

Comparison of bystander cardiopulmonary resuscitation (BCPR) performance in the absence and presence of timing devices for coordinating delivery of ventilatory breaths and cardiac compressions in a model of adult cardiopulmonary arrest

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Abstract

Astronaut crew medical officers (CMO) aboard the International Space Station (ISS) receive 40 hours of medical training during the 18 months preceding each mission. Part of this training includes two-person cardiopulmonary resuscitation (CPR) per training guidelines from the American Heart Association (AHA). Recent studies concluded that the use of metronomic tones improves the coordination of CPR by trained clinicians. Similar data for bystander or “trained lay people” (e.g. CMO) performance of CPR (BCPR) have been limited. The purpose of this study was to evaluate whether use of timing devices, such as audible metronomic tones, would improve BCPR performance by trained bystanders. Twenty pairs of bystanders trained in two-person BCPR performed BCPR for 4 minutes on a simulated cardiopulmonary arrest patient using three interventions: 1) BCPR with no timing devices, 2) BCPR plus metronomic tones for coordinating compression rate only, 3) BCPR with a timing device and metronome for coordinating ventilation and compression rates, respectively. Bystanders were evaluated on their ability to meet international and AHA CPR guidelines. Bystanders failed to provide the recommended number of breaths and number of compressions in the absence of a timing device and in the presence of audible metronomic tones for only coordinating compression rate. Bystanders using timing devices to coordinate both components of BCPR provided the recommended number of breaths and were closer to providing the recommended number of compressions compared

with the other interventions. Survey results indicated that bystanders preferred to use a metronome for delivery of compressions during BCPR. BCPR performance is improved by timing devices that coordinate both compressions and breaths.

Keywords

Bag-valve mask, Bystander CPR, Cardiopulmonary resuscitation (CPR), Out-of-hospital CPR, Ventilation

1. Introduction

Astronaut crew medical officers (CMO) aboard the International Space Station (ISS) receive 40 hours of medical training during the 18 months preceding each mission. Part of this training is dedicated to instruction in two-person cardiopulmonary resuscitation (CPR). Ground-based and flight-based refresher training for CPR is available to CMOs, however, preflight training requirements and over-subscribed timelines during the mission tend to limit the opportunities for this training. Therefore, CPR training for CMOs, as well as bystanders, should include skills that are easy to remember and medical tools that help coordinate the application of those skills.

Work by Milander *et al* has suggested that use of metronomic tones improves the coordination of cardiac compressions during CPR by personnel with formal clinical training [1]; however, similar data on how these tones affect CPR performance by trained bystanders (“lay people”) is limited. Bystander performance of CPR (BCPR) is important towards patient survival [2,3,4]. Most of the CMO cohort can be considered bystanders as approximately 90% of the astronaut corps has not received formal medical training. It remains to be seen how the use of metronomic tones and other timing devices would affect BCPR performance by bystanders, including the CMO cohort.

The focus of this study was to determine whether use of timing devices, such as audible metronomic tones, improves BCPR performance by bystanders compared to non-timed BCPR. This study compares BCPR performance with and without the presence of a timing device as the bystanders deliver breaths and compressions to a simulated cardiopulmonary arrest patient. Our hypothesis was that use of a timing device would improve BCPR performance.

2. Methods

Participants: As indicated by the NASA Johnson Space Center (JSC) Committee for the Protection of Human Subjects (CPHS), the protocol for this study met CPHS guidelines for the safe use of human subjects. Forty educated professionals (23 men, 17 women) volunteered to participate as subjects in this study based on the following criteria: 1) Subject was certified to perform two-person “bystander” CPR (BCPR) using standards set by the American Heart Association (AHA); training was received 18 to 24 months before the study, 2) Subject was not formally trained in a medical discipline (e.g., physician, nurse, paramedic, military medic), and 3) Subject signed a consent form indicating willingness to participate. Subjects were then paired to perform BCPR on a simulated patient with an unintubated airway.

Simulated patient and Ventilation Devices: The simulated patient consisted of an airway training manikin (Airway Management Trainer, Laerdal Medical Corporation, Armonk, NY) connected to test lungs with adjustable lung compliance (Training/Test Lung, Model 2600i, Michigan Instruments, Grand Rapids, MI; lung compliance = 20 ml/cmH₂O). The simulated patient was instrumented to record delivered tidal volumes (*ml*), delivered airway pressures (*cmH₂O*) and delivered airway flows (*L/min*) using a linear pneumotach flow sensor (3700 Series, Hans-Rudolph, Inc., Kansas City, MO) that was installed between the ventilation device and the face mask (Adult-5, Vital Signs, Inc., Totowa, NJ) (Figure 1).



Figure 1

Each subject was briefly trained to provide breaths using one of two ventilation devices attached to the face mask: 1) bag-valve mask (BVM) with self-inflating bag (Ambu® Ventilation Bag, Clearwater, FL) and 2) Impact Model 730 ventilator (M730; Impact Instrumentation, Inc., West Caldwell, NJ). The M730 is a pneumatically powered automatic transport ventilator (ATV) that is specifically developed for field use by personnel with a wide range of training and expertise [5]. The operator enters the victim's approximate weight and the minute ventilation is determined by an internal algorithm that uses the Radford nomogram [5,6]. The M730 has a CPR mode where a metronome prompts the rescuer to deliver compressions and pause while two breaths are delivered automatically from an external oxygen source using the M730's internal, timed delivery system [5].

Data were collected on a laptop computer (600M Inspiron; Dell Inc., Austin, TX) using devices and software from a Research Pneumotach System (RSS 100HR, Hans Rudolph, Inc., Kansas City, MO). A 5 cm H₂O PEEP valve (Boehringer Laboratories, Inc., Norristown, PA) was attached to the manikin's esophagus, mimicking the lower esophageal sphincter. The amount of air per breath exiting the PEEP valve was measured using a respirometer (Model 295, Anesthesia Associates, Inc., San Marcos, CA) and manually recorded.

Chest compressions were performed on a compression simulator (Actar 911, Actar Airforce Inc., via Vital Signs, Inc., Totowa, NJ). The number of compressions was recorded via a pressure transducer connected to the auxiliary pressure port on the Hans Rudolph RSS 100HR. The transducer measured the change in air pressure within an air-filled IV bag that was contained within the compression simulator. Each pressure change or “spike” represented one compression and each compression was recorded on a laptop computer.

Experimental Protocol: Each bystander performed two-person bystander CPR (BCPR; 2 breaths/15 compressions per cycle) using three interventions in the following order: 1) BCPR using a BVM for breaths without use of timing devices [NONE], 2) BCPR using a BVM for breaths plus a computer-based metronome for coordinating compressions only [COMP ONLY], 3) BCPR using both the M730’s internal timing device to deliver breaths and the M730’s metronome to coordinate compressions [BOTH]. For each configuration, the bystander ventilated the patient for 4 minutes followed by performing compressions for 4 minutes or vice-versa. The bystanders were evaluated for their ability to meet the Guidelines 2000 (AHA) [7] of 32 breaths and 240 compressions for each 4-minute interval. Each session was videotaped for retrospective analysis.

Ventilation device and metronome use for each intervention was as follows:

| | Interventions | | |
|--------------------|---------------|---------------------------------|---|
| | NONE | COMP ONLY | BOTH |
| Ventilation Device | BVM | BVM | M730 |
| Timing Device | None | Metronome for compressions ONLY | M730’s timing devices for breath and compressions |

Surveys: Preference of metronome use for coordinating the delivery of compressions was measured using a 10 cm visual analog scale. The scale was "1=bystander has no need whatsoever for using a metronome" through "10=bystander must have a metronome."

Data Analysis: A Repeated Measures Analysis of Variance (ANOVA) with a Bonferroni Multiple Comparison Test was used to compare differences between the three groups for actual and recommended number of breaths and compressions ($p \leq 0.001$).

3. Results

All 40 bystanders performed BCPR on a simulated patient using either a BVM or a M730 with a face mask. Bystanders not using a timing device (NONE) failed to provide the recommended number of breaths as indicated by Guidelines 2000 (AHA) [7] (Table 1). Addition of an audible metronomic tone for compressions only (COMP ONLY) led to a significant increase in the number of breaths applied to the simulated patient compared to the number of breaths recorded during the NONE configuration. In contrast, bystanders using a timing device to apply both breaths and compressions (BOTH) were able to provide the recommended number of breaths.

Table 1

Comparison of the number of breaths given by bystanders in the presence or absence of timing device(s) using either a bag-valve mask (BVM) system or an automatic transport ventilator (M730) to ventilate a simulated patient during two-person BCPR. Groups: NONE: Timing device not used; COMP ONLY: Metronome used for compressions only; BOTH: Timing device and metronome within the M730 used for delivery of breath and compressions, respectively.

| Group | Number of breaths in 4 minute cycle (guideline=32) | Average difference between actual and recommended number of breaths in 4 minutes | Average of percentage difference between actual and recommended number of breaths in 4 minutes |
|-----------|--|--|--|
| NONE | 38.1 ± 1.0 √ | 7.4 ± 0.9 √ | 23.0 ± 2.9 √ |
| COMP ONLY | 42.4 ± 0.9 √ ‡ | 10.5 ± 0.4 √ ‡ | 32.8 ± 8.6 √ ‡ |
| BOTH | 32.0 ± 0.0 * | 0.0 ± 0.0 * | -0.0 ± 0.0 * |

* - Significantly different from both NONE and COMP ONLY (p<0.001)

‡ - Significantly different from NONE (p<0.001)

√ - Significantly different from Guidelines 2000 (AHA) recommendations [1] (p<0.001)

Similar to the application of breaths, bystanders failed to provide the recommended number of compressions to the simulated patient in the absence of a timing device (NONE) or the presence of a timing device for coordinating compressions only (COMP ONLY). Table 2 shows a significant

increase in compressions applied for the NONE and COMP ONLY groups as compared to the recommended number of compressions stated in Guidelines 2000 (AHA) [7]. Bystanders using a timing device for applying both breaths and compressions (BOTH) also failed to provide the recommended number of compressions; however, the number delivered was lower and significantly closer to the recommended value compared with the NONE and COMP ONLY configurations.

Table 2

Comparison of the number of compressions given by bystanders in the presence or absence of timing device(s) using either a bag-valve mask (BVM) system or an automatic transport ventilator (M730) to ventilate a simulated patient during two-person BCPR. Groups: NONE: Metronome not used; COMP ONLY: Metronome used for compressions only; BOTH: Metronome use for compressions and a device (M730) for automatically delivering breaths.

| Group | Number of compressions in 4 minute cycle (guideline=240) | Average difference between actual and recommended number of compressions in 4 minutes | Average of percentage difference between actual and recommended number of compressions in 4 minutes |
|-----------|--|---|---|
| NONE | 281.9 ± 8.5 √ | 41.85 ± 8.5 √ | 17.5 ± 3.5 √ |
| COMP ONLY | 317.5 ± 3.4 √ ‡ | 77.50 ± 3.4 √ ‡ | 32.3 ± 1.4 √ ‡ |
| BOTH | 230.8 ± 1.1 √ * | -9.25 ± 1.1 √ * | -3.9 ± 0.5 * |

* - Significantly different from both NONE and COMP ONLY (p<0.001)

‡ - Significantly different from NONE (p<0.001)

√ - Significantly different from Guidelines 2000 (AHA) recommendations [1] (p<0.001)

Lastly, bystanders preferred metronome use to coordinate the timing and rate for delivering cardiac compressions during BCPR as demonstrated by the 6.1 ± 0.4 rating from the survey (Please note that the scale was "1=bystander has no need whatsoever for using a metronome" through "10=bystander must have a metronome").

4. Discussion

The main finding from this study is that use of a timing device or audible metronomic tones to coordinate the application of both ventilatory breaths and cardiac compressions during bystander CPR (BCPR) improves bystander performance of BCPR. The number of breaths and compressions delivered using a timing device and audible tones from a metronome, respectively, was closer to the recommended number of breaths and compressions stated in Guidelines 2000 (AHA) [7]. Also, bystanders preferred to use a metronome for coordinating the delivery of compressions during BCPR as opposed to performing this life-saving procedure in the absence of one.

BCPR performance, based on recommendations from Guidelines 2000 (AHA) [7], differed depending upon 1) whether a timing device was used and 2) how a timing device was used. Absence of a timing device was associated with bystanders administering an incorrect number of breaths and compressions. Use of a metronome to coordinate the delivery of compressions only did not improve BCPR performance. In fact, metronome-driven compression delivery led to more significant deviations of the numbers of both breaths and compressions compared to numbers collected in the absence of a timing device. It is unclear whether the observed increase in delivery of breaths and compressions would be deleterious to a victim's sensitive medical condition and thus have an impact on patient survivability. Using a timing device to coordinate both breath and compression delivery, however, improved BCPR performance. This finding suggests that use of timing devices to coordinate both components of BCPR may be beneficial to bystanders, including astronaut CMOs, as they perform this procedure.

Not using a timing device was associated with bystanders not providing the recommended number of breaths and compressions, based on Guidelines 2000 (AHA) [7]. The failure of the bystanders to meet

these recommended values may be explained by their inability to remember the recommended rate for delivering breaths and compressions per their CPR training. Breath delivery rate and compression delivery rate were not recorded for this study; however, retrospective video analysis indicated that faster breath delivery rates and faster compression delivery rates, compared to recommended rates, were observed for most bystanders when a timing device was not used. This is not surprising considering that performance of BCPR introduces a level of stress and excitement [1,8] that can cause a bystander to aggressively treat a patient (e.g., excessive ventilation) [1]. This ‘human element’ may lead to different rates for both components and thus, affect BCPR performance. Interestingly, the bystander teams in this study that administered the correct number of breaths were observed to deliver compressions slower than other teams and thus were more likely to administer the recommended number of breath-compression cycles for the 4-minute interval. Overall, the results indicate that bystanders, in the absence of a timing device, have difficulty applying the recommended rate for delivering breaths and compressions during BCPR.

Addition of a metronome to help coordinate the delivery of cardiac compressions led to none of the bystanders meeting the recommended breath and compression guidelines. It appeared that standardizing the compression rate was not able to counteract the influence of the ‘human element’ on bystander breath delivery. Retrospective video analysis indicated shorter breath delivery times and faster breath delivery rates for most bystanders in the presence of audible metronomic tone for compressions only. In general, shorter breath delivery times and faster breath delivery rates in the presence of the proper compression rate would lead to more breath-compression cycles being performed in the 4-minute interval. Hence, there would be more breaths and compression delivered to the patient. The data supports this observation.

For our study, air entered the simulated stomach for each breath given, independent of the delivery method (data not shown); however, use of audible tones to coordinate only the compression delivery rate resulted in the largest number of breaths being delivered and thus the most amount of air to enter the stomach. An immediate consequence of increased air entering the stomach is gastric aspiration [9] which could exacerbate the medical condition of a cardiopulmonary arrest victim. Gastric aspiration in the microgravity environment experienced during space flight would lead to gastric contents floating, thus increasing the likelihood of an airway becoming blocked and subsequent worsening of an astronaut's medical condition. Overall, these findings suggest that coordinating only one BCPR component, in this case compressions, does not improve BCPR performance.

Timed coordination of both BCPR components improves performance. The M730's internal timing device for delivering breaths and its audible tones for coordinating compression delivery led all bystanders to provide the recommended number of breaths and a total number of compressions closer to Guidelines 2000 (AHA) [7]. This was expected because the M730 removes part of the 'human element' from each BCPR component. The M730 automatically delivers breaths without direct influence from the bystander and its audible metronomic tone drives the rate at which the bystander delivers compressions to the patient, thus helping bystanders deliver the recommended number of breath-compression cycles. Use of audible metronomic tones to coordinate compression delivery is not novel. Milander *et al* demonstrated the ability of Basic Cardiac Life Support professionals to align their compression rates to AHA-recommended standards with the aid of audible tones [1]. Our study indicates similar results for bystanders. It is understood that use of timing devices for both BCPR components resulted in a significant decrease in compressions delivered; however, this experimental

configuration provided results that were the closest to the compression guidelines (Percent difference from Guidelines 2000 (AHA) [7]: BOTH = -4% vs. NONE= 18% vs. COMP ONLY=32%). These results indicate that use of timing devices to coordinate breath and compression delivery by bystanders improves BCPR performance for this cohort.

Bystanders preferred to use a timing device for coordinating the delivery of compressions during BCPR according to survey data taken after the study. Communication with the bystanders indicated that use of a timing device during BCPR allowed them to follow a specific cadence without having to rely on their memory of proper timing. Without these devices, bystanders would have to retain and apply ventilatory and compression rates learned months or years before. Results from the first part of this study indicate that it is difficult for bystanders to retain the required ventilation and compression rates. Use of timing devices removed the rate variability among the study cohort.

Study Limitations

The limitations of this study are identified. Bystanders for this investigation performed BCPR in a designated order to minimize bias from both timing devices. Bystanders hearing the compression rate via audible tones early in the study could have retained that rate later in the study when not using of a timing device; this could have influenced compression delivery. Also, use of the M730's internal timing device for breath delivery before BVM use could have influenced bystander delivery of breaths with the BVM, thus skewing performance and retention data. In addition, it is understood that our experimental design does not exactly duplicate the respiratory mechanics of a cardiopulmonary arrest patient despite careful selection of components for our simulated patient and the similarities it has with established CPR bench models [10,11]. Specific respiratory parameters were either constant (e.g.,

airway resistance) or set to characterize a worst case scenario (e.g. compliance = 0.02 cm/H₂O); neither of these settings can fully represent all of the respiratory parameters presented by out-of-hospital cardiopulmonary arrest patients or astronauts during space flight. This also applies to cardiovascular mechanics and gastrointestinal limits (e.g. chest and stomach compliance, respectively, were nonexistent). The LESP value for this study is based on animal data [12]. As stated by Wagner-Berger *et al*, LESP data during human cardiopulmonary arrest is limited; however, there is the presumption that decreases in LESP in humans can occur as indicated by the high incidence of regurgitation and aspiration in cardiopulmonary arrest patients [13], especially following prolonged ventilation using an unprotected airway [11,14]. Similar to the Wagner-Berger study, the effect of acute supraglottal airway obstruction on the peak airway pressure is not taken into account in the simulated patient for this study [11]. Lastly, bystanders have historically ventilated a patient using mouth-to-mouth resuscitation. However, better public access to bag-valve mask (BVM) systems (e.g. businesses have incorporated BVM systems into emergency medical kits used by bystanders) has increased the likelihood of bystanders using a BVM to ventilate a victim of respiratory and/or cardiac arrest. Astronaut-CMOs aboard the International Space Station (ISS) can use the BVM system that is contained within the Advanced Life Support Pack (ALSP) for BCPR during ISS space missions. Hence, our team chose to use a BVM system as well as the M730 for providing the ventilatory breaths in this study.

5. Conclusion

We found that bystander performance of BCPR was improved using timing devices that coordinated the delivery of breaths and compressions to our simulated cardiopulmonary arrest patient. Timing devices used to coordinate both BCPR components allowed a bystander to better meet the standard of

care as recommended by Guidelines 2000 (AHA) [7]. Implementation of timing devices into BCPR training and BCPR medical kits can help bystanders and astronaut CMOs enhance the standard of care for treating cardiopulmonary arrest in terrestrial settings and in the microgravity environment experienced during space flight, respectively.

6. Acknowledgements

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7. Conflict of Interest

Author George Beck is the Director of Engineering and Research at Impact Instrumentation, Inc. Mr. Beck did not participate in the data collection or analysis for this study.

8. References

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