Characterizing the Learning Curve for Performing Surgical Airway Management

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Introduction

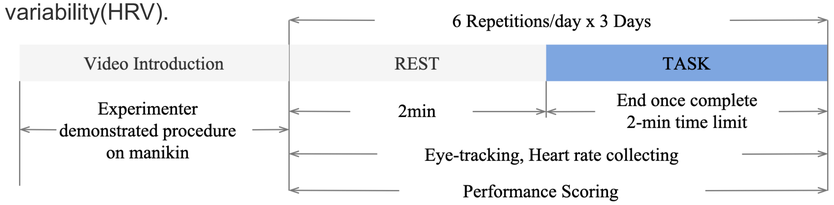
- Cricothyrotomy (CCT) is a lifesaving emergency airway procedure with rare incidence and poor success rates, reported at 66% in the US military and 75% in UK hospitals[1-3].
- Non-invasive physiological measurements have shown associations with surgical expertise; however, validation across medical skills is limited and evidence in critical airway procedures is lacking [4].

Objective:

- Examine the learning curve of behavioral performance and the associated changes in physiological responses during longitudinal surgical airway management skill training.

Methods

- **10 medical students** completed three days of CCT training, performing six repetitions per day on a manikin, with each trial limited to 2 minutes.
- **Measures:** Performance (completion time, errors, correct steps); Eye-tracking, Heart rate variability(HRV).



- **Statistical Analysis:** Completion time across the 18 repetitions was modeled using Pegels' discrete exponential learning curve model [5]. HRV, gaze metrics and completion time at the first repetition and the last (6th) repetitions of each day were compared using a repeated-measures analysis of variance (ANOVA). A one-sample t-test was used to compare the values with the mean performance data of emergency medicine residents from our previous study[6].

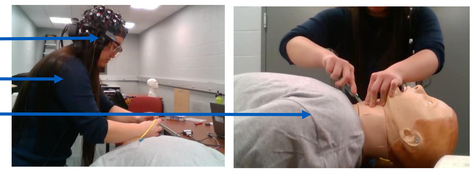


***Figure 1*:** Experimental setup.

Results

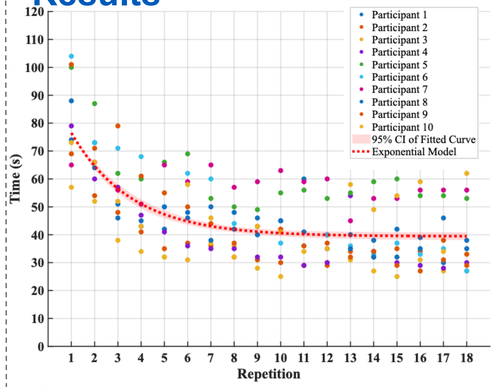


***Figure 2*:** Completion time curve. Parameter uncertainty and confidence bands were estimated using the Jacobian-based covariance matrix.

- **Completion Time Curve:** The exponential learning curve modeling, implemented within a nonlinear least-squares regression with random intercepts to account for between-participant variability, provided a strong fit to the pooled trial-level data (R^2 = 0.83, RMSE = 6.35). Parameter estimates indicated **0.68 learning rate** (95% CI [0.64, 0.72]), with performance approaching an **asymptotic completion time at 39.4 seconds** (95% CI [38.01, 40.83]). **(Fig. 2)**.

$$t_n = 0.68^{n-1}(t_1 - 39.4) + 39.4$$

***Function 1*:** Completion time prediction model.

t_1 is the completion time of first trail
n is the repetition count

- The learning curve of completion time over eighteen training trials showed a dynamic pattern in which completion time dropped rapidly and significantly ($p < 0.05$) during the first day, reached a level comparable to that of residents by the sixth repetition ($p>0.05$), and shifted to a more gradual rate of improvement thereafter. **(Fig. 3A)**.
- A modest increase in completion time was also observed at the onset of the second and third days, suggesting a potential forgetting effect between days.

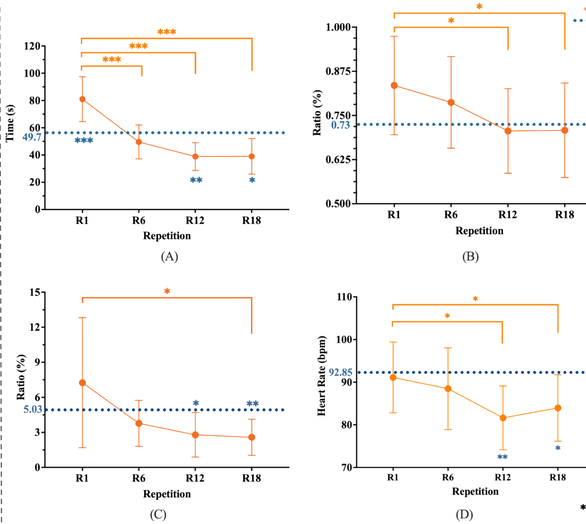


***Figure 3*:** Statistical results. (A) completion time; (B) saccade and fixation count ratio; (C) low frequency and high frequency (LF/HF) ratio; (D) heart rate. The orange solid lines represent the repetitions across the first, sixth, twelfth and eighteenth repetition during medical students' training. The blue dotted line shows the corresponding data from emergency medicine residents.

$^{*}p < 0.05$
$^{**}p < 0.01$
$^{***}p < 0.001$

- **Heart Rate Variability - Stress Adaptation Curve:** The HRV measures indicated that heart rate and the LF/HF ratio exhibited significant reductions by the twelfth (p=0.01) and eighteenth (p=0.04) repetitions, respectively, suggesting a shift toward parasympathetic predominance and improved stress adaptation. **(Fig. 3D)**.
- **Gaze Pattern - Attention Regulation Curve:** The significant decrease in the saccade-to-fixation count ratio indicated enhanced fixation stability and reduced scanning behavior. **(Fig. 3B)**.

Conclusion

- The learning curve of CCT technical skill acquisition showed a **rapid and significant improvement on the first day, followed by a slower progression that eventually plateaued.**
- Contrary to performance, stress adaptation and attention distribution, as reflected by HRV and gaze behavior, emerged from the outset, but required a longer duration to achieve stable adaptation.

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