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Retention and cross-device transfer of an anticipatory AED action rule in novice learners: a multicentre repeated-measures simulation study with delayed follow-up

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Abstract

Background

Avoidable interruptions in chest compressions during automated external defibrillator (AED) use may reduce coronary and cerebral perfusion during a time-critical phase of resuscitation. We evaluated the immediate effect, delayed retention, and cross-device transfer of a concise anticipatory action rule designed to delay interruption until immediately before shock delivery.

Methods

This prospective multicentre simulation study used a single-group repeated-measures pre-intervention, immediate post-intervention, and delayed follow-up design. Seventy-five first-year learners (25 medical, 25 paramedicine, and 25 dietetics students) completed standard and modified AED procedures, followed by an independent assessment after a mean of 205.3 days (range 201–210 days) using a different AED trainer. The primary outcome was pre-shock pause (T7-T4). Paired differences, 95% confidence intervals (CIs), Holm-adjusted p values, Cohen's dz, repeated-measures analyses, and exploratory programme-specific models were calculated.

Results

All 75 participants completed all assessments. Mean pre-shock pause was 25.46 s under the standard procedure, 1.93 s under the modified procedure, and 2.20 s at follow-up. The modified procedure reduced the pause by 23.53 s versus standard (95% CI 23.07 to 23.99; Holm-adjusted $p < 0.001$; Cohen's dz = 11.83). At follow-up, the pause remained 23.26 s shorter than standard (95% CI 22.80 to 23.72; $p < 0.001$), but was 0.27 s longer than during the immediate modified procedure (95% CI 0.24 to 0.30; $p < 0.001$). No critical errors were recorded.

Conclusions

A short anticipatory AED instruction was associated with a very large immediate reduction in peri-defibrillation interruption and substantial retention after a mean of 205.3 days (range 201–210 days), including transfer to another AED trainer. The findings support explicit teaching of compression-preserving AED choreography. As this was a simulation study with protocol-defined device intervals, no claim can be made regarding survival or neurological outcome; clinical benefit should be tested prospectively.

Background

High-quality cardiopulmonary resuscitation (CPR) and early defibrillation remain central components of treatment for shockable cardiac arrest. The 2025 European Resuscitation Council (ERC) and American Heart Association (AHA) guidelines continue to position high-quality chest compressions and timely defibrillation as core elements of resuscitation practice and education [1–4]. The AHA executive summary explicitly frames its recommendations as intended to improve survival and neurological outcomes after cardiac arrest, while emphasising high-quality compressions, early defibrillation, and integrated resuscitation systems [3].

The biological rationale for minimising interruptions is compelling. During CPR, forward blood flow is limited and depends on consistent compressions. Interruptions allow coronary and cerebral perfusion pressures to decline, and several subsequent compressions may be required to restore them. Observational studies have associated longer pre-shock pauses with lower shock success and poorer survival [5–8]. These associations do not prove that a specific educational intervention improves patient outcomes, but they establish peri-shock interruption as a clinically meaningful process target.

AED training is usually organised as a linear sequence: switch on the device, attach pads, follow prompts, stand clear for rhythm analysis, and deliver a shock when advised. For novices, the transition between rhythm analysis, capacitor charging, and shock delivery may be interpreted as one prolonged hands-off period. This interpretation is educationally important because avoidable no-flow time may be introduced not by lack of knowledge, but by imprecise choreography. A systematic review found support for brief, self-directed, and alternative AED training approaches, while noting that device characteristics can influence performance [12]. Current ERC and AHA education guidance emphasises simulation, assessment, feedback, technology-enhanced learning, rapid-cycle deliberate practice, cognitive aids, stepwise training, and adaptation to learner needs [13, 14].

A concise anticipatory action rule may solve this problem by telling the learner what to do before the critical transition occurs: continue or promptly resume chest compressions after rhythm analysis, allow charging to proceed during compressions when the training device and protocol permit, and interrupt only immediately before shock delivery. This approach converts a device-centred sequence into an action-centred rule. It is also compatible with cognitive load theory, although cognitive load was not measured in this study and is presented only as a possible explanatory mechanism [9].

Our initial within-participant study showed a large immediate reduction in pre-shock pause with the modified rule. The present analysis extends that work by incorporating an independent delayed assessment conducted after a mean of 205.3 days (range 201–210 days) on a different AED trainer. The primary objective was to determine whether the compression-preserving effect was retained and transferred across devices. We hypothesised that follow-up performance would remain substantially better than the standard procedure, although some attenuation relative to immediate modified-procedure performance was anticipated.

Methods

Study design and settings

This prospective multicentre simulation study used a single-group repeated-measures pre-intervention, immediate post-intervention, and delayed follow-up design. Each participant completed a standard and modified procedure during the initial study and an independent follow-up assessment after a mean of 205.3 days (range 201–210 days). The initial assessments were conducted during October-December 2024 and October-December 2025 at three Polish higher-education institutions. Follow-up occurred after a mean of 205.3 days from the initial assessment (range 201–210 days).

The study was designed as an educational performance study, not a clinical trial. No patient was involved, no clinical treatment was delivered, and outcomes were derived from controlled manikin-based simulation. Reporting was guided by STROBE principles and simulation-specific reporting considerations [10, 11].

Participants

The sample comprised 75 first-year learners without previous resuscitation experience: 25 medical students, 25 paramedicine students, and 25 dietetics students. Eligibility required first-year enrolment, completion of both initial procedures, availability for follow-up, and analysable recordings. Exclusion criteria included prior certified BLS/AED training, Polish Qualified First Aid certification, previous medical education, or participation in real-life resuscitation or rescue involving an actual casualty.

Educational comparison

In the standard condition, participants followed the previously taught sequential AED approach without an explicit instruction to preserve compressions during charging. Before the modified condition, participants received a concise behavioural rule: continue or promptly resume compressions after rhythm analysis, continue during charging when permitted by the scenario, and interrupt only immediately before shock delivery. No performance feedback or debriefing was provided between initial measurements beyond the assigned instruction.

The initial sequence was fixed: the conventional procedure was assessed before instruction, and the modified procedure was assessed after the compression-preserving rule had been taught. Reversing this sequence would not have recreated an untreated conventional condition because the educational effect was expected to persist. Accordingly, this was not a crossover trial. Performance scores, timing results, corrective feedback, and debriefing were withheld until both initial assessments had been completed.

Follow-up and control of intervening exposure

At the initial session, participants were asked not to participate in additional AED training before the delayed assessment. Student curricula were arranged so that AED content was revisited only after follow-up. No participant reported using an AED in a real emergency between assessments. The absence of real-life use resulted from the natural absence of such events rather than an imposed prohibition.

Simulation equipment and scenario

The initial procedures used a Resusci Anne QCPR manikin with AED Link functionality and an XFT-120C+ training AED. Follow-up used a Laerdal AED Trainer with Polish-language prompts. Sessions were video-recorded. The analysis origin was set at the 30-second point of each recording and normalised to T0 = 0.00 s; all subsequent event times were expressed relative to this origin. The scenario, manikin position, electrode placement, rhythm pathway, and safety requirements were standardised. At delayed follow-up, T5 and T6 were not independently coded and were therefore retained as missing values rather than imputed; the primary endpoint was calculated directly as T7 minus T4.

Operational definitions and timing model

For temporal standardisation, the acoustic start signal occurring 30 s after the beginning of each recording was defined as T0 = 0. All subsequent events were coded as cumulative elapsed seconds from T0; the initial 30 s of pre-measurement chest compressions were excluded from reported procedural times. T1 denoted AED activation; T2, rhythm-analysis start; T3, the end of analysis and shock-advised prompt; T4, maximum depth of the final complete compression before shock; T7, actual simulated discharge; and T8, maximum depth of the first complete post-shock compression. With the XFT-120C+, T5 denoted shock readiness and T6 denoted initiation of SHOCK-button depression. At delayed assessment, the Laerdal trainer delivered the simulated shock automatically 9.00 s after the shock-advised prompt; therefore, participant-triggered T6 did not apply. The primary outcome, pre-shock pause, was defined consistently across devices as T7-T4. Tk was defined as T7-T6, the button-depression-to-discharge interval.

Definitions were harmonised before final analysis. In follow-up, T3-T2 was 9.00 s, compression activity during charging was 7.00 s, T6-T5 was 1.00 s, Tk was 0.20 s, and T8-T7 was 6.85 s. These intervals reflected the protocol and trainer timing and were not treated as independently observed behavioural outcomes. Participant-dependent variation was concentrated in earlier activation and analysis events and in the relation between the final compression and shock delivery.

Outcomes

The primary outcome was pre-shock pause, calculated as T7-T4. Secondary outcomes were post-shock pause (T8-T7), peri-shock pause (T8-T4), no-compression time from T3 to T8, time to AED activation,

time to shock, compression coverage during charging, safety, critical errors, and interface problems. Lower time values represented better process performance.

Statistical analysis

Continuous outcomes were summarised using mean and standard deviation (SD) and median and interquartile range (IQR). The primary analysis used within-participant comparisons among the standard, modified, and follow-up conditions. Paired-samples t tests estimated mean paired differences and 95% CIs. Two-sided Wilcoxon signed-rank tests were used as non-parametric sensitivity analyses. Holm correction was applied to the three pairwise comparisons within each outcome. Cohen's dz quantified standardised within-participant effects. Repeated-measures analysis assessed the overall condition effect. Exploratory mixed-effects models included condition, educational programme, and their interaction, with participant as a random intercept. A two-sided alpha of 0.05 was used. No primary-outcome data were missing, and no imputation was performed.

Ethics and consent

Formal ethics committee approval was not required for this study under the institutional regulations of the Research Ethics Committee of VIZJA University (Komisja ds. Etyki Badań Naukowych Uniwersytetu VIZJA), Warsaw, Poland. The study involved voluntary educational simulation using training manikins and AED trainers, did not involve patients, biological material, medical records, clinical interventions, or medical experimentation involving human participants, and the data used for analysis were anonymized. The Chair of the Research Ethics Committee of VIZJA University confirmed that, under the Committee's regulations, this type of simulation-based educational study did not constitute a medical experiment and did not require formal prospective ethics committee review or approval. No approval or reference number was assigned because the study was not subject to a formal ethics committee application or approval procedure. All procedures involving the participants and their data were conducted in accordance with the applicable institutional and national guidelines and regulations and with the ethical principles of the Declaration of Helsinki. Written informed consent for participation and video recording was obtained from all participants before enrolment.

Results

Participant flow and completeness

All 75 participants completed the standard procedure, modified procedure, and follow-up assessment, providing 225 participant-level observations. There were no missing primary outcomes. All follow-up records passed quality-control review. No additional AED training or real-life AED use was reported during the retention interval.

Primary and secondary outcomes

Mean pre-shock pause decreased from 25.46 (SD 1.99) s under the standard procedure to 1.93 (SD 0.12) s under the modified procedure. The paired reduction was 23.53 s (95% CI 23.07 to 23.99; Holm-adjusted $p < 0.001$; Cohen's dz = 11.83). At follow-up, mean pre-shock pause was 2.20 (SD 0.00) s. This remained 23.26 s shorter than under the standard condition (95% CI 22.80 to 23.72; $p < 0.001$), but was 0.27 s longer than during the immediate modified procedure (95% CI 0.24 to 0.30; $p < 0.001$).

The same directional pattern was observed for peri-shock pause and no-compression time. The modified condition produced a large immediate reduction relative to standard, and follow-up retained most of this improvement. Because post-shock time and several device-dependent intervals were protocol-defined constants, inferential interpretation focused on pre-shock pause and participant-dependent timing components. Detailed estimates are presented in Table 1. The temporal pattern of change in pre-shock pause across study conditions is illustrated in Fig. 1.

Table 1
Timing outcomes across the standard, modified, and delayed follow-up conditions

Outcome	Standard, mean (SD)	Modified, mean (SD)	Follow-up, mean (SD)	Modified vs standard, mean difference (95% CI)	Follow-up vs modified, mean difference (95% CI)
Pre-shock pause, s	25.46 (1.99)	1.93 (0.12)	2.20 (0.00)	-23.53 (-23.99 to -23.07)	0.27 (0.24 to 0.30)
Peri-shock pause, s	32.31 (1.99)	8.78 (0.12)	9.05 (0.00)	-23.53 (-23.99 to -23.07)	0.27 (0.24 to 0.30)
No-compression time T3-T8, s	31.82 (1.98)	8.78 (0.12)	9.08 (0.23)	-23.04 (-23.50 to -22.59)	0.30 (0.24 to 0.36)
Time to shock T7, s	59.40 (5.44)	20.10 (0.53)	28.89 (1.43)	-39.31 (-40.47 to -38.14)	8.79 (8.45 to 9.13)
Time to AED activation T1, s	25.87 (5.17)	3.61 (0.53)	1.76 (0.37)	-22.26 (-23.36 to -21.16)	-1.85 (-1.99 to -1.72)

Values are seconds unless otherwise indicated. Differences are calculated as the second condition minus the first; negative values indicate shorter times in the second condition. Pairwise p values for the primary outcome were < 0.001 after Holm correction. Protocol-defined follow-up intervals should not be interpreted as independent behavioural measurements.

Safety and transfer

All follow-up assessments met the prespecified safety criterion. No critical errors or interface problems were recorded. The maintenance of a short pre-shock pause on a different AED trainer supports transfer of the action rule beyond the device used during initial training. Nevertheless, because device and time changed together, retention and cross-device transfer cannot be separated experimentally. A contextual

comparison with previously published interventions that reduced peri-shock interruption is presented in Fig. 2.

Discussion

Methodological strengths include the within-participant design, complete delayed follow-up, inclusion of three learner programmes, predefined event definitions, video-based timing, and analysis of absolute paired differences with confidence intervals and multiplicity adjustment. Future research should use randomised sequence allocation, blinded adjudication, formal inter-rater reliability, multiple AED models, and more than one retention interval. Pragmatic educational trials should determine whether the rule improves compression fraction and peri-shock performance during complex team-based scenarios. Ultimately, clinical or system-level studies are required to examine shock success, return of spontaneous circulation, survival to discharge, and favourable neurological outcome.

Strengths and implications for further research

The magnitude and persistence of the process effect also have implications for curriculum design. BLS/AED programmes often assess whether steps are completed in the correct order, but may not assess temporal coordination between compressions and defibrillation. Adding a directly observable peri-defibrillation performance criterion could shift assessment from checklist completion toward clinically meaningful execution. Such an approach is consistent with competency-based education because it defines the expected behaviour, the critical transition, and the measurable performance outcome.

The intervention is brief, low-cost, and readily scalable. It can be incorporated into instructor demonstration, deliberate practice, objective structured assessment, and refresher training without adding equipment or substantially extending course duration. The relevant competency should be stated explicitly: continue or promptly resume compressions after rhythm analysis when permitted by the device and scenario, maintain compressions during charging where compatible with the training protocol, clear the patient before shock delivery, and resume compressions promptly after the shock. Implementation must always remain consistent with manufacturer instructions, electrical safety requirements, and local resuscitation guidance. This aligns with current resuscitation-education recommendations that favour structured simulation, deliberate practice, feedback, and instructional designs that make critical actions explicit [13, 14].

Educational significance and implementation

The delayed assessment used a different AED trainer, which increases the practical relevance of the observed retention. Performance did not depend exclusively on repeating the initial device interface, suggesting that learners retained an action principle that could be applied across devices. This supports a transfer-oriented interpretation: participants appeared to retain the rule governing when compressions should cease, rather than memorising only a prompt sequence or button location. At the same time,

device change and elapsed time occurred together, so pure retention cannot be separated from cross-device transfer. This is relevant because interface characteristics can affect AED performance [12], while delayed reassessment is needed to distinguish immediate acquisition from durable skill [18].

Retention and transfer of learning

The study did not measure return of spontaneous circulation, survival, or neurological outcome, and it cannot establish a patient-level benefit. Nevertheless, the measured outcome lies on a clinically plausible causal pathway. Interruptions in chest compressions reduce generated coronary and cerebral perfusion, and observational evidence has associated longer peri-shock pauses with lower shock success and poorer survival [5–8]. By reducing avoidable no-flow time immediately before defibrillation, the modified strategy may improve the physiological conditions in which a shock is delivered. If reproduced during real cardiac arrest, this mechanism could contribute to a higher probability of successful defibrillation, survival, and favourable neurological outcome. These outcomes remain hypotheses for future clinical evaluation, not outcomes demonstrated by the current simulation study. The interpretation is nevertheless supported at the process level by clinical and simulation studies associating shorter peri-shock interruptions with improved shock-related metrics and by system-level interventions that shorten pauses [5–8, 15–17].

Potential clinical pathway

The present findings add an educational implementation perspective to those recommendations. Conventional teaching may accurately describe the AED algorithm yet leave the analysis-to-shock transition operationally ambiguous. The anticipatory rule removes that ambiguity by specifying the desired behaviour before charging and shock readiness occur. The result suggests that a small change in instructional wording can produce a large change in a time-critical performance metric.

The rationale for the intervention is directly aligned with the 2025 European Resuscitation Council adult basic life support guideline, which integrates CPR quality, chest-compression delivery, AED use, and rescuer safety within the BLS sequence [1, 2]. The 2025 American Heart Association adult basic life support guideline likewise identifies high-quality CPR and AED use as essential elements of adult BLS [3, 4]. These guideline positions support the educational premise that AED instruction should be judged not only by procedural completion and shock delivery, but also by whether the learner preserves high-quality CPR throughout the device-mediated sequence.

Integration with ERC 2025 and AHA 2025 recommendations

The intervention should be interpreted as a change in resuscitation choreography rather than as a speed-training technique. The key instructional element was not faster completion of the entire AED sequence, but postponement of the hands-off interval until shock delivery was imminent. This distinction is clinically meaningful because it targets avoidable no-flow time while preserving the mandatory safety pause before discharge.

The principal finding is that a brief anticipatory AED action rule was associated with a large and durable reduction in pre-shock pause. The immediate modified procedure reduced the interruption from 25.46 s to 1.93 s, and performance remained substantially improved at delayed follow-up after a mean interval of 205.3 days. The follow-up value was close to the immediate modified-condition value, indicating that the behavioural sequence was not merely reproduced during the initial session but remained available after a prolonged period without additional AED training. The consistency of the direction of effect across all participants, together with complete follow-up and the absence of critical safety errors, supports the educational robustness of the intervention.

Principal findings

Limitations

This study has several limitations. First, the initial procedures and follow-up used different AED trainers, so retention and cross-device transfer cannot be separated. Second, the delayed assessment included a device-defined 9.00-s interval from the shock-advised prompt to automatic simulated discharge, restricting variance in device-dependent timing; absolute differences and confidence intervals are therefore more informative than standardised effects or p values alone. Third, the immediate comparison used a fixed pre-intervention/post-intervention sequence, so the instructional effect cannot be completely separated from practice, period, or repeated-task effects. Withholding scores, corrective feedback, and debriefing until both initial assessments were complete reduced, but did not eliminate, this risk. Fourth, a single delayed follow-up does not define longer-term skill decay, and no concurrent follow-up control group was tested on the original device. Fifth, intervening exposure was documented and supported by scheduling but informal exposure cannot be excluded completely. Finally, this was a controlled simulation study in predefined learner groups; survival, neurological outcome, and real-world team performance were not measured, limiting causal and clinical generalisability.

Implications for research

Future studies should randomise instructional sequence, separate retention from device transfer, include blinded outcome adjudication and formal inter-rater reliability, and assess multiple follow-up intervals. Cluster-randomised or stepped-wedge educational studies could examine implementation across institutions. Clinical or high-fidelity system studies should evaluate chest-compression fraction, shock success, return of spontaneous circulation, survival, and favourable neurological outcome while ensuring that any compression-during-charging strategy is compatible with device instructions and rescuer safety.

Conclusions

A concise anticipatory AED action rule was associated with a major reduction in pre-shock and peri-shock interruption among novice learners. Most of the effect was retained after a mean interval of 205.3 days and transferred to a different AED trainer. The intervention addresses a specific and modifiable educational mechanism: premature cessation of compressions during the analysis-to-shock transition.

These findings support further randomised and implementation-focused evaluation. Any potential effect on survival or neurological outcome remains a clinically plausible but untested consequence of improved CPR process performance.

Declarations

Ethics approval and consent to participate

Formal ethics committee approval was not required for this study under the institutional regulations of the Research Ethics Committee of VIZJA University (Komisja ds. Etyki Badań Naukowych Uniwersytetu VIZJA), Warsaw, Poland. The study involved voluntary educational simulation using training manikins and AED trainers, did not involve patients, biological material, medical records, clinical interventions, or medical experimentation involving human participants, and the data used for analysis were anonymized. The Chair of the Research Ethics Committee of VIZJA University confirmed that, under the Committee's regulations, this type of simulation-based educational study did not constitute a medical experiment and did not require formal prospective ethics committee review or approval. No approval or reference number was assigned because the study was not subject to a formal ethics committee application or approval procedure. All procedures involving the participants and their data were conducted in accordance with the applicable institutional and national guidelines and regulations and with the ethical principles of the Declaration of Helsinki. Written informed consent for participation and video recording was obtained from all participants before enrolment.

Consent for publication

Not applicable. The manuscript contains no identifiable individual data.

Competing interests

The authors declare that they have no competing interests.

Use of generative artificial intelligence

Generative artificial intelligence was used to assist with language refinement, document structuring, and consistency checking. All scientific content, analyses, interpretations, and references were reviewed and approved by the authors, who take full responsibility for the manuscript.

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Author Contribution

MAM conceived and designed the study, developed the educational intervention, coordinated study implementation, collected and analysed data, performed statistical analyses, interpreted the findings, prepared figures and tables, drafted the manuscript, and acted as guarantor of the study.DTG contributed to study design, data acquisition, independent review of video recordings, interpretation of results, and critical revision of the manuscript.AM provided clinical oversight, contributed to methodology development, participated in outcome adjudication and interpretation of results, supervised the project, and critically revised the manuscript.All authors read and approved the final manuscript and agree to be accountable for all aspects of the work.

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Data Availability

The de-identified dataset supporting the conclusions of this article is available from the corresponding author on reasonable request. A data dictionary and analysis-ready dataset may be provided subject to institutional and consent-related restrictions.

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Figures

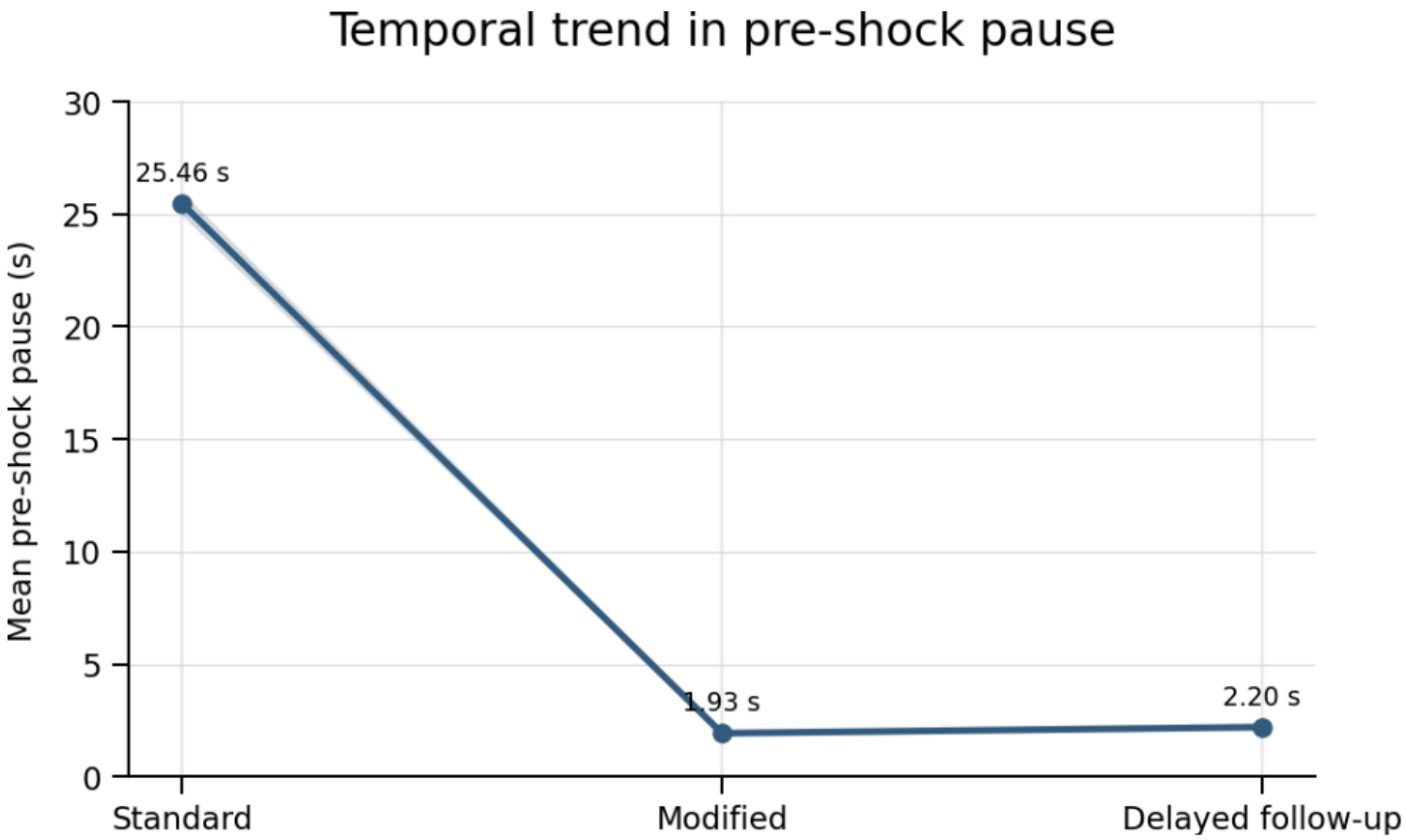


Figure 1

Mean pre-shock pause across the standard procedure, modified procedure, and delayed follow-up. The shaded band is visual only and reflects the narrow reported confidence intervals around the study means; exact inferential statistics are provided in Table 1.

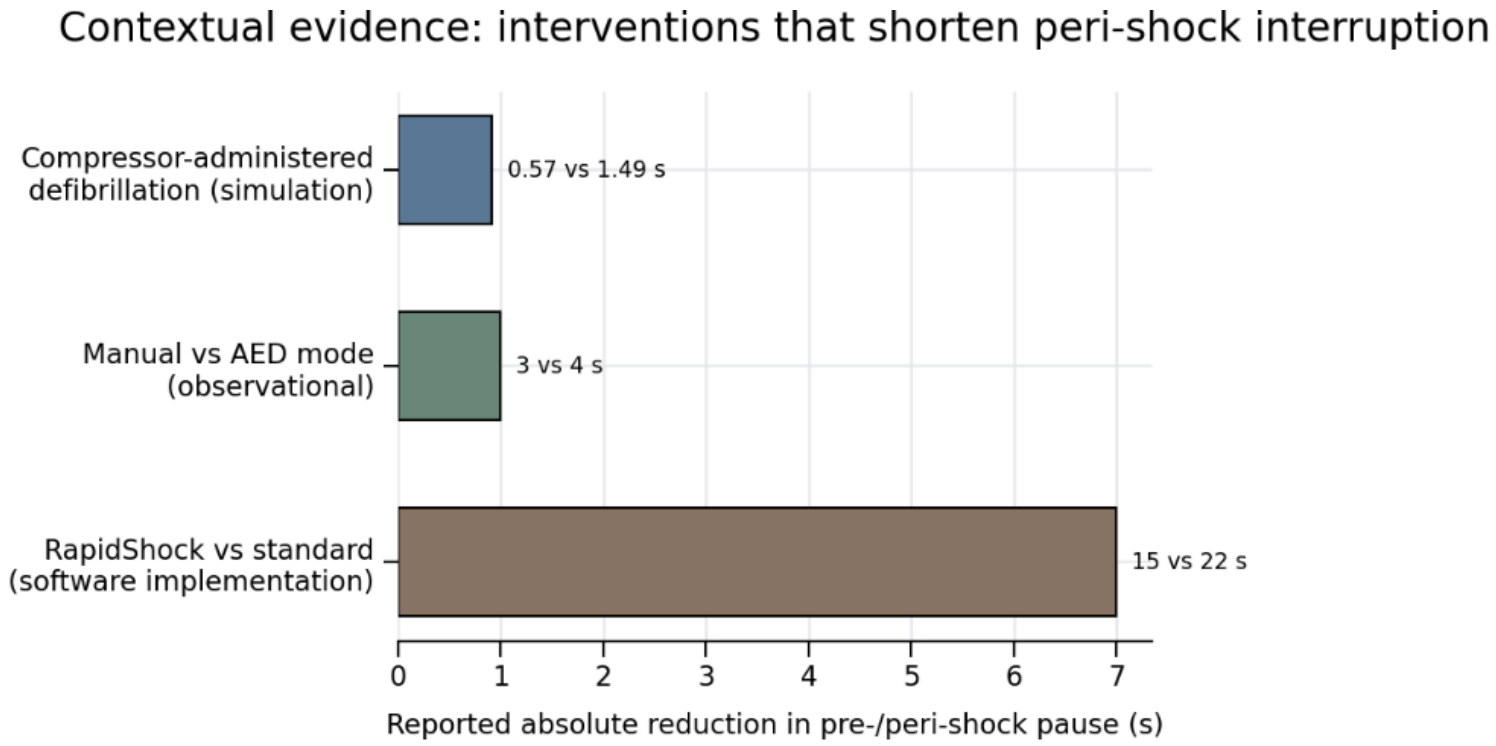


Figure 2

Contextual comparison of reported absolute reductions in pre- or peri-shock interruption from selected simulation, observational, and implementation studies. Values are not pooled because study designs, populations, devices, and outcome definitions differ [15-17].

Supplementary Files

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