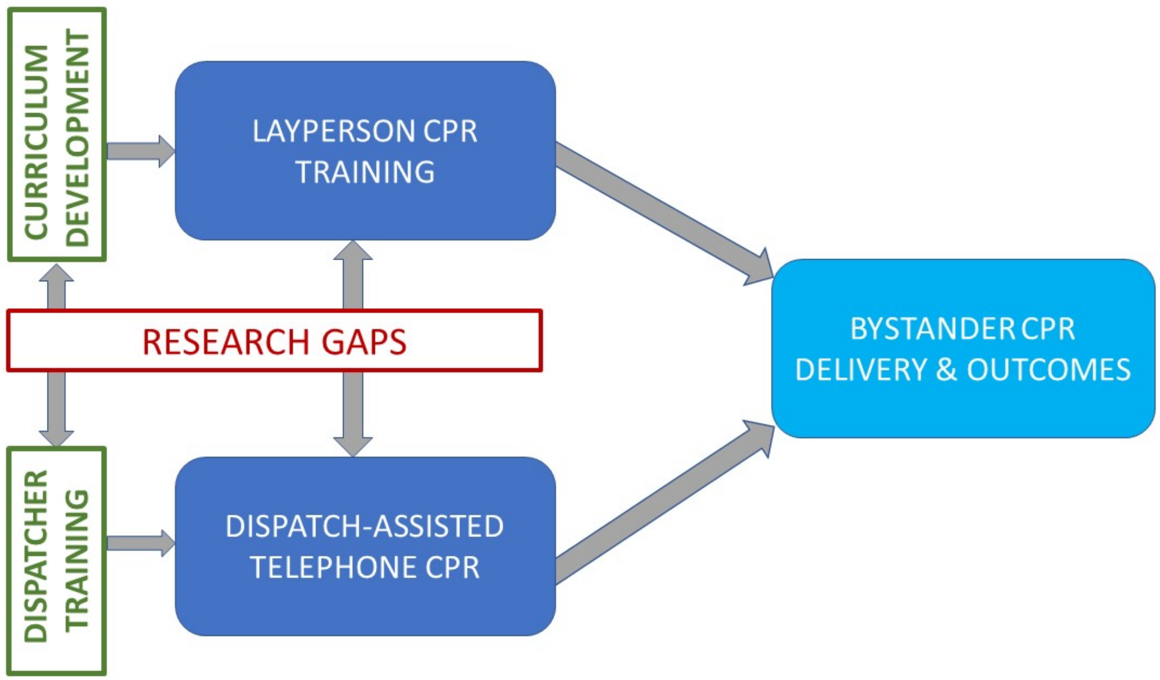


Figure 5. Dispatch-assisted CPR and CPR training



APPENDIX

Appendix 1. National CPR survey questionnaire

National CPR Survey

N=1000 in each Division

Census Division #1 : New England

Census Division #2 : Middle Atlantic

Census Division #3 : East North Central

Census Division #4 : West North Central

Census Division #5 : South Atlantic

Census Division #6 : East South Central

Census Division #7 : West South Central

Census Division #8 : Mountain

Census Division #9 : Pacific

The next few questions are related to cardiopulmonary (car-dee-o pull-ma-na-ree) resuscitation (recess-a-tay-shun) (CPR) training.

CP-01. Have you ever attended training in cardiopulmonary (car-dee-o pull-ma-na-ree) resuscitation (recess-a-tay-shun) (CPR)? This might include attending a formal class, watching a training video, or learning via an in-person demonstration

1 Yes (SKIP TO CP-3)

2 No

3 I do not know what CPR is (SKIP TO CP-6)

8 (DO NOT READ) Don’t know (SKIP TO CP-6)

9 (DO NOT READ) Refused (SKIP TO CP-6)

CP-02. What is the main reason you have not been trained in CPR?

(DO NOT READ; ENTER ONE RESPONSE)

01 Concerns about physical ability to perform CPR

02 Cost of training

03 Fear of being sued

04 Fear of contracting an infectious disease

05 Fear of performing CPR

06 Lack of awareness of need for training

07 Lack of interest

08 Lack of training opportunities

97 Something else (SPECIFY)_______________

98 (DO NOT READ) Don't know

99 (DO NOT READ) Refused

(IF CP-01=1)

CP-03. When did you last attend CPR training?

(READ LIST)

1 Within the past 2 years

2 2 to 5 years ago

3 5 to 10 years ago

4 More than 10 years ago

8 (DO NOT READ) Don't know

9 (DO NOT READ) Refused

(IF CP-01=1)

CP-04. CPR training can take many forms, and if requirements are met trainees can be certified. A CPR certification is usually given to you in the form of a card for your wallet that is valid for 1-2 years. Thinking about the last time you were trained, which statement about CPR do you most closely identify with?

(READ LIST)

1 I am CPR certified

2 I was previously CPR certified

3 I learned CPR but was not certified

0 (DO NOT READ) Something else (SPECIFY) ___________

8 (DO NOT READ) Don't know

9 (DO NOT READ) Refused

(IF CP-01=1)

CP-05. In your current job, what kind of work do you do?

(DO NOT READ LIST)

01 Business owner

02 Clerical or office worker (e.g., typist, secretary, postal clerk, telephone operator, computer operator, bank clerk)

03 Healthcare professional (doctor, registered nurse, technician, etc)

04 Laborer (e.g., plumber's helper, construction worker, longshoreperson, garbage collector, other physical work)

05 Manager (e.g., store manager, sales manager, office manager)

06 Profession worker (e.g., lawyer, scientist, engineer, accountant, programmer, musician)

07 Salesperson

08 Semi-skilled worker (e.g., machine operator, assembly line worker, truck driver, Taxi driver, bus driver)

09 Service worker (e.g., police officer, fire fighter, waiter or waitress, maid, nurse's aide, attendant, hairstylist)

10 Skilled tradesperson (e.g., printer, baker, tailor, electrician, machinist, linesperson, plumber, carpenter, mechanic)

11 Teacher/Educator

97 Other (Specify)_________________________

98 (DO NOT READ) Don't know

99 (DO NOT READ) Refused

The next few questions are related to Automated External Defibrillators (De fib ril la tors) also referred to as AEDs.

CP-06. Have you ever had AED training?

1 Yes

2 No

3 I do not know what an AED is (SKIP TO NEXT INSERT)

8 (DO NOT READ) Don't know (SKIP TO NEXT INSERT)

9 (DO NOT READ) Refused (SKIP TO NEXT INSERT)

(ASK IF CP-06=1 or 2)

CP-07. Who do you think can use a publically available AED?

(READ LIST; ENTER ONE RESPONSE)

1 Anybody

2 Medical professionals only

3 Only individuals who have been trained in AED use

4 Other (SPECIFY)_______________

8 (DO NOT READ) Don't know

9 (DO NOT READ) Refused

Appendix 2. Additional survey weight description

The study was weighted to provide nationally representative and projectable estimates of the adult population 18 years of age and older. The weighting process takes into account the disproportionate probabilities of household and respondent selection due to the number of separate telephone landlines and cellphones answered by respondents and their households, as well as the probability associated with the random selection of an individual household member, following procedures noted in Buskirk and Best[1].

Following application of the appropriate weights, nonresponse is addressed via post-stratification, balancing by a number of key demographics: age (18-29; 30-49; 50-64; 65+) by gender, Census region (Northeast, North-Central, South, West) by gender, Education (less than high school, high school graduate, some college, four-year college or more); race/ethnicity (white non-Hispanic; Black non-Hispanic; Hispanic; Other non-Hispanic); marital status (married/not married), population density (divided into quintiles) and phone-usage (cell phone only, landline only, both). Data was specifically weighted to known adult-population parameters based on the 2015 March Supplement of the U.S. Census Bureau's Current Population Survey (CPS), and in the case of phone usage, the 2015 National Health Interview Survey. Post-stratification utilized a standard iterative proportional fitting ("raking") procedure whereby weights are adjusted iteratively until the root mean square error for the differences between the sample and the population parameters is 0 or near-zero.

[1]Buskirk, TD and Best, J. Venn diagrams, probability 101 and sampling weights computed for dual frame telephone RDD designs. *Section on survey research methods – JSM.* 2012; 3696-3710.

Appendix 3. Multiple imputation code

ROC

```
*dspins variable including missing

gen dspins_mi = dspins_3


gen dspins_yn=dspins

replace dspins_yn=0 if dspins==1

replace dspins_yn=1 if dspins==2

replace dspins_yn=1 if dspins==.


**************20 iterations******************


*mi with augment

mi set mlong

mi register imputed dspins_mi

mi register regular race_hisp_un witness cprAttBin bysTimeCallArr_min loctyp rigtm1 rigtm2 rigtm3 callDspOrder v1DspOrder callDspAlnTm v1DspAlnTm v1ArrOrder age sexp cleantracts episodetm

mi impute logit dspins_mi cprAttBin race_hisp_un witness bysTimeCallArr_min loctyp rigtm1 rigtm2 rigtm3 callDspOrder v1DspOrder callDspAlnTm v1DspAlnTm v1ArrOrder age sexp sitecode_num episodetm, add(20) rseed(22321)force augment


mi xeq 0 50 100 150 200: summarize dspins_mi

mi estimate, or: logistic cprAttBin_nootherEMS_age dspins_mi


*do this:

mi estimate, irr: poisson cprAttBin_nootherEMS_age dspins_mi, vce(robust)


**************150 iterations******************


*mi with augment
```

```
mi set mlong

mi register imputed dspins_mi

mi register regular race_hisp_un witness cprAttBin bysTimeCallArr_min loctyp rigtm1 rigtm2 rigtm3 callDspOrder v1DspOrder callDspAlnTm v1DspAlnTm v1ArrOrder age sexp cleantracts episodetm

mi impute logit dspins_mi cprAttBin race_hisp_un witness bysTimeCallArr_min loctyp rigtm1 rigtm2 rigtm3 callDspOrder v1DspOrder callDspAlnTm v1DspAlnTm v1ArrOrder age sexp sitecode_num episodetm, add(150) rseed(22321)force augment


mi xeq 0 50 100 150 200: summarize dspins_mi

mi estimate, or: logistic cprAttBin_nootherEMS_age dspins_mi


*estimate RR

mi estimate, irr: poisson cprAttBin_nootherEMS_age dspins_mi, vce(robust)


**************250 iterations*******************

gen dspins_mi = dspins_3


*mi with augment

mi set mlong

mi register imputed dspins_mi

mi register regular race_hisp_un witness cprAttBin bysTimeCallArr_min loctyp rigtm1 rigtm2 rigtm3 callDspOrder v1DspOrder callDspAlnTm v1DspAlnTm v1ArrOrder age sexp cleantracts episodetm

mi impute logit dspins_mi cprAttBin race_hisp_un witness bysTimeCallArr_min loctyp rigtm1 rigtm2 rigtm3 callDspOrder v1DspOrder callDspAlnTm v1DspAlnTm v1ArrOrder age sexp sitecode_num episodetm, add(250) rseed(22321)force augment


mi xeq 0 50 100 150 200: summarize dspins_mi

mi estimate, or: logistic cprAttBin_nootherEMS_age dspins_mi


*estimate RR

mi estimate, irr: poisson cprAttBin_nootherEMS_age dspins_mi, vce(robust)
```

```
**************500 iterations******************

gen dspins_mi = dspins_3


*mi with augment

mi set mlong

mi register imputed dspins_mi

mi register regular race_hisp_un witness cprAttBin bysTimeCallArr_min loctyp rigtm1 rigtm2
rigtm3 callDspOrder v1DspOrder callDspAlnTm v1DspAlnTm v1ArrOrder age sexp cleantracts
episodetm

mi impute logit dspins_mi cprAttBin race_hisp_un witness bysTimeCallArr_min loctyp rigtm1
rigtm2 rigtm3 callDspOrder v1DspOrder callDspAlnTm v1DspAlnTm v1ArrOrder age sexp
sitecode_num episodetm, add(500) rseed(22321)force augment


mi xeq 0 50 100 150 200: summarize dspins_mi

mi estimate, or: logistic cprAttBin_nootherEMS_age dspins_mi


*estimate RR

mi estimate, irr: poisson cprAttBin_nootherEMS_age dspins_mi, vce(robust)
```

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