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Personalized Training Schedules for Retention and Sustainment of Cardiopulmonary Resuscitation Skills

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Introduction: The study examined how the spacing of training during initial acquisition of cardiopulmonary resuscitation (CPR) skill affects longer-term retention and sustainment of these skills.

Methods: This was a multiphased, longitudinal study. Nursing students were randomly assigned to 2 initial acquisition conditions in which they completed 4 consecutive CPR training sessions spaced by shorter (1 or 7 days) or longer (30 or 90 days) training intervals. Students were additionally randomized to refresh skills for 1 year every 3 months, 6 months, or at a personalized interval prescribed by the Predictive Performance Optimizer (PPO), a cognitive tool that predicts learning and decay over time.

Results: At the end of the acquisition period, performance was better if training intervals were shorter. At 3 or 6 months after acquisition, performance was better if initial training intervals were longer. At 1 year after acquisition, compression and ventilation scores did not differ by initial training interval nor by 3-month or PPO-prescribed sustainment interval refreshers. However, 6-month interval refreshers were worse than the PPO for compressions and worse than 3 months for ventilations. At the final test session, participants in the personalized PPO condition had less variability in compression scores than either the 3- or 6-month groups.

Conclusions: Results suggest that CPR learning trajectories may be accelerated by first spacing training sessions by days and then expanding to longer intervals. Personalized scheduling may improve performance, minimize performance variability, and reduce overall training time.

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Key Words: Cardiopulmonary resuscitation, distributed practice, education, practice, skill retention, skill sustainment.

High-quality cardiopulmonary resuscitation (CPR) improves patient outcomes and the likelihood of surviving a cardiac arrest.[1–7] To develop competency, providers need to be trained in delivering CPR and to practice their skills periodically to retain them. Recertifying in basic life support (BLS) every 2 years, or even annually, is not sufficient for skill retention.[1]

Cardiopulmonary resuscitation practice with real-time performance feedback improves the quality of skills and promotes retention.[1,8–13] Practice sessions can be brief: health care providers demonstrate improvement in their CPR skills with just 2 minutes of practice with feedback.[10,14] In a study with nursing students, brief (6 minutes) monthly practice of CPR on voice-activated manikins allowed for improvement and retention of CPR skills over 12 months,[11–13] as well as the acquisition of greater confidence in CPR skills.[15]

The advantage of spaced practice on retention of CPR skills is well documented in the literature.[1,16,17] Practice of skills with breaks in between sessions (distributed practice) is more effective for retaining skills than practice that is done all at one time (massed practice). In a recent study, 167 nurses from varied types of units were randomly assigned to 4 groups: 1-, 3-, 6-, and 12-month CPR training.[16] They practiced CPR on an adult Resusci Anne manikin (Laerdal Medical, Stavanger, Norway) on a mobile training cart for 2 minutes and received both visual feedback and verbal coaching. Nurses who practiced monthly had significantly better CPR skills than other groups.

Purpose

Research has repeatedly documented a significant decay in CPR skills within weeks to months after training,[1,9,13,18] and benefits of continued and spaced practice for CPR skills have been shown to mitigate that skill deterioration.[1,19] Despite significant progress having been made in CPR training systems themselves, whereby performance is proficiency based, dynamically coached, and quantitatively assessed, it is still the case that optimal practice intervals for the retention and sustainment of CPR skills have not been established. This

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Laerdal Medical Corporation funded the study (through the National League for Nursing) and also supplied the RQI mobile simulation stations and program for the study at no cost to the schools of nursing that served as training sites. M.H.O. received a grant from the National League for Nursing to conduct the study. The US Air Force Research Laboratory (AFRL) funded the participation of M.A.K., T.S.J., and K.A.G.. Laerdal Medical Corporation was engaged in a Cooperative Research and Development Agreement with the AFRL during the execution of this study to test the utility of a personalized learning technology developed by the AFRL as an extension of this research. Data on participants' performance of CPR skills were collected through the RQI program and stored in HealthStream's learning management system and the AFRL Research Laboratory's MindModeling system.

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research seeks to leverage insights from the cognitive science and educational psychology disciplines and applies a state-of-the-art cognitive modeling tool known as the Predictive Performance Optimizer (PPO), to computationally bring to bear known human learning and memory regularities and deliver adaptive and personalized training prescriptions to learners based on individual learning needs.[20] The PPO consists of a set of nested mathematical equations that capture robust human learning, retention, and memory phenomena in the cognitive science literature associated with the temporal dynamics of learning and forgetting. These include the power law of learning, the power law of forgetting, the spacing effect, and effects of relearning.[20–27] The PPO has been revealed to outperform competing models via extensive evaluation efforts.[24] For a more thorough description of the mechanics of the cognitive model within the PPO, see the study by Walsh et al.[20]

Although researchers have posited that effects of spacing are an empirically supported principle for effective learning,[28,29] and that optimal CPR practice intervals will vary depending on the learner,[1] research evaluating personalized approaches for scheduling CPR maintenance training has not yet been conducted. This work represents the first prescriptive field study of its kind. In this study, we specifically examine how the spacing of training during the initial acquisition of CPR skill affects CPR skills retention and sustainment. Going a step further than most studies,[26] the current study also examined the longer-term sustainment of CPR skill over a 1-year period.

We hypothesized that because the PPO would prescribe more frequent refreshers for students who demonstrated difficulty reaching the 75 overall compression score proficiency standard, that performance would have been remediated through increased training by the end of the 1-year sustainment period, and the mean overall compression score for those in the PPO group would be greater than 75. We also hypothesized that more participants in all groups would perform above threshold at the end of the study, because of general learning effects from the CPR training. For consistently higher performers, we expected that the PPO would prescribe less frequent refreshers, because their performance would have stabilized greater than 75, and maintenance of skill would be less subject to decay. Thus, we hypothesized that participants in the PPO group would complete fewer refreshers on average compared with those in the 3-month group. Because the PPO prescription interval was constrained to a 6-month maximum retention interval, we hypothesized that high performers would have equivalent refreshers to the 6-month group, and intermediate performers would fall between the 3- and 6-month groups.

METHODS

Design

This was a multiphased, longitudinal study that evaluated how nursing students' CPR skills changed based on different spaced training schedules. Students were randomly assigned to 2 initial acquisition conditions in which they completed 4 consecutive CPR training sessions spaced by shorter (1 or 7 days) or longer (30 or 90 days) training intervals.[30] Students in each acquisition interval condition were additionally randomized into 3 retention/sustainment conditions in which they refreshed their CPR skills over a period of 1 year at intervals of every 3 months, every 6 months, or at a personalized interval prescribed by the PPO. For participants in the PPO condition, as soon as participants completed a session, the PPO analyzed their learning history on overall compression scores and prescribed the date for their next refresher training session. The PPO-prescribed intervals between refreshers that were optimized so that students quickly reached and sustained an overall compression score of 75, which is considered passing as measured by the Resuscitation Quality Improvement (RQI) system used in this study. Student performance on ventilations did not factor into the PPO prescriptions.

Retention of CPR skill was evaluated by comparing the last session of the acquisition phase (baseline) to the next session afterward, at 3 months, 6 months, or PPO-prescribed intervals. *Sustainment* was evaluated by comparing this baseline with the final session of the study, which was 1 year out from baseline. During each session, participants completed a pretest, defined as a blinded (no feedback) assessment; training,

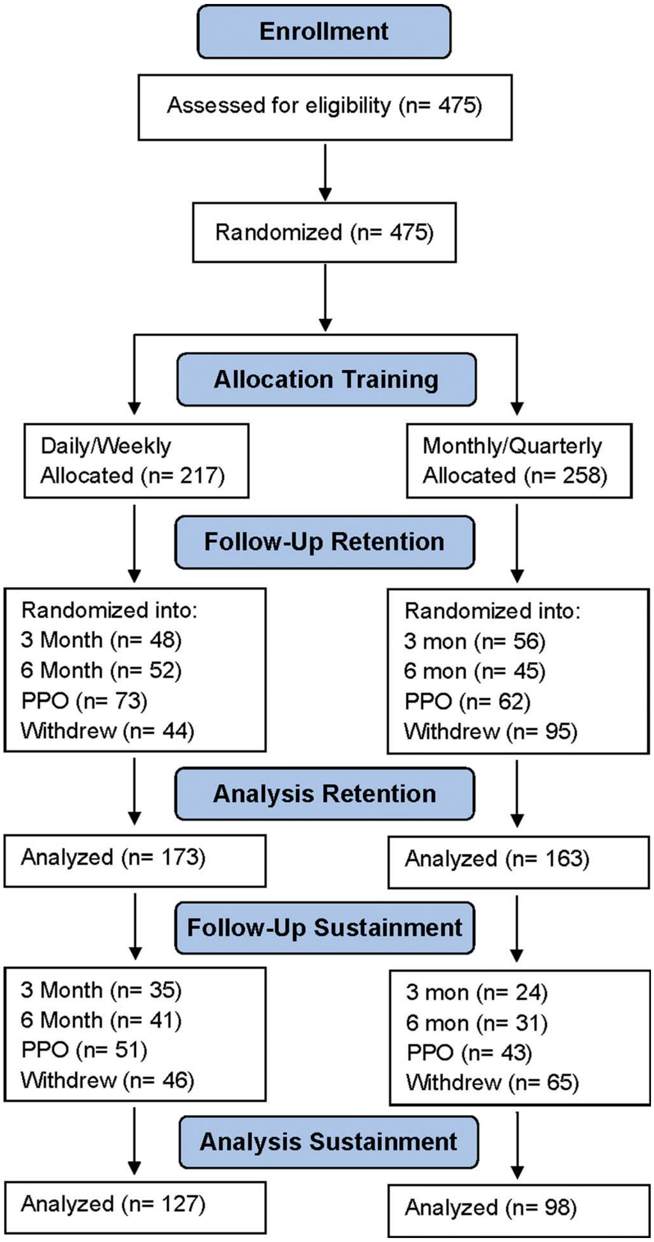

FIGURE 1. Participant flow chart.

defined as the standard RQI-based, dynamically coached assessment; and posttest, defined as a blinded (no feedback) assessment. The RQI system was customized to turn off dynamic coaching and feedback for pretests and posttests. To evaluate changes in CPR skill across sessions, we focused on pretest scores, which allowed us to assess whether students were ready to perform compressions and ventilations after different intervals between sessions. Figure 1 shows the study design.

Participants

A total of 475 nursing students from 10 schools of nursing across the United States began the study. All students were enrolled into the study during the first semester of their nursing program, and they all completed the study while they were still students in the program. Inclusion criteria required that participants be nursing students in the first year of their prelicensure nursing program who received certification in BLS from either the American Heart Association or the American Red Cross. Exclusion criteria included any health condition that prevented participants from performing CPR. The study was approved by the Duke University Health System (Pro00053223), Air Force Research Laboratory (FWR20140115X), Robert Morris University (#20160106357), and Indiana University of Pennsylvania (IRB00004175) Institutional Review Boards (IRBs). The other sites relied on the Duke University Health System IRB approval under the IRB Authorization Agreement for an Individual Protocol.

Training Intervention

Students trained in CPR on a Laerdal Resusci Anne adult manikin on the RQI mobile training cart.[31] Each CPR training session began with a pretest in which students performed 60 compressions and 12 bag-mask ventilations without feedback from the manikin (approximately 2 minutes total), followed by a training session where dynamic feedback on their performance was delivered. Students then completed the posttest to measure the quality of their performance without any feedback (same as the pretest).

Personalized Scheduling of Training

Students in the PPO group were prescribed personalized practice schedules that were optimized based on their overall performance score for compressions.[20–25] The PPO was fit to each participant's data history to create unique learning trajectories based on optimized model parameters associated with individual learning and forgetting rates. The equations and individual parameter values were then used to make out-of-sample predictions of overall compression scores into the future.

The PPO was designed to schedule the timing of refresher training so that students quickly reached and sustained overall compression scores of 75, the RQI minimum proficiency threshold. If a participant's performance had not yet stabilized above the target of 75 for overall compression scores, the PPO scheduled the next training in 7 days, which was the minimum interval. If a participant's performance had stabilized greater than 75, then the PPO predicted when performance was expected to decay to the 75 threshold and scheduled the next training session on this date. The maximum interval for the PPO was 6 months, so if the PPO predicted that performance would drop less than 75 *after* 6 months, then the date to return was at 6 months from the session that the student just completed. To not overly burden participants who might struggle to reach and maintain performance at the 75 threshold, the maximum number of training sessions was 10 during the sustainment phase. If the PPO scheduled the next training session beyond the 1-year duration of the study, then performance was scheduled on the date at 1 year. After each PPO session, the PPO reanalyzed all of the performance data from an individual and generated a new prescription for CPR practice and date of the next training session.

Measures

Cardiopulmonary resuscitation performance was measured using the RQI program. The RQI provides composite scores on a scale of 0 to 100 based on the quality of compressions and ventilations. The more the performance varies from the American Heart Association standards, the lower the score.[32]

Procedures

After students agreed to participate in the study and signed a consent form, they were randomly assigned to conditions by selecting cards that contained a unique identification (ID): a number that represented the school code, initial training group [shorter (1 or 7 days) or longer (30 or 90 days)], and reassessment interval (every 3 months, every 6 months, or at a personalized interval prescribed by the PPO). Students used this ID number for logging into the RQI program.

Sample Size

The sample size was determined based on a power analysis evaluating differences at baseline between initial training intervals of 1 and 7 days compared with 30 and 90 days and at retention and sustainment among the 3-month, 6-month, and PPO groups. Twenty-nine participants per group, or 174 total (29 students per 2 initial training conditions $\times$ 3 retention/sustainment conditions), were required to detect moderate to large effects (Cohen $d = 0.7$) at an α value of 0.05 and power of 0.75. We expected substantial attrition, especially for the 90-day initial training conditions, which were 21 months in duration. Thus, at the onset of the study, we randomly assigned 140 participants to the 1-, 7-, and 30-day initial training conditions, and 165 to the 90-day group. One year after we started data collection, we evaluated attrition for the number of participants in each group who had completed all 4 sessions to baseline and adjusted recruitment goals accordingly. At the time that we designed the study, the RQI system was relatively new, and we had no evidence from past longitudinal studies to gather strong estimates of expected effect sizes, especially because we modified the RQI program for this study to remove feedback from pretests. As a result, we estimated that the effects would be medium to large.

Statistical Analysis

Data on participants' CPR skills were collected through RQI and stored in HealthStream's learning management system (HealthStream, Inc, Nashville, TN) and in the Air Force Research Laboratory's MindModeling system.[33,34] A research assistant entered demographic data into Research Electronic Data Capture (REDCap). All data were merged for analyses.

Data were analyzed using the R statistical software (R Core Team, 2019). To determine how spacing manipulations affected overall compression and ventilation scores, we used

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the LME4 package to estimate mixed effects models that included acquisition interval, retention/sustainment interval, and session (baseline vs. retention and sustainment) as fixed effects and participant as a random effect. We analyzed the data with a linear mixed model because it accounts for unequal numbers of students across conditions in a repeated measures design. Significance values were estimated with the AFEX (analysis of factorial experiments) package, and effect sizes were estimated with the effect size package. Post hoc contrasts were estimated with the emmeans (estimated marginal means) package. To determine how the variance in scores differed across conditions, we used the Fligner-Killeen test. All significance testing was done at the 0.05 level. Because of the substantial dropout rate between retention and sustainment, separate statistical models estimated retention and sustainment effects.

RESULTS

Of the 475 nursing students who began the study, 336 completed the retention phase of the study and 225 completed the sustainment phase. Most of the students who withdrew or were lost to follow-up (for retention and sustainment) had graduated from the nursing program before study completion and had moved away or were no longer available. Demographic data are reported on 300 of the 336 participants; there were missing data for 36 participants. Most participants were female (n = 267). The mean age was 27.43 (SD = 8.23) years, with a range of 18 to 61 years. There were 13 participants who provided CPR in an actual cardiac arrest during the length of the study and 41 students (n = 8 daily, 13 weekly, 9 monthly, 11 quarterly) who had an additional CPR training, although they were already certified in BLS. There were no significant differences in CPR experience across the groups.

Retention of Compression Skills

At baseline (the pretest for the last training session), overall compression scores were higher for nursing students whose initial training was spaced by 1 or 7 days relative to those that were spaced by 30 or 90 days ($F = 7.19$, $df = 1{,}315$, $P = 0.0077$, $d = 0.30$). There were no differences among the 3-month, 6-month, and PPO groups at baseline ($F = 1.65$, $df = 2{,}314$, $P > 0.05$). From baseline to retention, those with 1- or 7-day initial training intervals had a significant decrease in compression scores at 3 months ($t = 3.92$, $df = 311$, $P < 0.001$, $d = 0.44$) or 6 months ($t = 3.39$, $df = 311$, $P < 0.001$, $d = 0.38$). If students' initial training intervals were 30 or 90 days, there was no change from baseline to 3 months ($t = 0.54$, $df = 311$, $P > 0.05$) or 6 months ($t = 1.33$, $df = 311$, $P > 0.05$). For those in the PPO group, there was no change from baseline to retention either for shorter ($t = 0.088$, $df = 311$, $P > 0.05$) or longer ($t = 0.16$, $df = 311$, $P > 0.05$) initial training groups (Fig. 2). At retention, there were no differences among the groups, regardless of the interval during initial training ($F = 1.47$, $df = 1, 315$, $P > 0.05$) or retention ($F = 0.25$, $df = 2{,}314$, $P > 0.05$).

The distribution of actual retention intervals for students in the PPO group is depicted in Figure 3A (mean = 129, SD = 87). The distribution is bimodal, as most intervals were clustered around the minimum and maximum intervals of 7 and 180 days.

Sustainment of Compression Skills

Students' overall compression scores did not change significantly from baseline (pretests of the last training session) to the end of the 1-year sustainment phase of the study, regardless of whether their initial training was spaced at intervals of 1 or 7 days, or 30 or 90 days ($F = 1.08$, $df = 1{,}212$, $P > 0.05$), or whether they refreshed their skills every 3 months, every 6 months, or PPO prescribed ($F = 0.96$, $df = 2{,}211$, $P > 0.05$; Fig. 4). After 1 year, there was no overall difference between participants whose initial training intervals were 1 or 7 and 30 or 90 days ($F = 1.80$, $df = 1{,}212$, $P > 0.05$). However, students who refreshed with 3-month or PPO-prescribed intervals had overall higher compression scores compared with those who refreshed at 6-month intervals ($t = 2.59$, $df = 208$, $P = 0.027$, $d = 0.36$, and $t = 2.44$, $df = 208$, $P = 0.041$,

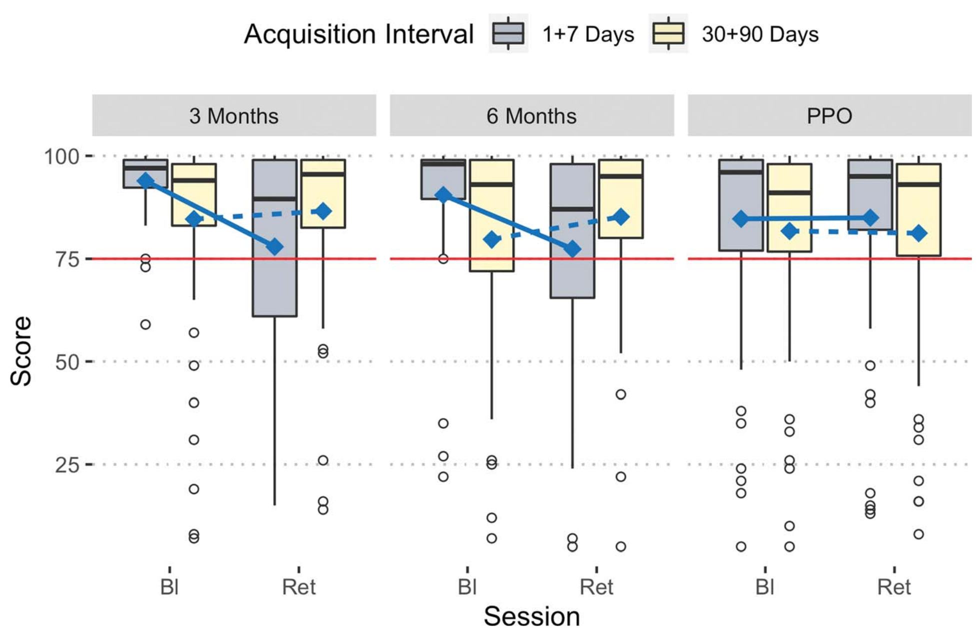

FIGURE 2. Mean overall compression scores (blue lines) and boxplots by session [baseline (Bl) and retention (Ret)], acquisition interval, and retention interval. Horizontal red line at 75 represents minimum performance target.

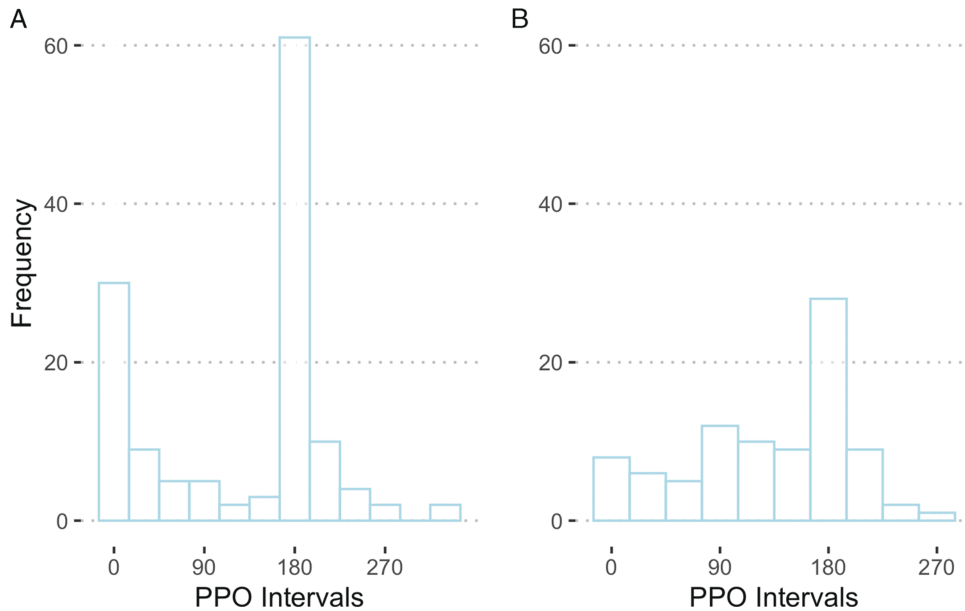

FIGURE 3. Histograms of actual PPO intervals just before retention (A) and sustainment (B).

d = 0.34, respectively). There was no difference between the PPO and the 3-month group ($t = 0.46$, $df = 208$, $P > 0.05$).

The approach used in this study to personalize learning was *not* to maximize participants' overall compression scores at 100. Rather, the PPO was designed to prescribe personalized training schedules such that individual learners quickly reached and maintained performance at or above the RQI threshold of 75 on compressions, thereby minimizing time spent below threshold. Thus, in addition to comparing mean performance of the PPO group relative to the fixed 3- and 6-month schedules, we also compared the distribution of scores among the groups, as depicted through boxplots in Figure 4. At baseline, the variance in students' overall compression scores was smaller when initial training was spaced by 1 or 7 days compared with 30 or 90 days (15.23, $df = 1$, $P < 0.001$). There were no overall differences in variances among the 3-month, 6-month, and PPO groups (2.90, $df = 2$, $P > 0.05$) at baseline. From baseline to the end of the study, if students initial training was 1 or 7 days, there was an increase in variance among students whose refreshers were spaced by 3 months (7.78, $df = 1$, $P = 0.0052$), but there was no difference for the 6-month (2.31, $df = 1$, $P > 0.05$) or PPO (50, $df = 1$, $P > 0.05$) groups. If students' initial training was 30 or 90 days, there was no change from baseline to sustainment for the 3-month (0.044, $df = 1$, $P > 0.05$), 6-month (0.34, $df = 1$, $P > 0.05$), or PPO (1.39, $df = 1$, $P > 0.05$) groups. After 1 year, compression scores for students whose initial training was 1 or 7 days had less variance than the 30- or 90-day group (7.13, $df = 1$, $P = 0.0076$). Finally, after 1 year, the PPO group had less variance compared with the 3-month (6.23, $df = 1$, $P = 0.013$) and 6-month (11.19, $df = 1$, $P < 0.001$) groups, but there was no difference between the 3- and 6-month groups (0.74, $df = 1$,

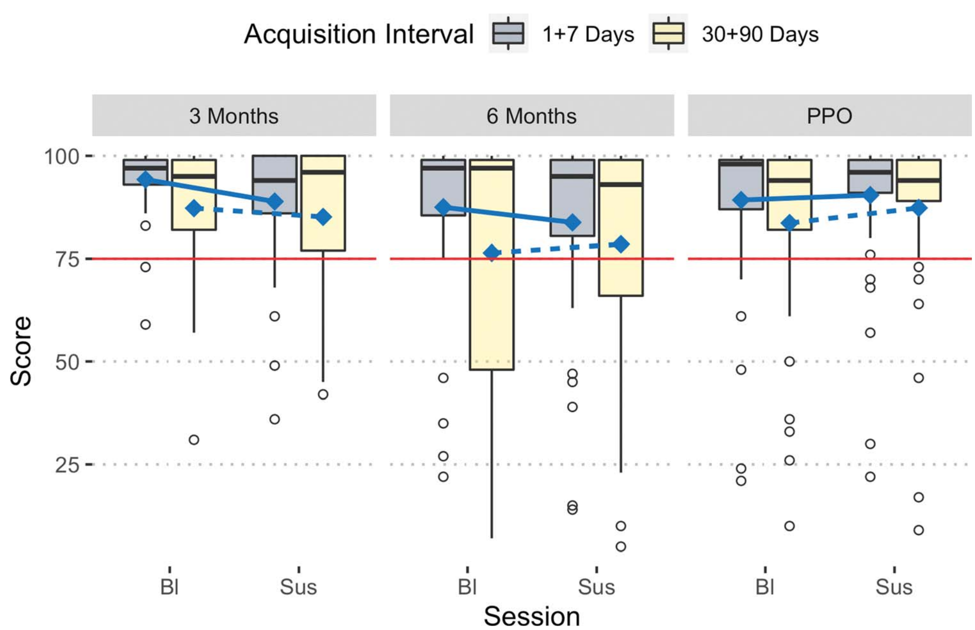

FIGURE 4. Mean overall compression scores (blue lines) and boxplots by session [baseline (Bl) and sustainment (Sus)], acquisition interval, and retention interval. Horizontal red line at 75 represents minimum performance target.

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$P > 0.05$). In Figure 4, see that the boxes and whiskers for the PPO groups, which represent the spread of the data, are above the RQI 75 threshold, whereas the boxes and whiskers for the 3- and 6-month groups extend less than 75.

In addition to comparing the means and variances of overall compression scores across the 1-year sustainment period, we also compared the number of refreshers during this period and the intervals between refreshers. Over the 1-year sustainment phase of the study, participants in the 3- and 6-month groups returned for 4 and 2 sessions, respectively. The actual intervals were consistent with the design, with average intervals of 95 (SD = 26.3) and 184 (SD = 34.2) days for the 3- and 6-month groups, respectively. Participants in the PPO group returned for an average of 3.28 sessions, with 52% of these participants returning for a minimum of 2 sessions, 33% returning for 3 to 4 sessions, 10% returning for 5 to 9 sessions, and 4% returning for the maximum 10 sessions. Thus, only 14% of the participants in the PPO condition were prescribed more sessions than those in the 6-month condition. The average interval for the PPO group over 1 year was 108 days (SD = 82). Figure 3B shows the distribution of actual intervals for the PPO group on the final interval of the study, just before the final session. The modal interval was 180 days.

Retention of Ventilation Skills

At baseline, overall ventilation scores were higher for those whose initial training was spaced 1 or 7 days compared with those spaced 30 or 90 days ($F = 20.33$, $df = 1{,}317$, $P < 0.001$, $d = 0.51$; Fig. 5). From baseline to retention for the 3-month, 6-month, and PPO groups, ventilation scores decreased significantly when initial training intervals were 1 or 7 days ($t = 6.84$, $df = 317$, $P < 0.001$, $d = 0.77$), but there was no change when training intervals were 30 or 90 days ($t = 0.61$, $df = 317$, $P > 0.05$). At retention, overall there were no significant differences in ventilation scores between students whose initial training was 1 or 7 days compared with 30 or 90 days ($F = 2.29$, $df = 1{,}317$, $P > 0.05$). However, students did better overall after 3 months compared with 6 months ($t = 3.46$, $df = 316$, $P = 0.0018$, $d = 0.39$), but not compared with the PPO group ($t = 2.11$, $df = 316$, $P > 0.05$).

Sustainment of Ventilation Skills

Similar to compressions, from baseline to the end of 1 year, there were no differences for students whose initial training interval was 1 or 7 days and who refreshed every 3 months ($t = 0.45$, $df = 208$, $P > 0.05$) or by PPO-prescribed intervals ($t = 0.80$, $df = 208$, $P > 0.05$), but scores decreased for those who only refreshed at 6-month intervals ($t = 4.80$, $df = 208$, $P < 0.001$, $d = 0.67$; Fig. 6). For students whose initial training interval was longer, ventilation scores also showed no change from baseline to sustainment for all intervals: 3 months ($t = 1.60$, $df = 208$, $P > 0.05$), 6 months ($t = 0.88$, $df = 208$, $P > 0.05$), and PPO ($t = 0.42$, $df = 208$, $P > 0.05$). At the end of the study, there were no overall differences between students with shorter and longer training intervals ($F = 0.055$, $df = 1, 212$, $P > 0.05$). However, after 1 year, students who refreshed every 3 months had overall higher ventilation scores than those with 6-month intervals ($t = 3.82$, $df = 211$, $P < 0.001$, $d = 0.53$), but there was no difference compared with the PPO group ($t = 2.04$, $df = 211$, $P > 0.05$).

DISCUSSION

Nursing students completed 4 initial RQI training sessions spaced by days (1 or 7) or months (1 or 3) to create 4 different training interval conditions. Training at shorter intervals resulted in higher compression and ventilation scores at the end of this training period.[30] Taking this as baseline, we then assessed retention at intervals of 3 months, 6 months, and PPO prescribed and saw the advantage of shorter spacing during initial training disappear. Finally, we assessed the longer-term sustainment of compression and ventilation skills, comparing baseline with the end of a 1-year period where refreshers were spaced by 3 months, 6 months, or PPO prescribed. For both

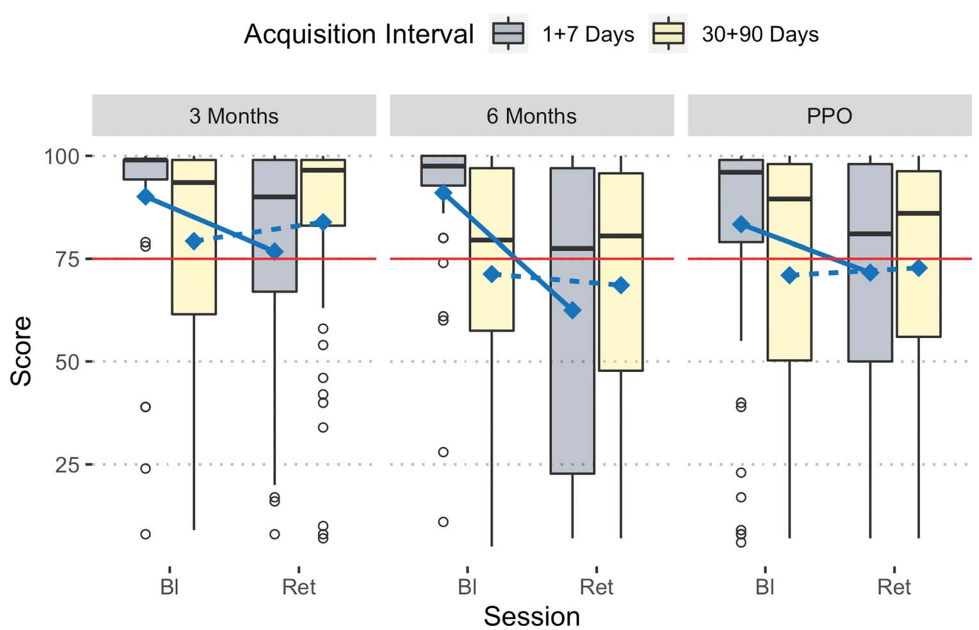

FIGURE 5. Mean overall ventilation scores (blue lines) and boxplots by session [baseline (Bl) and retention (Ret)], training interval, and retention interval. Horizontal red line at 75 represents minimum performance target.

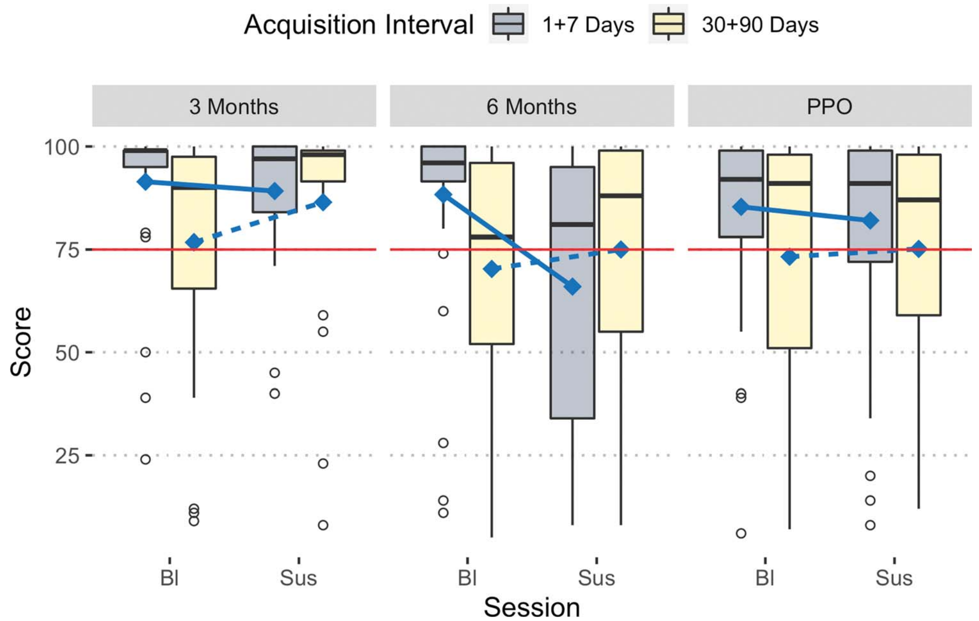

FIGURE 6. Mean overall ventilation scores (blue lines) and boxplots by session [baseline (Bl) and sustainment (Sus)], training interval, and sustainment interval. Horizontal red line at 75 represents minimum performance target.

compressions and ventilations, after 1 year, there was no difference between those whose initial training was spaced by shorter or longer intervals. Overall, however, at the end of the study, compression scores were higher for students who refreshed at 3-month or PPO-prescribed intervals compared with 6-month intervals, and ventilation scores were higher for students who refreshed at 3-month compared with 6-month intervals. For both compressions and ventilations, after 1 year, there was no difference between 3-month and PPO-prescribed intervals.

Taken together, these results suggest that CPR learning trajectories across time may be accelerated by first spacing training sessions by days and then expanding to longer intervals for skill refresher. Cardiopulmonary resuscitation training managers should consider having initial onboarding spaced over several days or weeks, rather than fixing training refreshers at standard 3-month intervals, which is the current RQI approach. Results in the psychological science literature suggest training schedules that gradually expand over time may be more effective than fixed schedules. The theoretical rationale is that expanding schedules—refreshing skills over successively longer periods of time—continue to challenge learners by maintaining desirable difficulty, which leads to more stable learning.[35,36] In the CPR literature, the current study is unique as we know of no other research comparing the initial acquisition and retention of CPR skills, followed by a longer-term period assessing the sustainment of these skills.

The current research is also unique in exploring personalized scheduling of CPR training. Results suggest that for compressions, the PPO and 3-month groups resulted in comparable levels of mean performance at the end of the study, and both were better than the 6-month group. For all 3 groups, average performance on compressions was above the 75 RQI threshold after 1 year of sustainment retraining. However, the PPO methodology was not designed to *maximize* average compression scores. Rather, the PPO was used to help students quickly *acquire* and *maintain* an overall compression score of 75, RQI's minimum passing threshold. For higher performing students (eg, those who reached a stable level of performance greater than 75), the PPO prescribed fewer training sessions. Figure 4 illustrates this by revealing the box and whiskers spread of compression scores at sustainment for the PPO group fall greater than 75. This suggests that the PPO managed training delivery as intended. Moreover, analyses show that the variance for those in the PPO group was significantly smaller than variances in the fixed interval, 3-month, and 6-month groups where the spread of scores fell less than 75. These results suggest that the personalized PPO approach managed risk of performing below the target proficiency level better than 3- and 6-month fixed training schedules.

Furthermore, personalized training did not come with an increased number of refreshers relative to the 3- and 6-month fixed conditions. On average, the PPO prescribed 3.28 sessions, even as the minimum number of sessions for the PPO group was 2. Only 14% of the subjects were prescribed more than 4 refresher sessions. These results suggest that the PPO may reduce the overall cost for learners in time that they spend on CPR retraining and demonstrates the fact that a one-size-fits-all approach to scheduling CPR training is both inefficient (for high performers) and potentially ineffective (for lower performers requiring additional practice).

The potential value of a personalized scheduling tool like the PPO is not limited to CPR training. We have several ongoing research projects that explore the application value of the PPO for skills maintenance in other medical domains and tasks, including laparoscopic surgery, trauma assessment, advanced cardiac life support, and intracranial pressure monitoring,[25] and we are exploring the cognitive component of knowledge acquisition and sustainment for trauma assessment and triage using virtual, computer-based learning platforms. We are also applying the PPO to other complex training

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domains, including linguist training, aircraft piloting, and aircraft maintenance. We have found that the PPO works well when optimizing the scheduling of training in domains where the consequences of not maintaining proficiency are high, opportunities for practice are low, and performance metrics and assessments are as objective, quantitative, and discriminative as possible.[25] In addition, we are extending PPO's capabilities beyond scheduling prescriptions for optimal timing of training refreshers, moving toward a broader intelligent tutoring system platform, capable of recommending optimal remediation content based on identified student performance lapses, and integrating performance input from both manikin and virtual learning environments to determine the optimal training curricula for individual learners. This would allow for greater opportunity and flexibility for learners to hone in on problem areas and deliberately practice specific components of larger tasks.

Limitations

Results presented in the current research provide promising evidence for the value of personalized training technologies like the PPO over existing one-size-fits-all, calendar-based scheduling approaches that are commonly used in healthcare training. However, more research is needed to determine the benefits and costs of these personalized training technologies in practical settings, the logistics of implementing them on a larger scale, and how to seamlessly integrate them with training simulation platforms such as RQI.

Several design decisions related to the implementation of the PPO for this study limit the generalizability of our findings. First, the PPO prescribed the refresher training schedules based on overall compression scores. Ventilation scores did not factor into the PPO predictions, but results show that the rate of skill acquisition is much slower with ventilations and performance is much more variable. Future research on personalized CPR training should look to personalized training using a composite measure that combines both compressions and ventilations to deliver a training prescription. Second, the PPO prescribed training to help participants acquire and maintain the RQI overall compression score threshold of 75. For mastery of CPR skills, future research should explore whether this threshold should be higher. Third, the PPO was bounded by a maximum prescription interval of 6 months, although model prescriptions predicted that students would not need to return at that time. Many students consistently displayed high compression scores, and it would be interesting to see whether the maximum interval could be extended without degradation of performance or loss to PPO's predictive validity. Fourth, the administrative load was relatively high for scheduling and managing retention intervals prescribed to the day, with a minimum interval of 7 days. For scale, future research should explore different approaches to scheduling that reduce the logistical load to find the optimal balance between scheduling fidelity and potential risk reduction. Ultimately, training managers will need to make decisions regarding the logistics for effectively using personalized learning tools like the PPO. Fifth, the study was conducted with nursing students. Additional research is needed to determine whether the results generalize to practicing health care providers. Finally, there was substantial dropout between retention and sustainment, which may limit interpretation of a direct comparison of retention and sustainment. However, exit interviews with students who dropped out suggest that most did so because they were graduating and moving away.

CONCLUSIONS

For acquiring and sustaining high-level CPR skills in a shorter timeframe, these results combined with previously published literature[1] suggest that a 2-phase schedule may be most effective, with an initial training phase consisting of trainings spaced by days, followed by a longer-term sustainment phase with refreshers spaced by months. Furthermore, personalized training schedules seem warranted given the degree of scheduling variability in PPO user prescriptions and the reduced variability in PPO group overall compression scores. This implies that use of the PPO for the personalized retention of CPR skills would allow for efficiency in training time and resources for higher performers and more effective acquisition and retention of CPR skills for lower or intermediate-level performers, who require a different dose of training compared with what any fixed training intervals could provide.

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