How Much Training Is Enough? Low-Dose, High-Frequency Simulation Training and Maintenance of Competence in Neonatal Resuscitation

Joanna C. Haynes, PhD;
Siren I. Rettedal, PhD;
Anastasia Ushakova, PhD;
Jeffrey M. Perlman, MBChB;
Hege L. Ersdal, PhD

Introduction: Facemask ventilation is a crucial, but challenging, element of neonatal resuscitation.

In a previously reported study, instructor-led training using a novel neonatal simulator resulted in high-level ventilation competence for health care providers (HCPs) involved in newborn resuscitation. The aim of this study was to identify the optimal frequency and dose of simulation training to maintain this competence level.

Methods: Prospective observational study of HCPs training through 9 months. All training was logged. Overall ventilation competence scores were calculated for each simulation case, incorporating 7 skill elements considered important for effective ventilation.

Overall scores and skill elements were analyzed by generalized linear mixed effects models using frequency (number of months of 9 where training occurred and total number of training sessions in 9 months) and dose (total number of cases performed) as predictors. Training loads (frequency + dose) predictive of high scores were projected based on estimated marginal probabilities of successful outcomes.

Results: A total of 156 HCPs performed 4348 training cases. Performing 5 or more sessions in 9 months predicted high global competence scores (>28/30). Frequency was the best predictor for 4 skill elements; success in maintaining airway patency and ventilation fraction was predicted by performing training in, respectively, 2 and 3 months of 9, whereas for avoiding dangerously high inflating pressures and providing adequate mask seal, 5 and 6 sessions, respectively, over the 9 months, predicted success. Skills reflecting global performance (successful resuscitation and valid ventilations) and ventilation rate were more dose-dependent.

Conclusions: Training frequency is important in maintaining neonatal ventilation competence. Training dose is important for some skill elements. This offers the potential for individualized training schedules.

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Key Words: Simulation-based training, in situ simulation, low-dose high-frequency simulation training, training frequency, deliberate practice, competency, quality improvement, patient safety, neonatal resuscitation, neonatal ventilation.

Positive pressure ventilation (PPV) is the cornerstone of resuscitation for newborns who do not breathe at birth. International studies show that 5% to 10% of newborns require PPV,[1,2] although individual institutions may report lower figures.[3] Many HCPs working on the delivery suite have little opportunity to practice the complex skill of PPV in real life, leaving them poorly prepared for this time-critical emergency. The stress and anxiety this creates may negatively impact their performance.[4]

Simulation training has been widely adopted to bridge the gap and is a permanent feature of many neonatal resuscitation training programs.[5,6] Increasing volumes of literature over the past decade leave us in no doubt as to the potential of such training to improve ventilation skills, both in the simulated and clinical situations.[7–11] It is recognized that skills learned during simulation decay rapidly without the opportunity for continued practice, be that in real life or some form of booster or refresher training.[12–14] Although much research has been undertaken proving the value of repetitive simulation practice,[15,16] the optimum training frequency to maintain skills remains unknown.[14,17] To compound the uncertainty, optimum training frequency may vary according to profession, previous training, and clinical experience.[7,18] There is increasing interest in the personalization of training schedules to make efficient use of the individual HCP's valuable time.[19–21]

From the Department of Anaesthesia (J.C.H., H.L.E.), Stavanger University Hospital, Stavanger, Norway; Faculty of Health Sciences (J.C.H., S.I.R., H.L.E.), University of Stavanger, Stavanger, Norway; Department of Paediatrics (S.I.R.), Stavanger University Hospital, Stavanger, Norway; Department of Biostatistics (A.U.), Stavanger University Hospital, Stavanger, Norway; and Department of Pediatrics (J.M.P.), Weill Cornell Medicine, New York, NY.

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Correspondence to: Joanna C. Haynes, MD, Department of Anaesthesia, Stavanger University Hospital, Gerd-Ragna Bloch Thorsens Gate 8, Stavanger, Rogaland 4011, Norway (e-mail: joanna.claire.haynes@sus.no).

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Previously conducted research from our group using a novel newborn simulator, NeoNatalie Live, compared data from real-life resuscitations with those obtained from the mannequin. The study demonstrated that NeoNatalie Live effectively simulates conditions encountered by HCPs during neonatal ventilation.[22] After instructor-led training with the mannequin, all HCPs, irrespective of previous experience, demonstrated providing effective PPV. In addition, their ventilation competence test scores significantly improved from baseline to the equivalent high level (38/40 points) as that achieved by experienced pediatricians[10] The aim of the current study was to identify the optimum dose and frequency (ie, low-dose, high-frequency [LDHF] training load) to maintain this high competence level in this diverse group of HCPs.

METHODS

Study Setting

Stavanger University Hospital, Norway, is the only hospital in the region with both delivery and newborn services. Annually, approximately 4200 births are attended, split between the main labor ward, the midwife-run low-risk delivery unit, and the cesarean section operating theater. Neonatal resuscitation occurs primarily in 1 of these 3 locations. Positive pressure ventilation is provided to 3.6% of newborns,[3] most of which is delivered by the pediatrician called to attend, and in most cases, using a flow-driven T-piece resuscitator (NeoPuff, Fischer and Paykel, Auckland, New Zealand). In some unanticipated resuscitations, PPV is initiated by midwifery or anesthetic staff.

Obstetric and midwifery staff undergo yearly off-site neonatal resuscitation training according to the national guidelines.[23] In addition, a fortnightly in situ multidisciplinary team training session is offered to HCPs working on the delivery unit on the day.

An ongoing research collaboration, Safer Births,[24] aims to contribute new knowledge on newborn transition and improve the care of newborns on the day of birth. Initiatives include rapid monitoring of newborns' heart rate using NeoBeat (Laerdal Medical, Stavanger, Norway),[25] and multidisciplinary ventilation training with a novel neonatal simulator, NeoNatalie Live (Laerdal Medical).[22]

The Neonatal Simulator

NeoNatalie Live is a low-cost newborn simulator produced with the specific aim of training competence in PPV. Health care providers can practice management of newborns with differing initial lung compliance. Real resuscitation data derived from 1237 newborns informs the algorithm guiding the realistic heart rate response according to PPV provided.[26] A cry sound indicates spontaneous respiration and successful resuscitation. Communication with a training application (NeoNatalie Live, Laerdal Global Health) allows HCPs to review their performance, and the app gives immediate, targeted feedback to improve skills in any of 4 simulation scenarios of increasing difficulty. Time to successfully complete each scenario (achieve baby cry) is dictated by a minimum optimum ventilation time, varying from 30 seconds for scenario 1 to 90 seconds for scenario 4. Suboptimal ventilation increases time to baby cry. Bluetooth technology allows collection of training data in a Weblog. Figure 1 shows the mannequin and highlights important technical features.

Study Design

This is a prospective, observational study of LDHF simulation training in neonatal PPV, performed between April 2019 and April 2021. In parallel with the current study, a randomized controlled study involving the same participant group was performed.[10] In the randomized study, participants were allocated to train twice a month or as often as desired to test the effectiveness of LDHF as a training strategy. In the current study, we used actual LDHF training frequencies achieved, irrespective of the training frequency arm assigned in the randomized study, to investigate ongoing variation in competence scores over the 9-month training period. Relevant for both studies, after instructor-led education with the NeoNatalie Live simulator, all participants achieved, and demonstrated in simulation testing, a high ventilation competence level before starting LDHF training.

Any of the approximately 300 HCPs at our institution potentially involved in neonatal resuscitation and working in more than 50% employment were eligible to participate and invited to give informed, written consent. This stipulation was made to ensure that simulation training frequency was minimally affected by absence from work. Those ineligible for, or declining, participation were nonetheless given the same opportunities to perform simulation training as those who took part.

Health care providers from 6 different professions in obstetric, anesthetic, and pediatric services were recruited from April 2019 through July 2020. They completed a preparticipation questionnaire and received individualized instructor-led education in neonatal resuscitation along with training in the use of NeoNatalie Live. Participants were asked to train independently with the simulator for a period of 9 months, starting immediately after the instructor-led education. They were free to choose the difficulty of the scenarios (levels 1–4) and whether to perform PPV with a self-inflating bag or T-piece resuscitator. Three NeoNatalie Live mannequins, each stored with ventilation equipment, a NeoBeat heart rate meter, and an iPad loaded with the NeoNatalie Live training app, were placed in the resuscitation room in all 3 birthing locations.

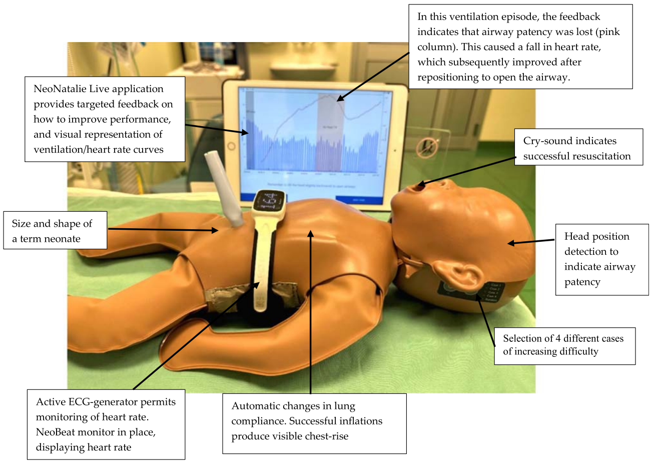

FIGURE 1. A NeoNatalie Live mannequin on the Resuscitaire at the conclusion of a resuscitation case. The dry-electrode heart rate meter, NeoBeat, is seen placed around the mannequin's abdomen, with the heart rate displayed on the screen. Feedback is visible in the NeoNatalie Live application on the iPad.

Data Collection

For each participant, all training performed in each of the 9 months was automatically logged concurrently by the NeoNatalie Live training app. Every training session (a single uninterrupted period of training, irrespective of number of cases undertaken, ie, duration of the training session) performed was analyzed, providing data on every simulated case undertaken in each session. Every case was scored by 1 investigator (J.H.) using a matrix allocating points according to performance in 7 skill elements (Appendix 1). Objective ventilation data were obtained from the simulator. The 7 elements the simulator provided data on were algorithm-derived proportion of valid ventilations, ventilation rate, ventilation fraction (defined in Appendix 1), time to baby cry (time to successfully complete the scenario, as a factor of the minimum possible time), proportion of too low pressure ventilations (indicating inadequate mask seal), avoiding dangerously high inflating pressures (≥45 cm H_2O), and proportion of ventilations with no head tilt (airway not patent). Percentage valid ventilations and time to baby cry, being composite measures of ventilation performance, were weighted heavily. The 7 individual skill element scores were summed to a global competence score of a maximum 30 points. A score of higher than 28 was defined as demonstrating maintained high competence, with adequate mastery of all the 7 skill elements.

Each participant's scores were registered consecutively, providing data on the number of months of 9 in which training was performed (frequency data), the number of training sessions undertaken each month (frequency data), and the number of cases per session (dose or time spent in session). The difficulty level of each case (scenario level 1–4) and the ventilation device used were also recorded. Table 1 summarizes definitions of training months, sessions, and cases and of training frequency, dose, and load.

Ethical Considerations

The study was conducted according to the guidelines of the Declaration of Helsinki and was approved by the Regional Committee for Medical and Healthcare Research Ethics, Region West, reference number 2018/330/REK vest (approved March 23, 2018).

Statistical Analysis

Data analysis was undertaken using SPSS (IBM SPSS Statistics for Windows, Version 26.0, IBM Corp, Armonk, NY) and R Project for Statistical Computing, version 4.2.2.

TABLE 1. Summary of Terms Training Month, Session, Case, Frequency, Dose, and Load

Term	Definition
Month	Month 1 through 9 of study participants' own training
Session	A single discrete period of training, irrespective of duration or number of simulation cases performed
Case	A simulation scenario, difficulty levels 1, 2, 3, and 4
Training frequency	How often participants train in terms of number of months out of 9 and/or number of sessions per month
Training dose	Time spent training; higher dose = longer time spent, ie, greater number of cases
Training load	The combination of training frequency and dose; an overall description of the amount of training undertaken

Preparticipation questionnaire data regarding frequency of previous neonatal resuscitation simulation training and clinical experience with neonatal ventilation were described by profession as pie charts.

Training data were first visualized in scatter plots to give an overview of how global competence scores varied according to the consecutive session number in any individual month and the consecutive case number in any individual session.

We then studied which of the 3 types of training load (number of months trained, total number of sessions, and total number of cases) predicts most accurately the training outcomes. Accuracy of prediction was determined by Akaike information criterion.[27,28]

Two outcome variables were used: 1) the global competence score (converted to a failure score as required by the statistical model used, and given as the maximum possible global competence score of 30 minus the actual score; for this score, 0 is the best outcome, equating to a global competence score of 30, with higher scores indicating poorer performance) and 2) individual skill element scores, defined as success (maximum points) or failure (<maximum points).

Associations between training load and outcomes were modeled using generalized linear mixed-effects models (GLME). The distribution families for the 2 outcomes were 1) negative binomial and 2) binomial, respectively. Training load was the only fixed effect. The random effects were participant-specific random intercepts and random slopes, whereas profession, the ventilation device, and the scenario difficulty were included as random intercepts. If the estimated variance of a random effect was negligibly small ($<10^{-5}$), the corresponding random effect was removed.

Cutoff training load values for predicting success (defined as >28/30 for global competence scores or maximum score for skill elements) were obtained from the marginal models such that sum of sensitivity and specificity was maximized.[29] The model for the individual skill of ventilation frequency within 30–60 was the only one that did not exclude the profession-specific random intercept. For this outcome, the model was redefined to include profession as a fixed effect, and the cutoff was chosen such that predicted proportion of success and its 95% confidence interval (CI) was higher than 0.8. All outcomes were averaged across the ventilation devices and the levels of case difficulty. All models were checked for correct distributional assumptions using scaled quantile residuals by R package DHARMa version 0.4.6. For more detailed information on the statistics used, see Supplementary Digital Content 1 (see Word document, Supplementary Digital Content 1, http://links.lww.com/SIH/B53, How much training is enough? Low-dose, high-frequency simulation training and maintenance of competence in neonatal resuscitation: - extended discussion of statistical analysis).

RESULTS

Of the approximately 300 HCPs involved in neonatal resuscitation, approximately 10 were ineligible for study participation due to a part-time contract. A total of 220 participants were initially recruited, 191 participated in the instructor-led education, and 187 agreed to participate in the 9-month LDHF training period. However, 31 chose not to perform any LDHF training during these 9 months. The remaining 156 HCPs performed

TABLE 2. Number of Participants Recruited, Participating in Instructor-Led Education, and Performing LDHF Training From Each of the 6 Profession Groups, and for Each Group, Median (Interquartile Range; Range) Number of Months Trained, Sessions Per Month and Cases Per Session

Profession	Number Recruited	Number Attending Instructor-Led Education	Number Who Performed LDHF	Cases Performed by Group in 9 mo	Median (IQR; Range) No. Months in Which Training Occurred	Median (IQR; Range) No. Sessions Per Month	Median (IQR; Range) Cases Per Session
Anesthesia nurse	54	46	38	1604	5 (4; 1–9)	1 (1; 1–4)	4 (4; 1–29)
Anesthetist	38	34	24	537	5 (6; 1–9)	1 (1; 1–11)	2 (3; 1–15)
Midwife	72	62	60	1365	5 (5; 1–9)	1 (1; 1–5)	2 (3; 1–10)
Pediatric nurse assistant	17	17	15	456	4 (4; 1–9)	1 (1; 1–3)	3 (3; 1–10)
Pediatrician	18	18	13	212	4 (3; 1–9)	1 (1; 1–3)	3 (3; 1–12)
Obstetrician	21	14	6	174	4 (5; 1–9)	1 (1; 1–4)	3 (3; 1–11)
Totals	**220**	**191**	**156**	**4348**			

IQR, interquartile range.

LDHF training and were included in this study. In total, they performed 4348 cases in 9 months. Table 2 shows the number of participants recruited, participating in instructor-led education, and performing LDHF training from each of the 6 profession groups. For each group, the median (interquartile range; range) number of months trained, sessions per month, and cases per session are presented. The 6 groups performed training in a median of either 4 or 5 months of 9, with a median of 1 session per month and a median of 2 to 4 cases per session. Table 3 shows the overall distribution of the total 4348 cases across the 9 months, the training sessions per month, and individual training sessions. The cases were, after an initial enthusiasm in month 1, evenly distributed across the 9 months, and were performed mostly in the first or second session per month, and usually as a maximum of 10 cases at a time.

The pie charts in Figure 2a show how often the 6 professions reported participating in neonatal resuscitation simulation training before study start. Figure 2b shows how recently the different professions had provided PPV for a newborn at study inclusion. Anesthetic staff participated in neonatal resuscitation simulation training less frequently than labor ward and pediatric staff, and 17.6% (anesthetists) and 13% (anesthesia

TABLE 3. Distribution of the Total 4348 Cases Across the 9 Months, the Training Sessions Per Month, and Individual Training Sessions

	Months			Sessions			Cases		
	Month Number	No. Cases (%)	Cumulative Percentage	Session Number in Month	Number Cases (%)	Cumulative Percentage	Case Number in Session	No. Cases (%)	Cumulative Percentage
	1	761 (18.1)	18.1	1	2927 (67.3)	67.3	1	967 (22.1)	22.2
	2	434 (9.9)	28	2	1233 (28.4)	95.7	2	919 (21.1)	43.4
	3	473 (10.8)	38.8	3	112 (2.6)	98.3	3	727 (16.7)	60.1
	4	463 (10.6)	49.4	4	35 (0.8)	99.1	4	531 (12.2)	72.3
	5	462 (10.5)	59.9	5	13 (0.3)	99.4	5	356 (8.2)	80.5
	6	507 (11.6)	71.5	6	2 (0)	99.4	6	244 (5.6)	86.1
	7	360 (8.2)	79.7	7	2 (0)	99.4	7	172 (4)	90.1
	8	392 (8.9)	88.6	8	2 (0)	99.5	8	120 (2.8)	92.8
	9	496 (11.4)	100	9	3 (0.1)	99.6	9	85 (2)	94.8
				10	4 (0.1)	99.7	10	52 (1.2)	96
				11	15 (0.3)	100	11	33 (0.8)	96.7
							12	29 (0.7)	97.4
							13	24 (0.6)	98
							14	21 (0.5)	98.4
							15	16 (0.4)	98.8
							16	9 (0.2)	99
							17	8 (0.2)	99.2
							18	6 (0.1)	99.3
							19	6 (0.1)	99.5
							20	4 (0.1)	99.6
							21	4 (0.1)	99.7
							22	3 (0.1)	99.7
							23	2 (0)	99.8
							24	2 (0)	99.8
							25	2 (0)	99.9
							26	2 (0)	99.9
							27	2 (0)	100
							28	2 (0)	100
							29	1 (0)	100
Total number (%)		**4348 (100)**			**4348 (100)**			**4348 (100)**	

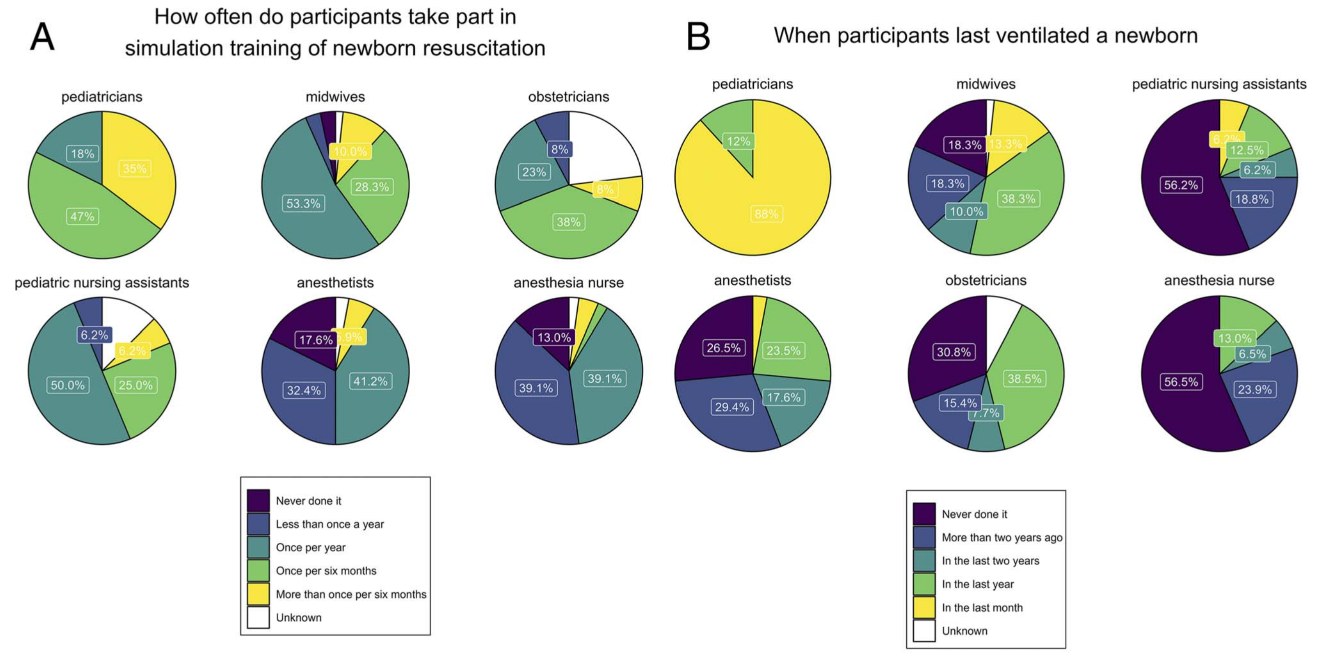

FIGURE 2. A, Pie charts showing the frequency of participation in neonatal resuscitation simulation training for the 6 professions. Data from preparticipation questionnaires. Profession groups are presented in order of decreasing frequency of simulation training. B, Pie charts showing how recently the 6 profession groups last ventilated a newborn. Data from preparticipation questionnaires. Profession groups are presented in order of increasing time since the last ventilation performed.

nurses) had never performed it. The pediatricians reported greatest exposure to real-life PPV within a month of study recruitment, and additionally most frequently participated in simulation training.

Scatter plots of global competence scores according to the consecutive session number performed in any given month (Fig. 3a) and the consecutive case number performed in any given session (Fig. 3b) indicate consistently higher scores with greater frequency (more sessions/month) or dose (more cases/session).

Table 4 summarizes the training loads predictive of success for the different skill elements and of high global competence scores (>28/30). For global competence scores, the model with number of sessions showed the best model fit. The model predicts that each additional session reduces the failure score (30 – actual score) by 2% (95% CI, 1%–3%), $P < 0.001$, and 1 additional session is associated with approximately 3% (95% CI, 2%–5%), $P < 0.001$, increase in the chances of scoring less than 2 points in the failure score, corresponding to a global competence score of higher than 28 points. The cutoff value of 5 sessions in 9 months predicted 66% (95% CI, 60%–72%) average marginal probability of obtaining global competence scores higher than 28 of maximum 30 points (Table 4).

Dose (total number of cases performed) best predicted performance of 3 of the 7 skill elements (Table 4). The number of cases needed to predict success in the 2 composite measures assessing overall performance, valid ventilations, and time to baby cry/successful resuscitation, were 35 and 18, respectively. For ventilation rate, the only skill element for which profession was not excluded due to a negligibly small effect, a case threshold for success could be calculated for each of the 6 professions. The midwives and the pediatricians were predicted to succeed (ie, ventilate with a rate of 30–60 inflations/minute) without any training, that is, training load predicting success in these 2 groups is a total case number = 0. This contrasts with the group needing the highest number of cases to predict success, the anesthetists (36 cases).

Training frequency was more important for the remainder of the skill elements (Table 4). Success in maintenance of airway patency and ventilation fraction was predicted by performing training in 2 and 3 of 9 months, respectively. For adequate mask seal and avoiding dangerously high inflating pressures, the thresholds were 6 and 5 sessions through 9 months, respectively.

DISCUSSION

In this prospective observational study, we aimed to evaluate simulation training loads for maintaining PPV competence

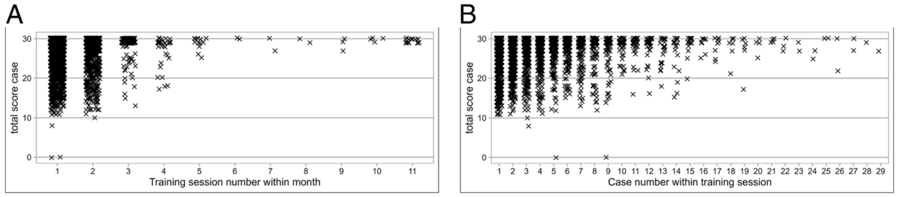

FIGURE 3. A, Scatter plot of global competence scores by session number within month. Most cases were performed in session 1 or 2 within any given month; 11 was the highest session number within any given month. B, Scatter plot of global competence scores by case number within session. Most cases were performed in a series of up to 10 cases per session. The maximum number of cases performed in any one session was 29.

TABLE 4. Training Load Thresholds Predictive of Competence for the Different Skill Elements and Global Competence Score

Score or Skill Element	Predictive Training Load:- Months/Sessions/Cases	Minimum Number to Maintain Competence	Average Marginal Predicted Probability of Successful Outcome With 95% CI*
Ventilation rate 30–60	Cases	Anesthesia nurse…………6 Anesthetist………………..36 Midwife……………….........0 Pediatric nurse assistant...10 Pediatrician………………...0 Obstetrician………………..9	0.89 (0.8–0.95) 0.91 (0.8–0.96) 0.9 (0.8–0.95) 0.91 (0.81–0.96) 0.93 (0.82–0.97) 0.93 (0.8–0.98)
Maintaining airway patency in >95% ventilations	Months	2†	0.88 (0.77–0.94)
Adequate mask seal to generate sufficient inflating pressure for valid ventilation in >95% ventilations	Sessions	6	0.85 (0.72–0.92)
Avoiding dangerously high inflating pressures (<45 cm$H_2$0) in >95% ventilations	Sessions	5	0.99 (0.88–1.0)
≥95% ventilation fraction	Months	3	0.85 (0.58–0.96)
Baby cry (successful resuscitation) in shortest time possible	Cases	18	0.73 (0.49–0.89)
>90% valid ventilations	Cases	35	0.65 (0.44–0.81)
Global competence score >28	Sessions	5	0.66 (0.6–0.72)

*Predicated at the minimum required training load.

†The regression analysis identified that the best predictor of success (months, sessions, or cases) was different for different skill elements. For maintaining airway patency, it identifies that training in 2 of 9 months (average of once every 4.5 months) maintains competence.

For each, the average estimated marginal probability of a successful outcome with its 95% CI is given.

among HCPs at our institution after initial achievement of high-level competence through instructor-led training. For these 156 HCPs with varying resuscitation experience, performing 5 training sessions in 9 months, on average 0.6 sessions per month, maintains a high level of simulated PPV competence. Frequency of training also predicted success in maintenance of airway patency, high ventilation fraction, managing adequate mask seal, and avoiding dangerously high inflating pressures. However, success in correct ventilation rate and the 2 skill elements reflecting global performance (the composite measures of proportion of valid ventilations and time to baby cry) was better predicted by dose, reflective of time spent training, that is, number of cases performed (Table 4).

Competency has been described as the combination of training, skills, experience, and knowledge that a person has and their ability to apply them to perform a task safely.[30] Dreyfus expands on the concept of the competent practitioner, clearly differentiating competent performance (good background knowledge and experience giving situational awareness and the ability to cope with complex situations through analysis and planning) from mastery level performance (authoritative knowledge and deep understanding allowing a holistic grasp of complex situations and the ability to apply both intuitive and analytical adaptations with equal ease).[31] This study has the goal of facilitating competent performance of ventilation in the first minutes of newborn resuscitation while awaiting more experienced help. However, as Whalen[32] notes, no standardized definition or measurement of competency in neonatal facemask PPV exists. Rather, performance is most often described by assessment by an expert provider, from which competency to perform ventilation is inferred. To the best of our knowledge, all previously published neonatal resuscitation scoring tools, although showing reliability and validity, are based on checklists, that is, involve an expert observing performance and marking tasks as completed.[33,34] Using ventilation data from this simulator may represent one of the first attempts to provide an objective measure of both the effectiveness and safety of neonatal ventilation performance.

Facemask ventilation at birth remains a global challenge.[35,36] Simulation training has shown potential to improve perfomance.[37–39] However, there is a need for ongoing work to improve the translation of skills from simulation to address ongoing gaps in bedside performance.[35,39]

In our previous randomized study of LDHF simulation training in neonatal ventilation, short, monthly training sessions promoted retention of competence gained in a previous formalized educational initiative.[10] These findings are consistent with results from other studies, demonstrating that deliberate practice maintains skills known to decay rapidly after instructor-led training[16,40–42]

Defining the most appropriate training frequency is rarely addressed in studies.[14,21] It may be imperative to identify an optimal training frequency to enable large-scale adoption of self-guided training programs, particularly in a busy health care service. Too infrequent training risks skill degradation, but too frequent training places unsustainable demands on often scarce resources. The findings in this report indicate that training 0.6 times per month maintains ventilation skills at a high level of competency for HCPs at our institution. Practically, this translates as training on average once every other month.

This study is unique in using actual training frequencies achieved in the workplace as the basis for assessing optimal training loads. Tables 2 and 3 provide real-world insights into the training loads achievable in a busy health care service. This use of real-life training frequencies contrasts with several recently published studies of deliberate practice to maintain resuscitation skills. Some are based on assessing the effects of the quarterly training recommended by the Resuscitation Quality Improvement (RQI) program[43] of the American Heart Association, with a clear skill-retention benefit shown in training once every 3 months.[44,45] However, some studies have considered shorter intervals using the RQI setup. Anderson found that monthly training was superior to quarterly training, with a significantly higher proportion of participants providing excellent cardiopulmonary resuscitation (CPR) at testing after 12 months.[17] Oermann considered even shorter intervals, finding that for nursing students, daily and weekly training resulted in higher RQI scores for chest compressions and ventilation after 4 training sessions than monthly or quarterly training.[46] That these studies suggest differing training schedules to our findings may be explained by a number of factors, including different populations and differing methods of assessment. One important factor, however, may be the prespecified training intervals in these studies (with only data of those achieving the target frequency analyzed), compared with the varied real-life training frequencies observed in our study. Using real-life training frequencies may provide a specificity of results potentially important in busy health care services.

A more personalized approach to optimum training intervals may be an intuitively beneficial approach for retention of ventilation skills. Our study participants varied in backgrounds, previous experience of simulation training, and have different clinical experience of neonatal ventilation (Figs. 2 a and b). Although the entire group maintained their skills with LDHF simulation training performed approximately once every other month, one might anticipate that less training than this may be required for the pediatricians, with ongoing real-time PPV experience in the delivery room. This was indeed the case for the one skill element it was possible to assess training load thresholds by profession, ventilation rate (Table 4). Midwives and pediatricians were predicted to achieve success without ongoing training, that is, case number = 0, whereas the anesthetists required 36 cases to ensure success in ventilation rate. That anesthesia staff reported the least exposure to neonatal resuscitation training before the study seems to align with this finding. It is also interesting to note that anesthesia staff were outliers, performing both high-frequency (anesthetists performed up to 11 sessions/month) and high-dose (anesthesia nurses performed up to 29 cases/session) training (Table 2). Profession does, therefore, seem an appropriate target for personalized training. Oermann et al use a different approach to identify personalized training intervals to maintain CPR skills at the minimum requirement for successful completion of RQI training, using a cognitive modeling tool known as the Predictive Performance Optimizer.[21] This study found no differences in CPR competencies between the personalized and quarterly training interval groups, lending credibility to that notion that should we have assessed training frequencies on a personalized basis in our study, it may be that a number of HCPs might maintain skills with fewer than 0.6 sessions per month.

It may be that the model predicting training thresholds for maintained competence in all participants is a rather blunt tool. This is reflected by the relatively low estimated marginal probability of success for global competence scores, 0.66 (Table 4), the implication being that approximately a third of this group may require more frequent training for maintenance of competence. The 2 skill elements assessing global performance, percentage valid ventilations and time to baby cry, also have lower marginal probabilities of success, 0.65 and 0.73, respectively. We believe that a study design facilitating assessment of training thresholds on a more personalized basis, such as by profession, will likely result in higher marginal probabilities of success.

However, thresholds for the entire group from Table 4 provide interesting insights. It is well documented that inadequate ventilation may be due to lack of upper airway patency and large leaks around the face mask.[47] Continued success in maintaining airway patency requires training in 2 of 9 months, that is, an average of once every 4.5 months, whereas for adequate mask seal, 6 training sessions through 9 months are required, that is, 1 session per 1.5 months. This suggests that more focus may be required on mask seal than on airway patency to improve PPV effectiveness. However, in real life, both mask seal and airway patency are known to be challenging. Airway patency may be compromised by soft tissue, airway secretions, and external pressure. Mask seal may be difficult due to bodily fluids and anatomical variation. All these factors were not simulated by the mannequin. Furthermore, for all the HCPs in this study, more practice is required in avoiding too high airway pressures (5 sessions through 9 months, approximately every other month) than for maintaining a very high ventilation fraction (training 3 months of 9, or once every 3 months). The marginal probabilities of success for these skills elements are higher than for those of the 3 composite scores (global competence, valid ventilations, and time to baby cry). Thus, we are more confident that these training thresholds are applicable to all HCPs performing neonatal resuscitation at our institution.

Strengths of our study include more than 4000 simulated cases with automatic collection of objective ventilation data, allowing repeatable assessment and robust conclusions about the quality of ventilation provided. We included a large number of study participants compared with other published studies of neonatal resuscitation LDHF simulation training. In addition, the study permitted observation of a variety of real-life training loads, in contrast to fixed training schedules commonly used in other studies.

Although the ventilation data from the simulator is objective, giving, for example, an absolute percentage of valid ventilations, the scoring matrix (Appendix 1) allocates points according to percentage bands. These point allocations can weight skill elements differently to the simulator's algorithm, such that the percentage of valid ventilations that is permitted to achieve minimum time to baby cry is lower than that required by the matrix for full points for valid ventilations. This difference in thresholds likely explains why, for example, a greater training load is required to predict success in valid ventilations than for time to baby cry. It can also be argued that the necessity of using 1 model for regression analysis of training loads predictive of successful ventilation in such a diverse group of HCPs is a rather blunt tool and as such, a design weakness. Although ventilation device and case difficulty were included in the statistical model, the training load output was averaged across both these, such that another weakness of this study is the lack of information on differing success thresholds according to ventilation device used or scenario difficulty.

It was not possible to provide analysis by profession for global competence scores or skill element scores other than ventilation rate. Future studies aiming to individualize training schedules may provide more robust data on optimal training load.

CONCLUSIONS

The most salient finding derived from this large training experience is that performing an average of 0.6 or more simulation training sessions per month maintained overall ventilation competence at a high level. Mastery of some skill elements underpinning ventilation competence was more dependent on dose, or time spent training, rather than frequency of training. Future studies aiming to individualize training schedules may provide more robust data on optimal training load.

REFERENCES

1. Niles DE, Cines C, Insley E, et al. Incidence and characteristics of positive pressure ventilation delivered to newborns in a US tertiary academic hospital. *Resuscitation* 2017;115:102–109.
2. Kapadia P, Hurst C, Harley D, et al. Trends in neonatal resuscitation patterns in Queensland, Australia—a 10-year retrospective cohort study. *Resuscitation* 2020;157:126–132.
3. Bjorland PA, Øymar K, Ersdal HL, Rettedal SI. Incidence of newborn resuscitative interventions at birth and short-term outcomes: a regional population-based study. *BMJ Paediatr. Open* 2019;3:e000592.
4. Nickerson JE, Webb T, Boehm L, et al. Difficult delivery and neonatal resuscitation: a novel simulation for emergency medicine residents. *West J Emerg Med* 2020;21(1):102–107.
5. Johnson L, Mu T, Sawyer T. Use of medical simulation in neonatal-perinatal fellowship training programs. *J Neonatal Perinat Med* 2012;5:339–345.
6. Sawyer T, Ades A, Erns K, Colby C. Simulation and the Neonatal Resuscitation Program 7th Edition Curriculum. *NeoReviews* 2016;17:e447.
7. Sawyer T, Sierocka-Castaneda A, Chan D, Berg B, Lustik M, Thompson M. Deliberate practice using simulation improves neonatal resuscitation performance. *Simul Healthc* 2011;6(6):327–336.
8. Mduma E, Ersdal H, Svensen E, Kidanto H, Auested B, Perlman J. Frequent brief on-site simulation training and reduction in 24-h neonatal mortality—an educational intervention study. *Resuscitation* 2015;93:1–7.
9. Størdal K, Eilevstjønn J, Mduma E, et al. Increased perinatal survival and improved ventilation skills over a five-year period: an observational study. *PloS One* 2020;15(10):e0240520.
10. Haynes JC, Rettedal S, Perlman J, Ersdal H. A randomised controlled study of low-dose high-frequency in-situ simulation training to improve newborn resuscitation. *Children (Basel)* 2021;8(12):1115.
11. Vadla MS, Moshiro R, Mdoe P, et al. Newborn resuscitation simulation training and changes in clinical performance and perinatal outcomes: a clinical observational study of 10,481 births. *Adv Simul* 2022;7:38.
12. Niles D, Sutton RM, Donoghue A, et al. "Rolling refreshers": a novel approach to maintain CPR psychomotor skill competence. *Resuscitation* 2009;8:909–912.
13. Patel J, Posencheg M, Ades A. Proficiency and retention of neonatal resuscitation skills by pediatric residents. *Pediatrics* 2012;130:515–521.
14. Sullivan A, Elshenawy S, Ades A, Sawyer T. Acquiring and maintaining technical skills using simulation: initial, maintenance, booster, and refresher training. *Cureus* 2019;11(9):e5729.
15. Issenberg SB, McGaghie WC, Petrusa ER, Gordon DL, Scalese RJ. Features and uses of high-fidelity medical simulations that lead to effective learning: a BEME systematic review. *Med Teach* 2005;27:10–28.
16. Sutton RM, Niles D, Meaney PA, et al. Low-dose high-frequency CPR training improves skill retention of in-hospital pediatric providers. *Pediatrics* 2011;128:e145–e151.
17. Anderson R, Sebaldt A, Lin Y, Cheng A. Optimal training frequency for acquisition and retention of high-quality CPR skills: a randomized trial. *Resucitation* 2019;135:153–161.
18. Cusack J, Fawke J. Neonatal resuscitation: are your trainees performing as you think they are? A retrospective review of a structured resuscitation assessment for neonatal medical trainees over an 8-year period. *Arch Dis Child Fetal Neonatal Ed* 2012;97:F246–F248.
19. Cheng A, Nadkarni VM, Mancini MB, et al. Resuscitation education science: educational strategies to improve outcomes from cardiac arrest: a scientific statement from the American Heart Association. *Circulation* 2018;138(6):e82–e122.
20. Pappada S, Owais MH, Aouthmany S, et al. Personalizing simulation-based medical education: the case for novel learning management systems. *Int J Healthc Simul* 2022; Available at: ijohs.com/article/doi/10.54531/mngy8113. Accessed December 15, 2022.
21. Oermann MH, Krusmark MA, Kardong-Egren S, Jastrzembski TS, Gluck KA. Personalized training schedules for retention and sustainment of cardiopulmonary resuscitation skills. *Simul Healthc* 2022;17:e59–e67.
22. Haynes J, Bjorland P, Gomo Ø, et al. Novel neonatal simulator provides high-fidelity ventilation training comparable to real-life newborn ventilation. *Children* 2021;8(10):940.
23. Norsk resusciteringsråd. Stabilisering og resuscitering av nyfødte. Available at: NRR_Guidelines_2021_Stabilisering_og_resuscitering_av_nyfodte.pdf Accessed December 15, 2022
24. Safer Births. Available at: www.saferbirths.com. Safer Births – Safer Births. Accessed January 06, 2023
25. Rettedal S, Kibsgaard A, Eilevstjønn J, et al. Impact of immediate and continuous heart rate feedback by dry electrode ECG on time to initiation of ventilation after birth: protocol for a randomised controlled trial. *BMJ Open* 2022;12:e061839.
26. Eilevstjønn J, Linde JE, Blacy L, Kidanto H, Ersdal HL. Distribution of heart rate and responses to resuscitation among 1237 apnoeic newborns at birth. *Resuscitation* 2020;152:69–76.
27. Akaike H. Information theory and an extension of the maximum likelihood principle. In: Petrov BN, Csáki F, eds. *2nd International Symposium on Information Theory*. Budapest, Hungary: Akadémia Kiadó; 1973:267–281.
28. Cavanaugh JE, Neath AA. The Akaike information criterion: background, derivation, properties, application, interpretation, and refinements. *Wiley Interdisciplinary Reviews: Computational Statistics* 2019;11.
29. Genders TS, Spronk S, Stijnen T, Steyerberg EW, Lesaffre E, Hunink MG. Methods for calculating sensitivity and specificity of clustered data: a tutorial. *Radiology* 2012;265(3):910–916.
30. Health and Safety Executive. What is competence? Available at: https://www.hse.gov.uk/competence/what-is-competence.htm#:~:text=Competence%20can%20be%20described%20as,to%20perform%20a%20task%20safely. Accessed December 5, 2022.
31. Dreyfus SE, Dreyfus HL. *A Five-Stage Model of the Mental Activities Involved in Directed Skill Acquisition*. Berkeley, CA: California Univ Berkeley Operations Research Center; 1980.
32. Whalen AM, Boyer D, Nishisaki A. Defining competency in neonatal and pediatric bag mask ventilation. *Pediatrics* 2019;144(2_MeetingAbstract):361.
33. van der Heide PA, van Toledo-Eppinga L, van der Heide M, van der Lee JH. Assessment of neonatal resuscitation skills: a reliable and valid scoring system. *Resuscitation* 2006;71:212–221.
34. Kane SK, Lorant DE. Creation and validation of tool to assess resident competence in neonatal resuscitation. *Acad Pediatr* 2019;19:394–398.
35. Bettinger K, Mafuta E, Mackay A, et al. Improving newborn resuscitation by making every birth a learning event. *Children* 2021;8:1194.
36. Chang C, Perlman J, Abramson E. Use of a novel manikin for neonatal resuscitation ventilation training. *Children* 2022;9:364.
37. Vadla MS, Mdoe P, Moshiro R, et al. Neonatal resuscitation skill-training using a new neonatal simulator, facilitated by local motivators: two-year prospective observational study of 9000 trainings. *Children* 2022;9:134.
38. Schwindt AM, Stockenhuber R, Kainz T, et al. Neonatal simulation training decreases the incidence of chest compressions in term newborns. *Resuscitation* 2022;178:109–115.
39. Halamek LP. Simulation and debriefing in neonatology 2016: mission incomplete. *Semin Perinatol* 2016;40:489–493.
40. Panchal AR, Norton G, Gibbons E, Buehler J, Kurz MC. Low dose- high frequency, case based psychomotor CPR training improves compression fraction for patients with in-hospital cardiac arrest. *Resuscitation* 2020;146:26–31.

41. Sree Kumar EJ, Makani P. 130 Impact of low-dose high-frequency in situ simulation on inpatient diabetes management: a pilot study. *Int J Healthc Simul* 2021;1(Supplement 1):A82–A83.

42. Auerbach M, Fein DM, Chang TP, et al. The correlation of workplace simulation-based assessments with interns' infant lumbar puncture success: a prospective, multicenter, observational study. *Simul Healthc* 2016;11:126–133.

43. American Heart Association. Resuscitation Quality Improvement Program. RQI | American Heart Association CPR & First Aid. Available at: https://cpr.heart.org/en/cpr-courses-and-kits/rqi. Accessed December 14, 2022.

44. Dudzik LR, Heard DG, Griffin RE, et al. Implementation of a low-dose, high-frequency cardiac resuscitation quality improvement program in a community hospital. *Jt Comm J Qual Patient Saf* 2019;45: 789–797.

45. Kuyt K, Mullen M, Fullwood C, et al. The assessment of a manikin-based low dose, high-frequency cardiac resuscitation quality improvement program in early UK adopter hospitals. *Adv Simul* 2021;6:14.

46. Oermann MH, Krusmark MA, Kardong-Edgren S, Jastrzembski TS, Gluck KA. Training interval in cardiopulmonary resuscitation. *PloS One* 2020; 15(1):e0226786.

47. Schmolzer GM, Dawson JA, Kamlin COF, O'Donnell CPF, Morely CJ, Davis PG. Airway obstruction and gas leak during mask ventilation of preterm infants in the delivery room. *Arch Dis Child Fetal Neonatal Ed* 2011;96:F254–F257.

Appendix 1. Scoring matrix for global competence scores.

Action Point	0	1	2	3	4	5
% Valid ventilations	<50%	<60%	≥60%	>70%	>85%	>90%
Ventilation rate	<30	>60	30–60			
VF % total ventilation time	<70%	<80%	<90%	<95%	≥95%	
Time to baby cry*	Time out†	> × 2	> × 1.5	> × 1.25	> × 1	× 1
% Too low pressure ventilations	>40%	>30%	>20%	>10%	>5%	<5%
% Too high pressure ventilations	>30%	>20%	>10%	>5%	<5%	
% Ventilations no head tilt	>25%	<25%	<20%	<15%	<10%	<5%

VF - ventilation fraction, defined as the total ventilation time (= time from first detected ventilation to baby cry) minus the sum of pauses >3 seconds between consecutive ventilations, divided by the total ventilation time.

*Time to baby cry is scored as a multiple of the minimum time possible to achieve this. For scenario level 1, the minimum time is 30 seconds, and this increases with increasing scenario difficulty to 90 seconds for level 4. Optimal performance gives a time multiple of 1, whereas poorer performance results in longer time to baby cry, and thus higher multiples of the minimum time.

†Time out function stops scenario after a predetermined period to alert participant to (an) uncorrected error(s) preventing successful completion, and presents this information in the feedback.