Effectiveness of infrared thermography in monitoring ventilation performance during cardiopulmonary resuscitation training: A cross-sectional simulation study in nursing students

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ABSTRACT

Providing reliable systems to assess ventilation outcomes in simulation-based scenarios is paramount to improve the performance during cardiopulmonary resuscitation (CPR) in real situations. The aim of this study is to investigate the reliability of infrared thermography (IRT) in monitoring the quality of resuscitative breaths in undergraduate nursing students during a simulated CPR-based clinical practice. We recruited a convenience sample of 21 volunteer students in the second year of the Bachelor of Nursing. Participants were instructed to perform CPR following the European Resuscitation Council guidelines in training manikins from Laerdal Medical® during two consecutive minutes. Demographic and knowledge data about CPR performance were collected with a questionnaire whilst ventilation quality parameters (volume, rate, time spent) were provided by the manikin software. Thermographic images from the manikin´s peripheral mouth region were recorded at the end of each CPR ventilation cycle. The temperature profile was examined at baseline and after 1 and 2 minutes of ventilation performance. A temperture increment of 1.357 °C was observed when comparing the maximum temperature at minute 1 with regard to baseline, whilst a significative decrease was obtained between minute 1 and minute 2 (0.457°C) of the study. The comparison between the number of ventilations and the temperature variation after 1 minute of CPR training produced good correlation values (rho = 0.658, p=0.0019). A positive association was also observed between IRT and t ventilation volume values (r = 0.503, p=0.02). Our results indicate that infrared thermography is a promising tool for assessing ventilation performance in CPR practice, thus enabling its potential use as predictor of the quality of resuscitative breaths in simulation-based scenarios.

CCS CONCEPTS

•Applied computing → Health care information systems • Computing methodologies → Simulation tools • Hardware → Emerging tools and methodologies • Hardware → Biology-related information processing

KEYWORDS

Simulation scenarios, Cardiopulmonary resuscitation, Training manikin, Ventilation performance, Thermal imaging.

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1 Introduction

Education in nursing practice is essential to ensure that undergraduate students attain sufficient technical skills and competences for the development of their professional expertise in the future [1,2]. Learning of clinical experiences in simulated patient scenarios allows students to improve both self-efficacy and self-confidence by combining theoretical and practical knowledge. In this sense, simulation provides the opportunity of performing a variety of clinical situations in low risk training environments. The immersion in interactive clinical experiences that replicate the real world offers significant benefits in comparison with traditional learning models [3-5].

The possibility of improving practice performance by evaluating the effectiveness of their own decisions and actions while increasing critical thinking and clinical judgement are also additional educational advantages for nursing students [6,7].

In particular, the utilization of simulated scenarios in emergency related situations such as cardiac arrest may reduce morbidity and mortality rates if the cardiopulmonary resuscitation (CPR) procedure is performed appropriately [3,8,9]. Since the quality of CPR is critical to improve survival and obtain good neurological outcomes, AHA (American Heart Association) and ERC (European Research Council) guidelines have emphasized their recommendations on chest compression focusing on compression fraction, depth, and rate [10-14]. Nevertheless, the role of ventilation remains practically unknown due to the few studies dedicated to investigate ventilation features during continuous CPR performance. AHA guidelines suggest that rescuers deliver one breath every 6 seconds (10 breaths/minute) after placement of an advanced airway [15]. Likewise, several studies have shown that hyperventilation may be associated with poor outcomes [12]. However, there is still poor evidence about tidal volume and the specific number of ventilations recommended to improve cardiac arrest outcomes.

Nursing students should be prepared to perform adequate ventilations during CPR training. Therefore, more focused research efforts are needed to validate better techniques for measuring ventilation performance during CPR training [16]. Manikin-based experiments may aid to overcome these limitations by using feed-back devices based on accelerometer sensors (i.e. Q-CPR, Laerdal, UK and real CPR Help, Zoll, UK) that provide information about the amount and characteristics of ventilations i.e. Volume, Number of ventilations, time spent and rate [17].

Additionally, data obtained by these instruments can be further enhanced by complementary innovative methods. In this sense, the use of Infrared thermography (IRT) as a noncontact imaging technique could provide relevant information about the energy emitted in the form of infrared radiation from the manikin surface during CPR training [18]. The assessment of the surface temperature in the infrared spectrum and the subsequent conversion to a digital signal allows the visualization of a thermal image by the human eye [19]. IRT has been successfully applied for monitoring a wide range of activities from industry and technology to health science [20-29]. The visualization of these events is usually performed by thermographs, particularly by thermographic cameras, which are special instruments capable of detecting the heat distribution of the surface [27]. The interpretation and quantification of the colorful hues represented in the thermal image provide consistent information about the increase or decrease of surface temperature.

The aim of this work is to assess the reliability of infrared thermography in combination with accelerometer sensors for evaluating the quality of ventilations along CPR simulation practices by nursing students. We hypothesized that temperature gradients obtained by IRT are related to the effectiveness of the ventilation performance parameters measured by accelerometer sensors.

2 Methods

2.1 Participants

We developed a descriptive cross-sectional study. Data were collected from January 2019 to February 2019. The study participants were voluntarily recruited from a group of second year nursing students of the Bachelor of Science (Nursing). All participants had received both CPR theoretical/ practical classes and low-fidelity simulation–based learning. Participants were about to commence their second 4-week practicum. The recruitment process was carried out via meetings at lecture time and online postings. There were no exclusion criteria other than being second year undergraduate students. It was stated that the participation was not part of their mandatory program and did not include remuneration or course credit.

2.2 Ethical considerations

The University's Institutional Review Board approved the study. All participants signed the informed consent form in accordance with the Helsinki Declaration guidelines. The confidentiality of the data and the anonymity of participants was guaranteed.

2.3 Study design

A simulated scenario consisting of a cardiac arrest was presented to the participants. Before intervention, each participant completed a knowledge test consisting of 8 multiple questions about the assessment and performance of CPR maneuvers during cardiac arrest. The participants were evaluated individually in ascending order of their ID numbers. Participants were asked to perform CPR according to ERC guidelines for two consecutive minutes. To evaluate CPR performance, the ResusciAnne® QCPR manikin™ (Laerdal Medical®) was used. Participants did not receive neither guidance nor feed-back on their performance during the test. The quality of ventilation was registered using Resusci Anne® Wireless SkillReporter™ Software. Data collected regarding quality parameters included: volume of ventilation, number of ventilations, time spent and rate.

2.4 Thermographic procedure

Thermographic images were acquired by using a FLIR E6 thermal imaging camera (FLIR Systems Ltd, Sweden) with an image resolution of 160 × 120 (19,200 pixels), a measurement range between -20 °C and 250 °C, an operating frequency of 9 Hz, a length spectral range of 7.5–13 μm, a thermal sensitivity below 60 mK and an accuracy for ambient temperature of ±2%.

All photographic records were carried out by the same observer to avoid interexaminer variation, in a closed room of about 40 m^2 illuminated with neon lights and low incidence of natural light. Temperature and humidity of the laboratory were constantly monitored. Temperature values were 22 ± 2°C, while relative humidity was 25% ± 4.4%.

Thermographic photographs corresponding to the peripheral mouth region of the simulation manikin were taken at the end of each CPR ventilation cycle (30:2 strategy, two ventilations after 30 compressions) during 2 consecutive minutes (Figure 1). The critical region of interest for this study was the entired mouth delimited by the tip of the nose, the chin and the right and left sides of the manikin lips. The same polygon size for the selected facial region was selected for each participant after ventilation performance.

The camera was positioned perpendicular to the ground, and the distance between the subject and the infrared camera was fixed at 0.5-1 m, depending on the position of subjects. The FLIR TOOLs Software Version 1.1 (FLIR Systems) provided by the camera's manufacturer was used for image processing of the thermographic images.

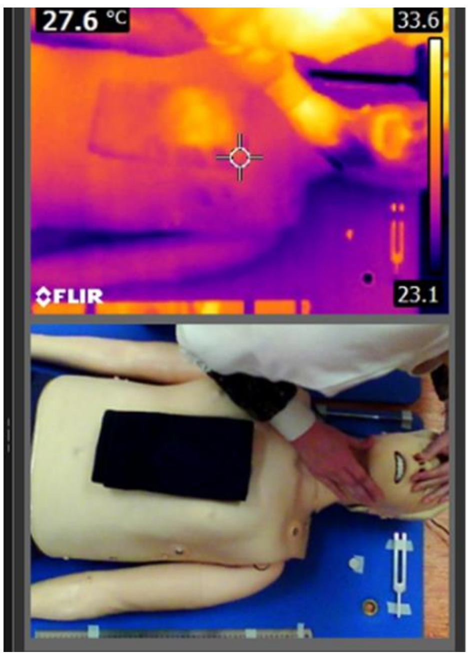

Figure 1: Model depicting thermal imaging collection during CPR.

2.5 Data analysis

SPSS for Windows version 24.0 (IBMSPSS, Inc, Chicago, IL) was used for data analysis. Socio demographical characteristics of the study subjects were described using means and SDs whilst the categorical variables were expressed as the percentage. The quality parameter differences were analyzed with the nonparametric Mann-Whitney U and Kolmogorov-Smirnov tests. Pearson or Spearman correlation coefficients were used to determine the correlation between thermographic data and other variables. Statistical significance was set at a p-value of <0.05.

3 Results

3.1 Participant characteristics

A total of 21 participants (18 females: 85.7%) were included in the study. All the participants completed the quality CPR test and were considered for the data analysis. Socio demographical characteristics (age, gender, educational level, number of special services visited, basic and highest learning in CPR), the mean scores on the knowledge test and the theoretical specific knowledge comprising ventilation management and airway perfusion ('Which of the following airway-opening maneuvers is not recommended' and 'Which is the compression to ventilation ratio for one/two rescuers') are shown in Table 1.

Table 1. Demographic characteristics of the participants (categorical variables expressed as absolute frequencies and continuous variables as mean ±standard deviation).

			N = 21 mean±SD (%)
Sex	Female		18 (85.7)
	Male		3 (14.3)
Age			21.0±4
Educational level	Baccalaureate		17 (81)
	Professional training		3 (14.3)
	Bachelor of Science (other)		1 (4.8)
Practicum in Special health Services	YES		0
	NO		21 (100)
Level of CPR training (Basic Life Support)	YES	< 2 years	1 (4.8)
		> 2 years	2 (9.5)
	NO		18 (85.7)
Basic learning duration (hours)			37.6±46.1
Knowledge test Global score (number of correct answers)			5.67±1.5(70.8)
Airway-opening maneuvers	Correct		13 (61.9)
	Incorrect		8 (38.1)
Compression to ventilation ratio	Correct		17 (81)
	Incorrect		4 (19)

3.2. CPR performance

Quality CPR parameters including chest compressions and ventilations are presented in Table 2. Regarding the quality of the breath provided by the rescuer during simulated CPR, the number of ventilations were 7.52 ± 4.65 breaths/minute whilst the mean ventilation volume was 418.81± 311.5 mL (Table 2). As expected, the correlation between the global ventilation score and the global CPR score (rho = 0.688, p = 0.001), volume ventilation (rho =0.575, p = 0.006), adequate volume ventilation (rho =0.887, p = 0.000) and mean ventilation rate in 1 minute (rho = .836, p =0.000) yielded statistically significant differences. Participants with higher scores in the knowledge test did not performed better in relation to ventilation volume than those who had poor scores. Therefore, no association was observed between higher scores in the knowledge test and the global CPR score (rho =0.152, p = 0.510).

Table 2. Practical cardiopulmonary resuscitation (CPR skills): CPR quality characteristics derived from the Laerdal SkillReporter™ Software

	Mean (%)	Significance level
CPR Global score	38.81±29.83	0.200
Compressions global score	44.48±32.86	0.189
Time spent without compressions/ventilations (seconds)	6±1	0.010
Ventilations global score	61.29±38.95	0.003
Ventilations Volume (mL)	418.81±311.53	0.200
Number of ventilations	7.52±4.65	0.000
Ventilation volume (adequate)	32±29.39	0.036
Ventilation volume (excessive)	17.33±26.32	0.000
Ventilation volume (insufficient)	26.86±33.21	0.000
Mean Ventilation rate (1 minute)	3.57±2.24	0.000

3.3 Thermographic measurements

A total of three thermographic images from the manikin's peripheral mouth region were analyzed after ventilation performance. Table 3 shows the minimum, maximum and average temperature recordings that were obtained throughout the analysis of the region of interest at baseline, minute 1 and minute 2 during CPR simulation. Temperature increments between minute 1 and baseline, minute 2 and baseline and minute 2 and minute 1 were also considered.

A characteristic thermographic profile represented by higher temperatures at lips peripheral sides, and a lower temperature in the central area was found after the intervention of all subjects, regardless of the time of recording (Figure 2).

The maximum values were found at minute 2 whilst a decrease in the temperature increment was observed in the last minute of the procedure in comparison with the first one. The thermal oscillation pattern presented significant differences in the mean, maximum and minimum values between minute 1 and baseline. A slight temperature increment was observed in the average temperature, with a difference of 0.457°C between minute 1 and minute 2.

By correlating the maximum, minimum and average temperatures presented in the region of interest with the ventilation quality variables, statistically significant associations were found for the number of performed ventilations and the average temperature at minute 1 (rho = 0.658, p = 0.001) and minute 2 (rho = 0.505, p = 0.020), as shown in Table 4. Likewise, the mean ventilation rate in 1 minute was also significantly and positively correlated with the average temperature at minute 1 (rho = 0.615, p = 0.003), the mean ventilation volume (r = 0.503, p = 0.020) and the adequate ventilation volume (rho = 0.455, p = 0.038).

Regarding the CPR global score, a statistically significant association was observed when comparing the effect of temperature with the average temperature at baseline (r = 0.505, p = 0.020), minute 1 (r = 0.562, p = 0.008) and minute 2 (r = 0.467, p = 0.032).

Table 3. Temperature profile at baseline, minute 1 and minute 2 and between the assessments at the time intervals considered

Temperature (°C)		Mean±SD	Significance level
Baseline	Maximum	27.290±0.851	0.200
	Minimum	24.929±0.869	0.200
	Average	26.229±0.834	0.200
Minute 1	Maximum	29.371±0.793	0.200
	Minimum	25.471±0.655	0.039
	Average	27.586±0.703	0.200
Minute 2	Maximum	30.219± 0.587	0.101
	Minimum	25.562±0.587	0.160
	Average	28.043±0.603	0.163
Increment	Baseline-minute 1	1.357±0.508	0.200
	Minute 1-minute 2	1.814±0.652	0.100
	Baseline-minute 2	0.457±0.393	0.200

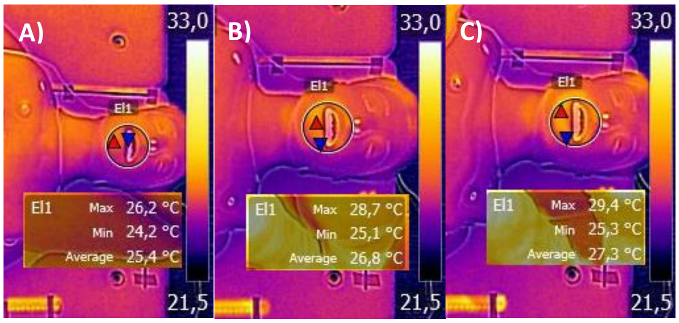

Figure 2: Infrared thermograms during CPR simulation (red and blue triangles represent the maximum and minimum temperature of the region of interest respectively): A) Baseline; B) Minute 1 and C) Minute 2.

Table 4. Correlations among CPR quality parameters and temperature profile values at baseline, minute 1 and minute 2 of the analysis

		Mean temperature			Temperature increment		
		Baseline	Min 1	Min 2	Baseline-Min 1	Min0-Min2	Min1-Min2
CPR global score†	Correlation coeficient	0.505*	0.562*	0.467*	-0,050	-0.213	-0.290
	Significance (2-tailed)	0.020 *	0.008 *	0.032 *	0.830	0.353	0.203
Ventilation global score	Correlation coeficient	0.150	0.359	0.281	0.295	0.130	-0.073
	Significance (2-tailed)	0.516	0.110	0.217	0.194	0.574	0.754
Ventilation volume†	Correlation coeficient	0.327	0.503*	0.399	0.159	-0.049	-0.288
	Significance (2-tailed)	0.148	0.020*	0.073	0.490	0.832	0.205
Number of ventilations	Correlation coeficient	0.396	0.658*	0.505*	0.202	0.001	-0.223
	Significance (2-tailed)	0.075	0.001	0.020*	0,380	0.995	0.331
Ventilation volumen (adequate)	Correlation coeficient	0.245	0.455*	0.383	0.330	0.090	-0.200
	Significance (2-tailed)	0.284	0.038*	0.087	0.145	0.700	0.385
Ventilation volumen (excessive)	Correlation coeficient	0.142	0.370	0.362	0.273	0.132	-0.033
	Significance (2-tailed)	0,.540	0.,099	0,107	0.231	0.570	0.,887
Ventilation volumen insufficient)	Correlation coeficient	0.382	0.415	0.209	0.086	-0.250	-0.195
	Significance (2-tailed)	0.088	0.061	0.363	0.711	0.274	0.397
Mean Ventilation rate (1 minute)	Correlation coeficient	0.364	0.615*	0.482*	0.224	0.013	-0.166
	Significance (2-tailed)	0.105	0.003*	0.027*	0.328	0.955	0.472

†Pearson; *Significance level $p<0.05$

4 Discussion

This study describes the effectiveness of infrared thermography in assessing the quality of ventilations during CPR simulation-based training by nursing students. Our findings showed that IRT can be considered as a feasible tool for accomplishing CPR learning while obtaining good correlation with conventional evaluation methods.

The effect of theoretical knowledge in improving the performance of the simulation practice was also measured. Since previous knowledge in the subject may increase the confidence during the simulation performance, higher confidence levels could be associated to the effective use of clinical skills [30,31]. Our results show that students with better scores in the knowledge test did not succeed in performing higher quality ventilations. These results are in agreement with previous studies, thus suggesting that simulation education may be implemented by alternative learning sessions such as role playing before the exercise practice [32].

In the particular case of CPR training, administration of high-quality ventilations may achieve increasing patient outcomes while ensuring airway management in real scenarios [12]. Therefore, the evaluation of clinical skills during CPR simulation may aid students to improve their performance in real situations. In our study the SkillReporter™ evaluation allows us to correlate the main variables related to ventilation performance. When assessing quality ventilations by manikin's integrated accelerometer sensor devices [33], several parameters such as the ventilation ratio and the ventilation (tidal) volume need to be considered [32]. Providing an adequate ventilation rate and volume is essential for the success of CPR procedures. In this study, mean ventilation volumes did not reach the recommended tidal volume according to ERC guidelines, since each resuscitative breath should be given over one second, administering enough volume (500–600 mL), to inflate the victim's chest [15]. These results do not correspond with previous studies wherein the administration of excessive breath volumes produced hyperventilation [12]. This common error was probably avoided due to the level of CPR training confirmed by the subjects in the knowledge test scores [32].

Regarding the ventilation rate, our findings indicate that mean ventilations were performed at the speed recommended by AHA guidelines [10]. Although a common reported mistake related to ventilation rate consists of performing faster ventilations, our results show that the majority of participants maintained adequate ventilation rates, thus indicating that performing the simulation practice in a controlled environment did not interfere with the expected response from the students.

Additionally, good correlation levels were obtained in spite of the lack of experience of the participants in real CPR scenarios when comparing quality ventilation parameters. These findings suggest that simulation-based practices may contribute to reduce possible disruptors experimented by rescuers when performing actual CPR situations [15].

Since significant differences were found in the thermograms depending on the recording time, our results suggest that the characteristics of the temperature profile distribution is determined by the duration of CPR training. These preliminary data could indicate the importance of administering refresher for the provider of rescue breathing [13]. Further study including an extended recording of thermal images during 10 minutes of CPR performance may confirm these results. Regarding the selected size of the region of interest, the distribution of the temperature pattern suggest that the determination of the warmest areas may be associated with a better seal during mouth to mouth ventilation. [34]. Therefore, the potential use of IRT as an analytical tool for assuring adequate mouth-to mouth seals could be considered as an interesting approach to monitor the performance of rescue breathing.

The assessment of the efficacy of IRT as a complementary tool of CPR training was also investigated by correlating ventilation quality parameters obtained by the SkillReporter™ manikin software with the temperature values at different time periods.

Our results show that stronger associations occurred between both the number of ventilation and the mean ventilation rate when correlated to the mean temperature either at minute 1 or minute 2 of the study. This may be explained by the temperature increment observed as the number of administered breathing rescues increased. Accordingly, IRT could be associated with the effective performance of the ventilation rate allowing the continuous and quantitative monitoring of temperature increments during the progress of CPR ventilation maneuvers.

Similarly, moderate to strong correlations were observed by comparing mean and adequate ventilation volumes with the mean temperature of the studied area at minute 1. Since administering an adequate tidal volume is heavily related to the quality of ventilations, these correlations suggest that IRT could be used as a valuable tool for the quantitative determination of the effectiveness of breath insufflation [32]. Moreover, the accuracy of thermographic data also indicates that measuring ventilations volumes particularly at minute 1 provides additional information about the quality of the breathing performance.

These results are supported by the good correlation observed between the global CPR score and the mean temperature values at all recording time periods. Consequently, IRT could be considered as an effective guidance for monitoring the ventilation performance, particularly by providing: (i) quantitative measurements while minimizing individual differences among both skilled and untrained providers; (ii) accurate and robust analysis in controlled educational environments.

Although, to our knowledge, this is the first study to evaluate ventilation performance by infrared thermography, several limitations need to be considered. First, the interpretation of thermographic information may be improved by: (i) optimizing the characterization of the registered data, (ii) enhancing the selection of the region of interest and (iii) using supplementary software not fully dependent on pixel temperature values. In addition, in spite of the clear advantage of IRT as a non-invasive imaging technique, more research is required to validate the method in clinical settings with skilled participants.

5 Conclusion

The performance of nursing students along cardiac arrest simulation training requires a comprehensive evaluation through reliable quantitative methods. To this end, the combination of sensor accelerometer measurements with infrared thermography imaging seems to be a promising approach for monitoring the administration of ventilations in manikin-based simulations. In this work, temperature changes visualized by thermal imaging during rescue breathing showed good correlation values with standard quality ventilation parameters. Further studies are needed to confirm the reliability of infrared thermography as a predictor tool in improving the quality of ventilation performance of CPR simulated scenarios.

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