Analysis of Video Laryngoscopy Systems Using Orthogonal Array Testing

Office of the Medical Director, D.C. Fire & EMS

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Background:

The Continuous Quality Improvement Division in the Office of the Medical Director is participating in a national quality improvement project through the EMS Quality Improvement Partnership (EQuIP) collaborative to improve airway management practices across participating agencies. The focus of EQuIP is reducing incidents of hypotension and hypoxia during advanced airway procedures, ensuring patients are treated with oxygen when indicated, and increase the use of wave form capnography for all invasive airways.

As part of this year long project, the CQI Division has been engaging in developing models for airway management and working on improvement cycles to increase our learning about our systems and processes around airway management and evaluation. This report and analysis outlines one of the improvement cycles used to build our knowledge of advanced airway management practices.

To accomplish this, the CQI Division examined three video laryngoscope systems, along with four other factors that are hypothesized to impact intubation performance: number of providers (1- vs. 2-person), stylet (bougie vs. rigid), BVM size (Adult vs. Child), and ventilation feedback (feedback vs. no feedback).

Study Aims:

1. Identify potential video laryngoscope systems that may improve intubation performance
2. Identify any potential factors that increase or decrease total intubation time

Predictions/Hypotheses:

- 2-person ETI will be the factor that contributes the most to efficiency
- No significant difference between systems will be detected
- No real effect will be seen between stylets
- No real effect will be seen with ventilation feedback

Methodology:

The study is conducted as part of Design of Experiments methodology in a simulation lab, using a high-fidelity airway simulation head (7-Sigma) to test each video laryngoscope system, and combination of factors. Five D.C. Fire & EMS paramedics, representing various levels of position and experience were selected to participate in the study. Each paramedic was given a paramedic partner to assist when indicated; and completed 12 successive intubations, with randomized combination of factors.

Total intubation time, defined as the last ventilation delivered pre ETI procedure to the second breath delivered after a successful intubation attempt, was measured using ZOLL RealBVM technology. Data files were then uploaded into the ZOLL Online Cloud where they were extracted and manually coded to indicate the intubation period.

To address the study aims of this project we used an Orthogonal Array Testing methodology. Orthogonal Array Testing allows for efficient testing of multiple factors to determine the main effects of each factor, in addition to some second order interaction terms (up to 2 factors). The specific Orthogonal Array: $\boldsymbol{L_{12}\ (3^{1},\ 2^{4})}$ indicating 12 tests, with one factor at 3 levels and four factors at 2 levels are randomly combined to ensure a balance of all combinations (orthogonality).

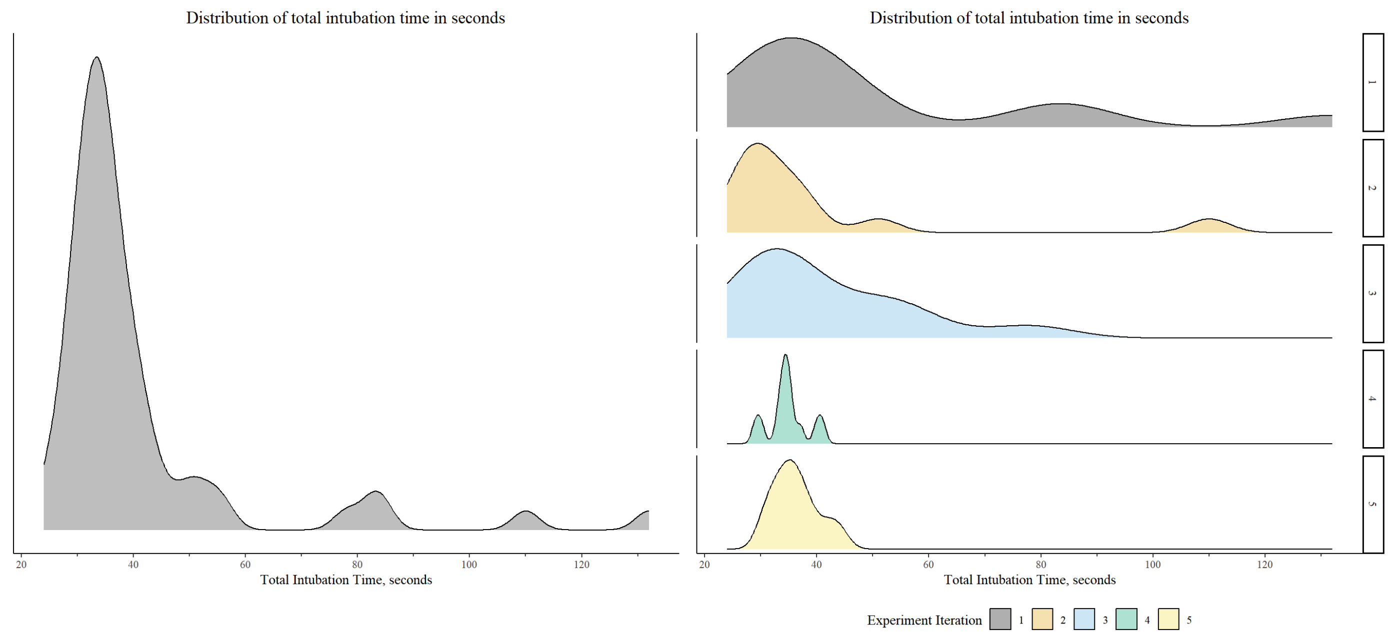
Summary statistics and run charts are used to described the total intubation time of each iteration. Small multiples analysis is used to identify smaller patterns existing within particular factors when necessary.

Analysis:

Overall, the average intubation time for the experiment was 40.7 seconds, with standard deviation of 19.3; median intubation time and interquartile range were 35 and 8.6 seconds respectively. Both of these limits exceed the standard for intubation time of 30 seconds. However, these are unlikely to be clinically impactful.

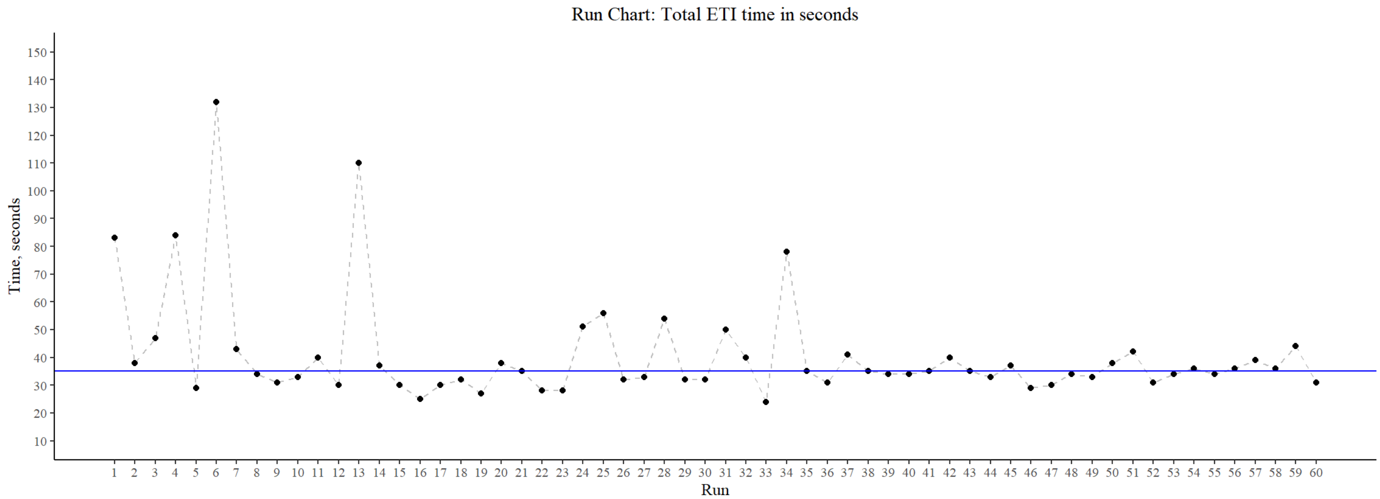
Data Distribution

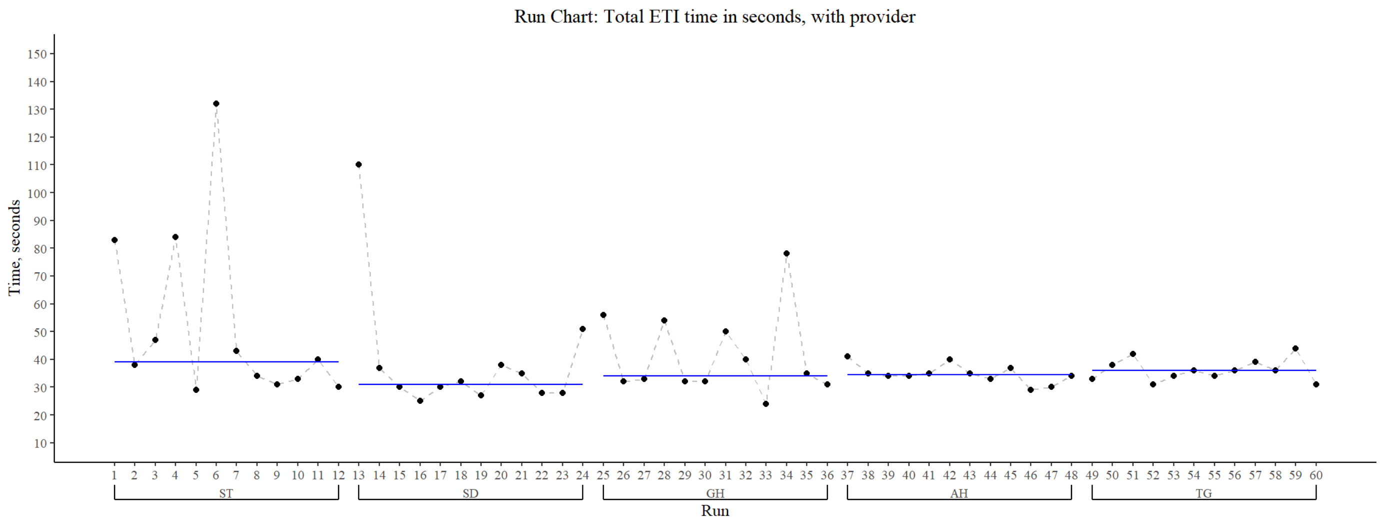
Visual examination of ETI time in seconds shows a heavy-right tail skew, with outliers consistent with time-measured associated data distributions.



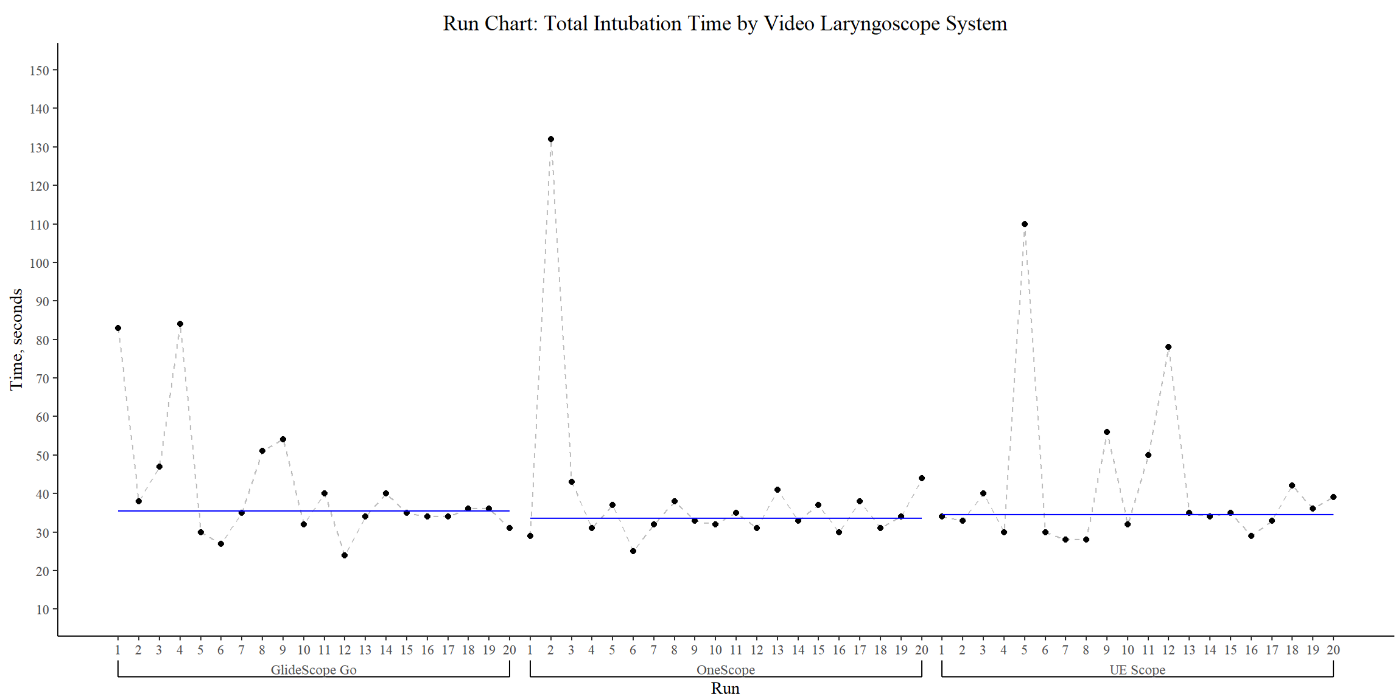
Run Charts:

Run charts associated with total ETI time shows a median time of 35 seconds, with five points that exceed 60 seconds - and would be considered ‘outliers’. Three outliers are associated with the first provider, one with the second provider, and one with the third provider.

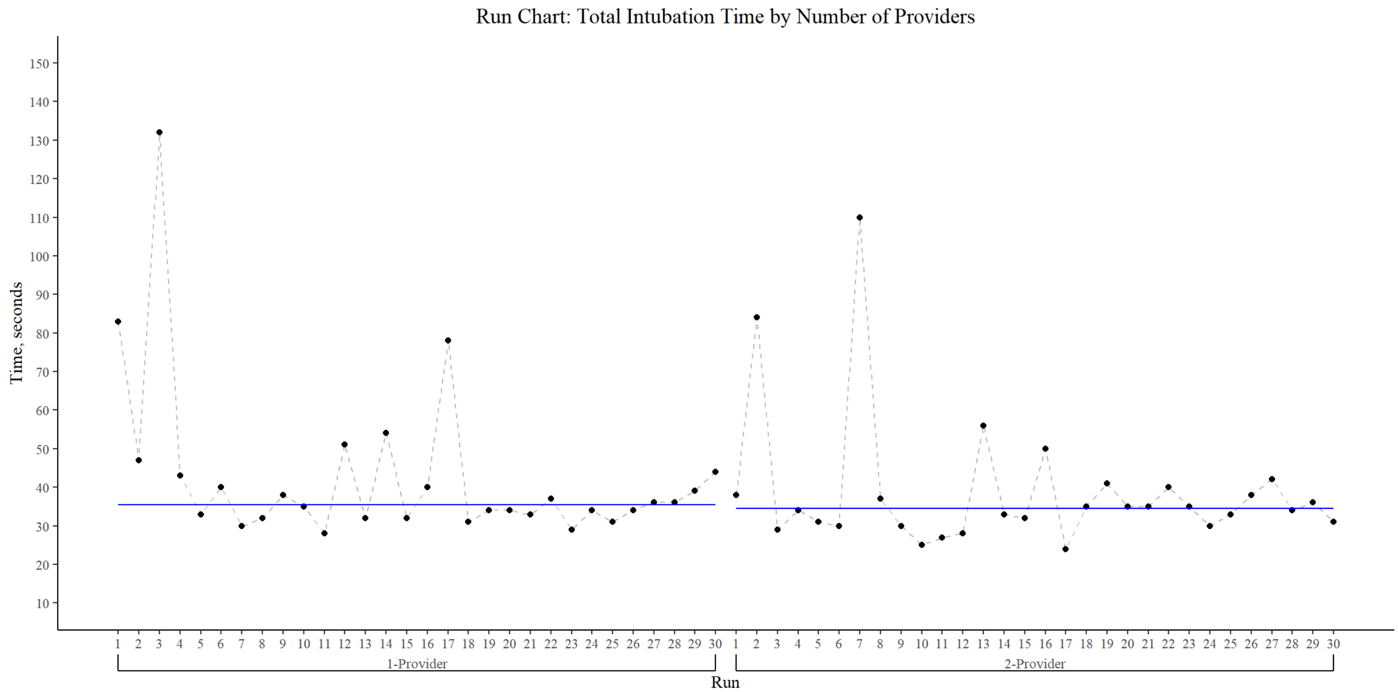




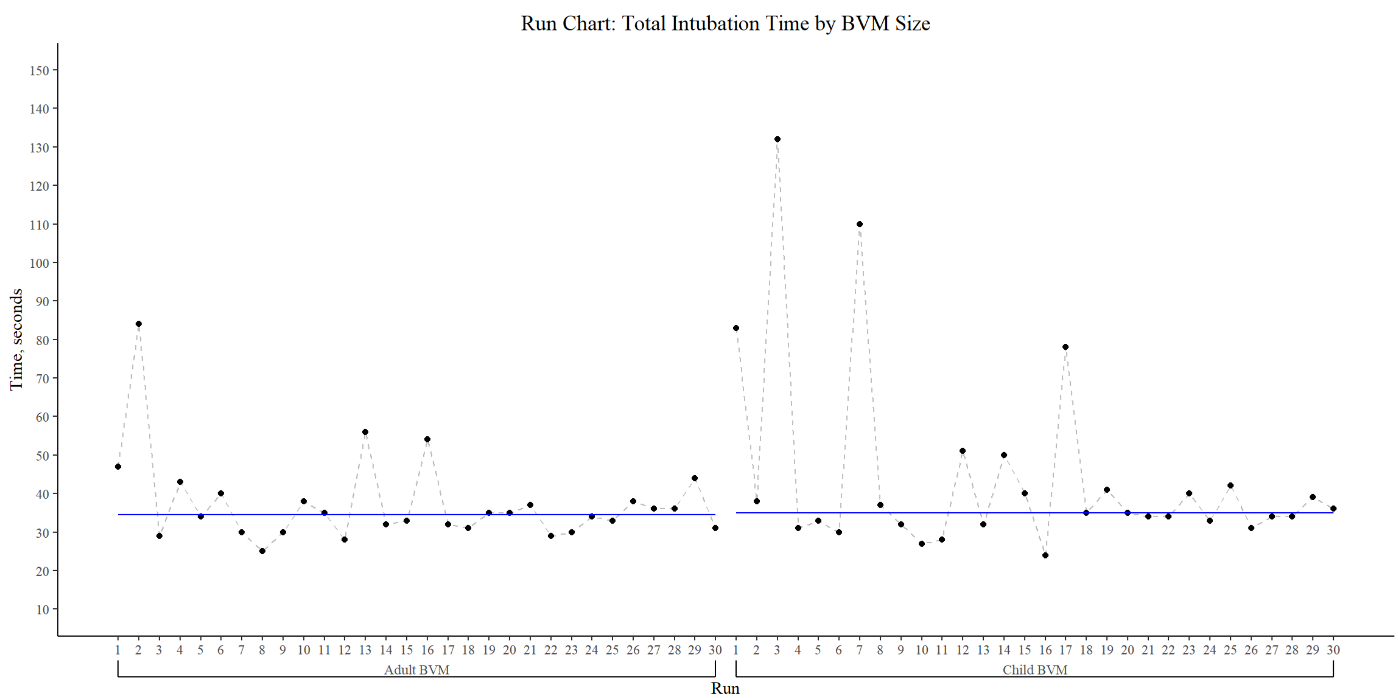
With respect video laryngoscope systems, there is no difference in median performance. However, there is notable variation in the GlideScope Go and UE Scope systems, while the OneScope shows consistent performance despite one outlying point.



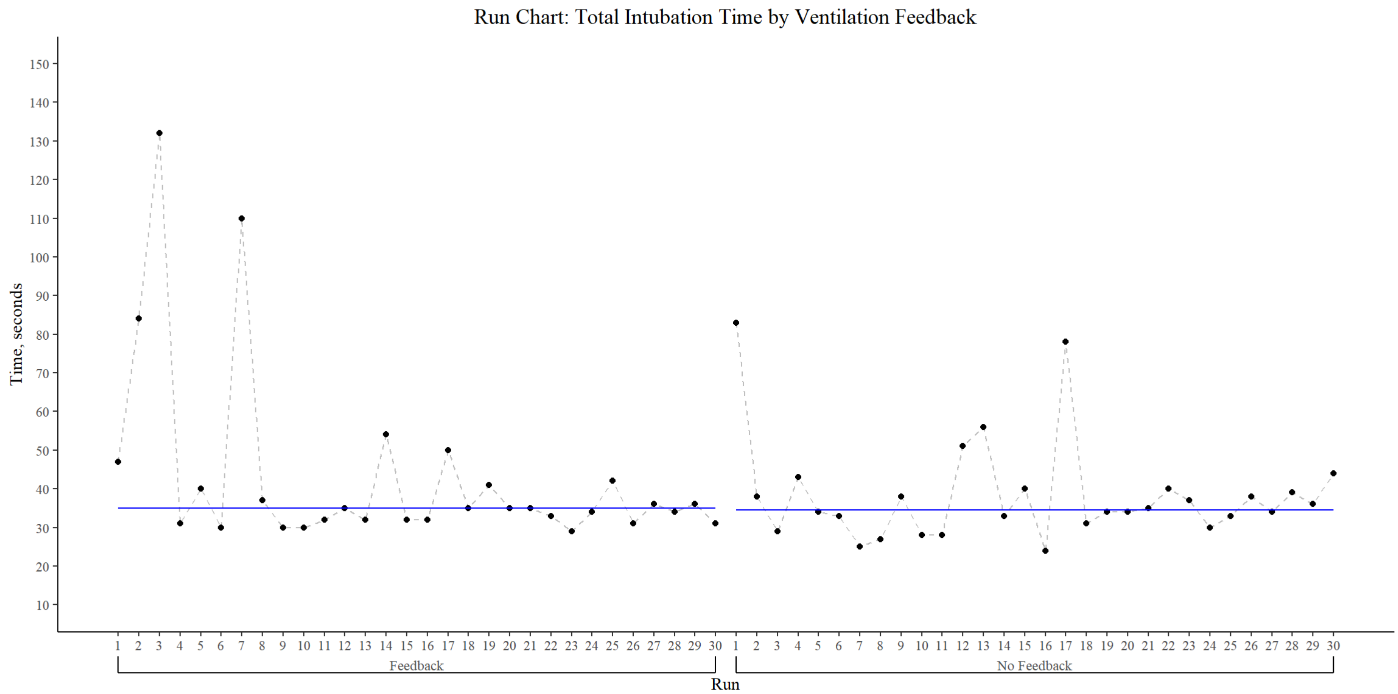
The run chart for the number of providers involved in endotracheal intubation shows similar performance across factors.



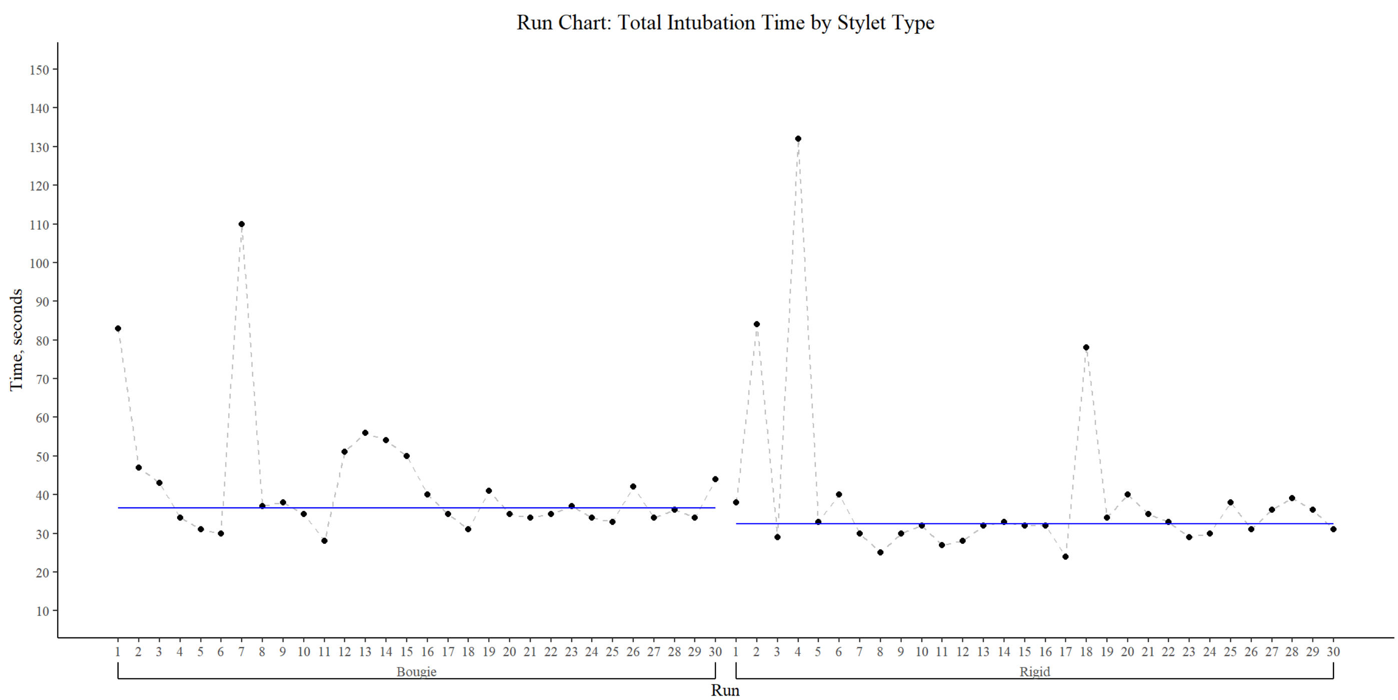
The BVM run chart also shows some similarity in performance. However, Child BVM's exhibit a higher degree of variation compared to Adult BVMs.



With respect to ventilation feedback, we also seem similar performance. However, there appears to be higher variation under the 'no feedback' factor despite smaller outliers in the data.



Stylets show the biggest difference between them - with rigid/malleable stylets contributing to faster ETI time. This is consistent with literature on the performance of the bougie, showing on average an increase in intubation time.(Hellmann et al. 2024), (Bonnette et al. 2021)



Orthogonal Array Test:

Below are the associated Orthogonal Array tables used in testing the factors in this study, along with associated endotracheal intubation time in seconds. The advantage of an Orthogonal Array Test is the efficiency in which factors can be evaluated.

		Video Laryngoscope System	Feedback/No Feedback	Stylet	BVM Device	Provider Config.	ETI Time (sec.)
Orthogonal Array Test Tables							
Provider 1	Run 1, Test 1	GSGo	No Feedback	Bougie	Child	1Person	83
	Run 2, Test 2	GSGo	No Feedback	Rigid	Child	2Person	38
	Run 3, Test 3	GSGo	Feedback	Bougie	Adult	1Person	47
	Run 4, Test 4	GSGo	Feedback	Rigid	Adult	2Person	84
	Run 5, Test 5	OneScope	No Feedback	Rigid	Adult	2Person	29
	Run 6, Test 6	OneScope	Feedback	Rigid	Child	1Person	132
	Run 7, Test 7	OneScope	No Feedback	Bougie	Adult	1Person	43
	Run 8, Test 8	UE	No Feedback	Bougie	Adult	2Person	34
	Run 9, Test 9	OneScope	Feedback	Bougie	Child	2Person	31
	Run 10, Test 10	UE	No Feedback	Rigid	Child	1Person	33
	Run 11, Test 11	UE	Feedback	Rigid	Adult	1Person	40
	Run 12, Test 12	UE	Feedback	Bougie	Child	2Person	30
	Min. ETI time	—	—	—	—	—	29.0
	Max. ETI time	—	—	—	—	—	132.0
	Median ETI time	—	—	—	—	—	39.0
	Mean ETI time	—	—	—	—	—	52.0
	SD ETI time	—	—	—	—	—	31.6
Provider 2	Run 13, Test 1	UE	Feedback	Bougie	Child	2Person	110
	Run 14, Test 2	OneScope	Feedback	Bougie	Child	2Person	37
	Run 15, Test 3	GSGo	Feedback	Rigid	Adult	2Person	30
	Run 16, Test 4	OneScope	No Feedback	Rigid	Adult	2Person	25

Orthogonal Array Test Tables

		Video Laryngoscope System	Feedback/No Feedback	Stylet	BVM Device	Provider Config.	ETI Time (sec.)
	Run 17, Test 5	UE	Feedback	Rigid	Adult	1Person	30
	Run 18, Test 6	OneScope	Feedback	Rigid	Child	1Person	32
	Run 19, Test 7	GSGo	No Feedback	Rigid	Child	2Person	27
	Run 20, Test 8	OneScope	No Feedback	Bougie	Adult	1Person	38
	Run 21, Test 9	GSGo	Feedback	Bougie	Adult	1Person	35
	Run 22, Test 10	UE	No Feedback	Bougie	Adult	2Person	28
	Run 23, Test 11	UE	No Feedback	Rigid	Child	1Person	28
	Run 24, Test 12	GSGo	No Feedback	Bougie	Child	1Person	51
	Min. ETI time	—	—	—	—	—	25.0
	Max. ETI time	—	—	—	—	—	110.0
	Median ETI time	—	—	—	—	—	31.0
	Mean ETI time	—	—	—	—	—	39.2
	SD ETI time	—	—	—	—	—	23.4
Provider 3	Run 25, Test 1	UE	No Feedback	Bougie	Adult	2Person	56
	Run 26, Test 2	UE	Feedback	Rigid	Adult	1Person	32
	Run 27, Test 3	OneScope	No Feedback	Rigid	Adult	2Person	33
	Run 28, Test 4	GSGo	Feedback	Bougie	Adult	1Person	54
	Run 29, Test 5	GSGo	Feedback	Rigid	Adult	2Person	32
	Run 30, Test 6	OneScope	Feedback	Rigid	Child	1Person	32

Orthogonal Array Test Tables

		Video Laryngoscope System	Feedback/No Feedback	Stylet	BVM Device	Provider Config.	ETI Time (sec.)
	Run 31, Test 7	UE	Feedback	Bougie	Child	2Person	50
	Run 32, Test 8	GSGo	No Feedback	Bougie	Child	1Person	40
	Run 33, Test 9	GSGo	No Feedback	Rigid	Child	2Person	24
	Run 34, Test 10	UE	No Feedback	Rigid	Child	1Person	78
	Run 35, Test 11	OneScope	Feedback	Bougie	Child	2Person	35
	Run 36, Test 12	OneScope	No Feedback	Bougie	Adult	1Person	31
	Min. ETI time	—	—	—	—	—	24.0
	Max. ETI time	—	—	—	—	—	78.0
	Median ETI time	—	—	—	—	—	34.0
	Mean ETI time	—	—	—	—	—	41.4
	SD ETI time	—	—	—	—	—	15.3
Provider 4	Run 37, Test 1	OneScope	Feedback	Bougie	Child	2Person	41
	Run 38, Test 2	UE	Feedback	Bougie	Child	2Person	35
	Run 39, Test 3	UE	No Feedback	Rigid	Child	1Person	34
	Run 40, Test 4	GSGo	No Feedback	Bougie	Child	1Person	34
	Run 41, Test 5	UE	No Feedback	Bougie	Adult	2Person	35
	Run 42, Test 6	GSGo	No Feedback	Rigid	Child	2Person	40
	Run 43, Test 7	GSGo	Feedback	Rigid	Adult	2Person	35
	Run 44, Test 8	OneScope	Feedback	Rigid	Child	1Person	33

Orthogonal Array Test Tables							
		Video Laryngoscope System	Feedback/No Feedback	Stylet	BVM Device	Provider Config.	ETI Time (sec.)
	Run 45, Test 9	OneScope	No Feedback	Bougie	Adult	1Person	37
	Run 46, Test 10	UE	Feedback	Rigid	Adult	1Person	29
	Run 47, Test 11	OneScope	No Feedback	Rigid	Adult	2Person	30
	Run 48, Test 12	GSGo	Feedback	Bougie	Adult	1Person	34
	Min. ETI time	—	—	—	—	—	29.0
	Max. ETI time	—	—	—	—	—	41.0
	Median ETI time	—	—	—	—	—	34.5
	Mean ETI time	—	—	—	—	—	34.8
	SD ETI time	—	—	—	—	—	3.5
Provider 5	Run 49, Test 1	UE	No Feedback	Bougie	Adult	2Person	33
	Run 50, Test 2	OneScope	No Feedback	Rigid	Adult	2Person	38
	Run 51, Test 3	UE	Feedback	Bougie	Child	2Person	42
	Run 52, Test 4	OneScope	Feedback	Rigid	Child	1Person	31
	Run 53, Test 5	GSGo	No Feedback	Bougie	Child	1Person	34
	Run 54, Test 6	GSGo	Feedback	Bougie	Adult	1Person	36
	Run 55, Test 7	OneScope	Feedback	Bougie	Child	2Person	34
	Run 56, Test 8	UE	Feedback	Rigid	Adult	1Person	36
	Run 57, Test 9	UE	No Feedback	Rigid	Child	1Person	39
	Run 58, Test 10	GSGo	No Feedback	Rigid	Child	2Person	36

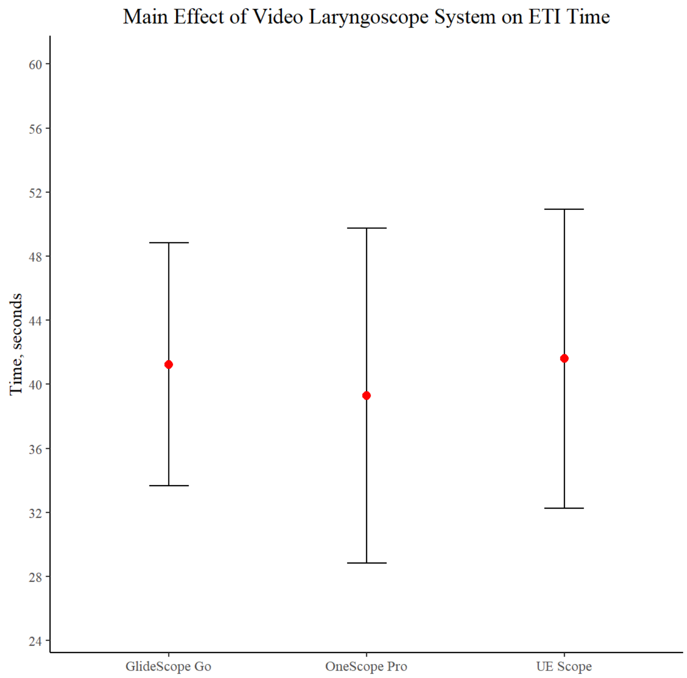
Orthogonal Array Test Tables							
		Video Laryngoscope System	Feedback/No Feedback	Stylet	BVM Device	Provider Config.	ETI Time (sec.)
	Run 59, Test 11	OneScope	No Feedback	Bougie	Adult	1Person	44
	Run 60, Test 12	GSGo	Feedback	Rigid	Adult	2Person	31
	Min. ETI time	—	—	—	—	—	31.0
	Max. ETI time	—	—	—	—	—	44.0
	Median ETI time	—	—	—	—	—	36.0
	Mean ETI time	—	—	—	—	—	36.2
	SD ETI time	—	—	—	—	—	4.0

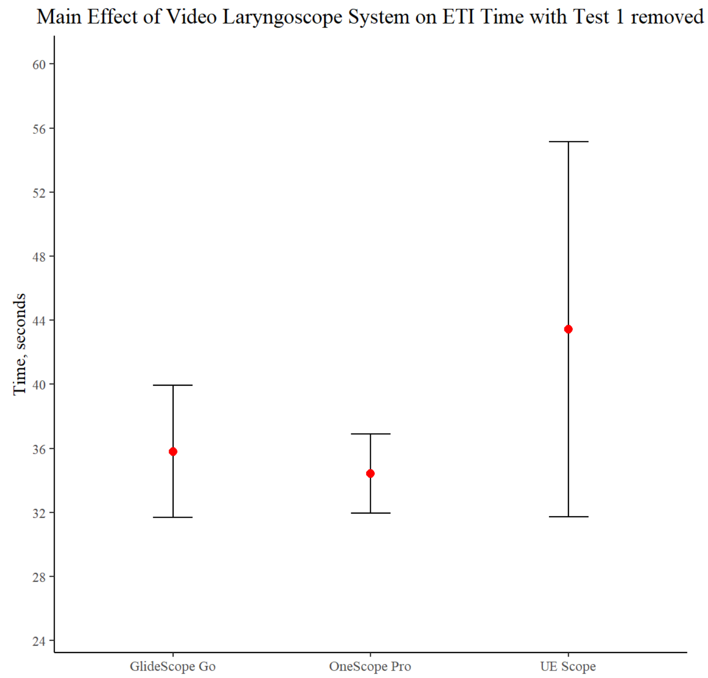
Main Effects:

Main effects analyzed as part of this study include: Video Laryngoscope Systems, Stylet, Number of Providers, and BVM size. The effect is measured as the average time of endotracheal intubation in seconds, leveraging the orthogonality of the design to ensure independence of factor estimates. This structured approach enables a neutral comparison of each factor level due to the balanced and equal exposure of all factors across experimental runs. While this section focuses on main effects, the orthogonal array used in this study is of sufficient resolution to allow exploration of two-factor interactions. These interactions are addressed in the subsequent analysis, providing additional insights into how combined factor effects influence the outcome. Randomization and replication were incorporated to minimize bias and account for experimental error, ensuring the validity of results.

Main Effects - Video Laryngoscope Scope Systems

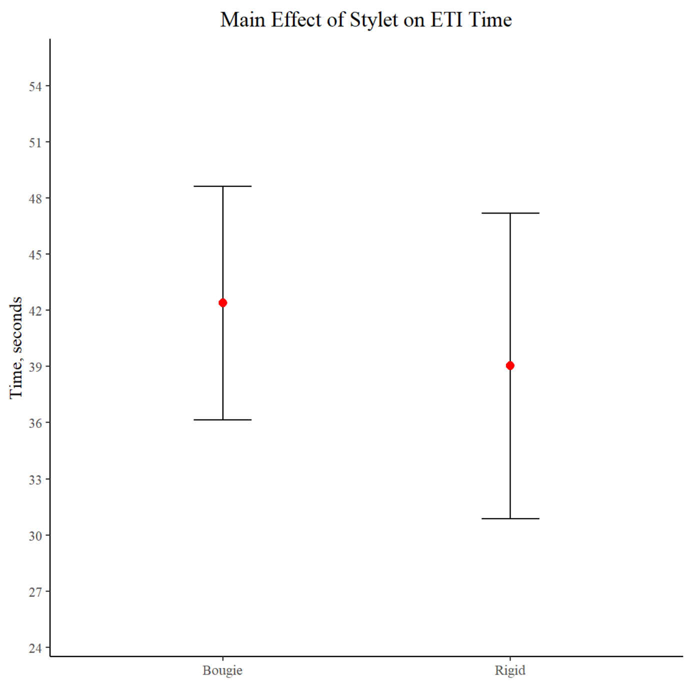
The main effects of the VLS systems show consistency across each factor. Excluding test 1, due to high degree of variability within their experimental set, we see the GlideScope Go and OneScope Pro performed better than the UE scope - additionally, we see higher consistency due to the short confidence level interval of the OneScope Pro (denoted by the whiskers).

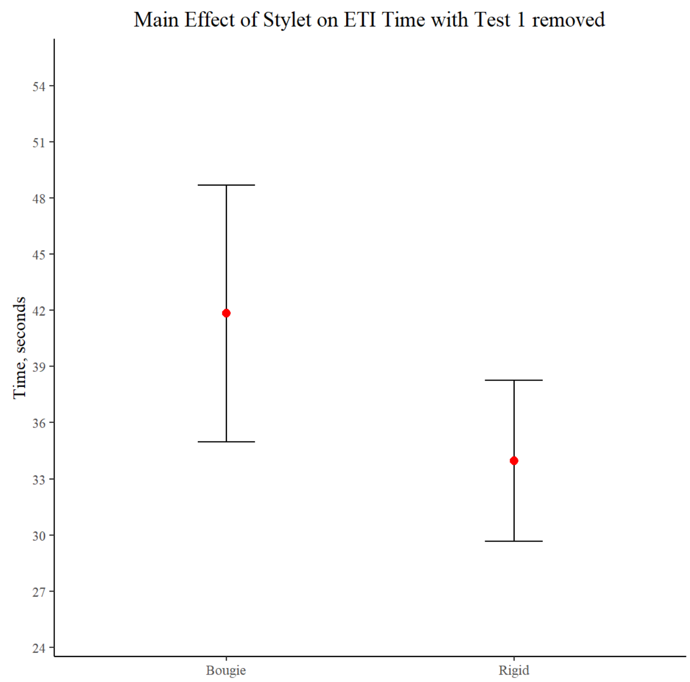




Main Effects - Stylets

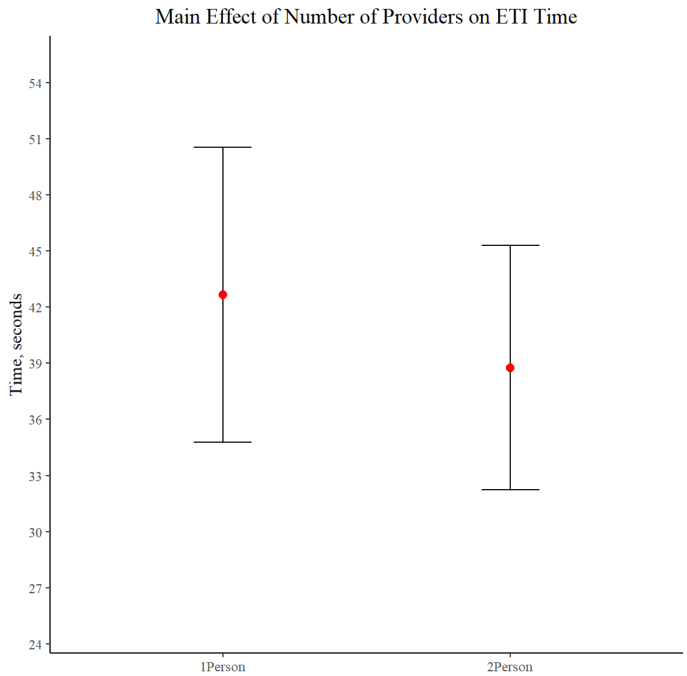
Choice of stylet seems to have the largest effect on total ETI time, with rigid/malleable stylet resulting in shorter ETI time. This is consistent with literature on the topic. Removing the experimental set of Test 1, we see a greater increase in the difference between the two devices.

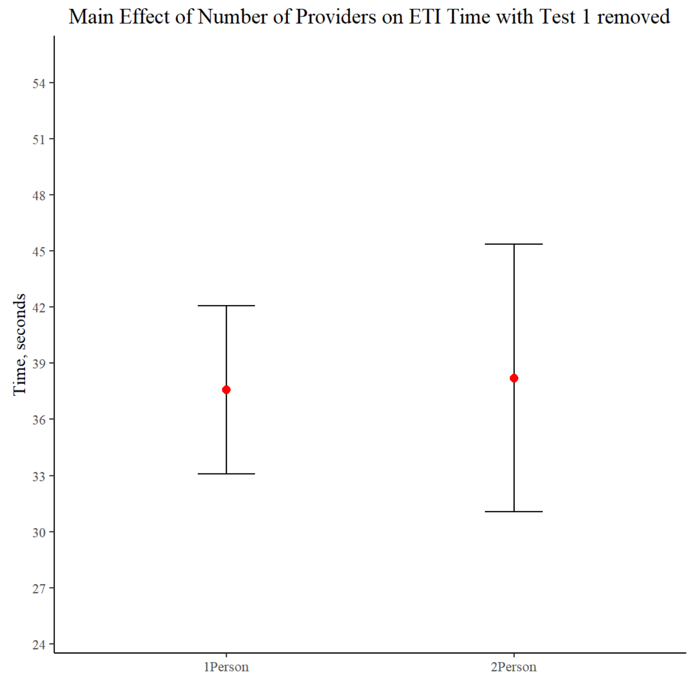




Main Effects - Number of Providers

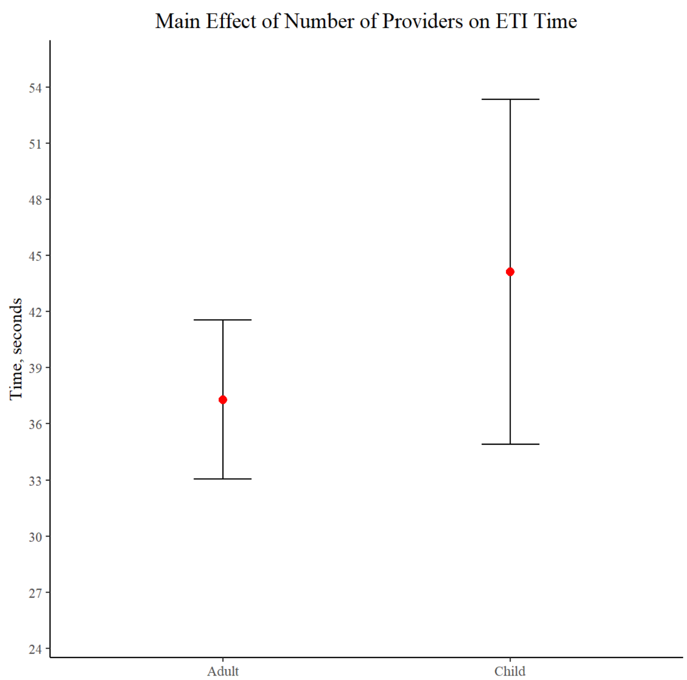
The number of providers engaged in Endotracheal intubation shows similar performance. When removing Test 1, the difference is practically negligible. However, we see slightly better consistency in 1-person ETI compared to 2-person all factors held constant.

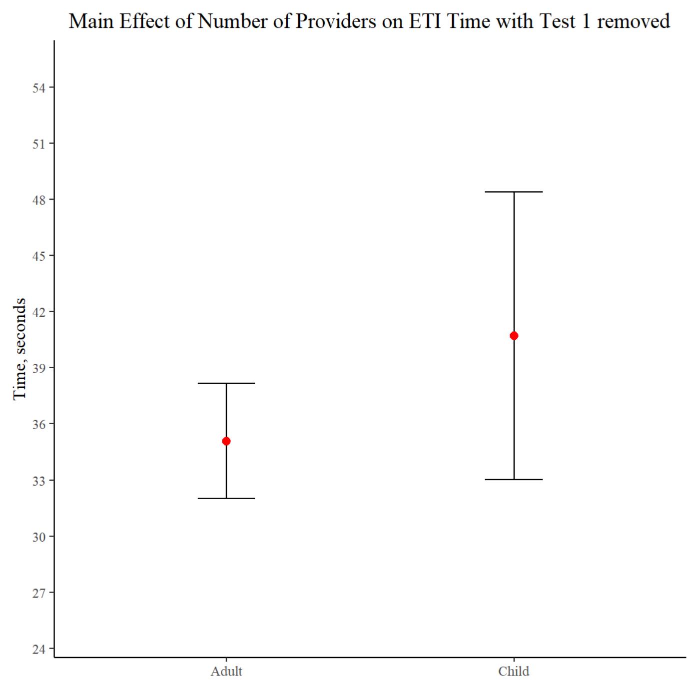




Main Effects - BVM Size

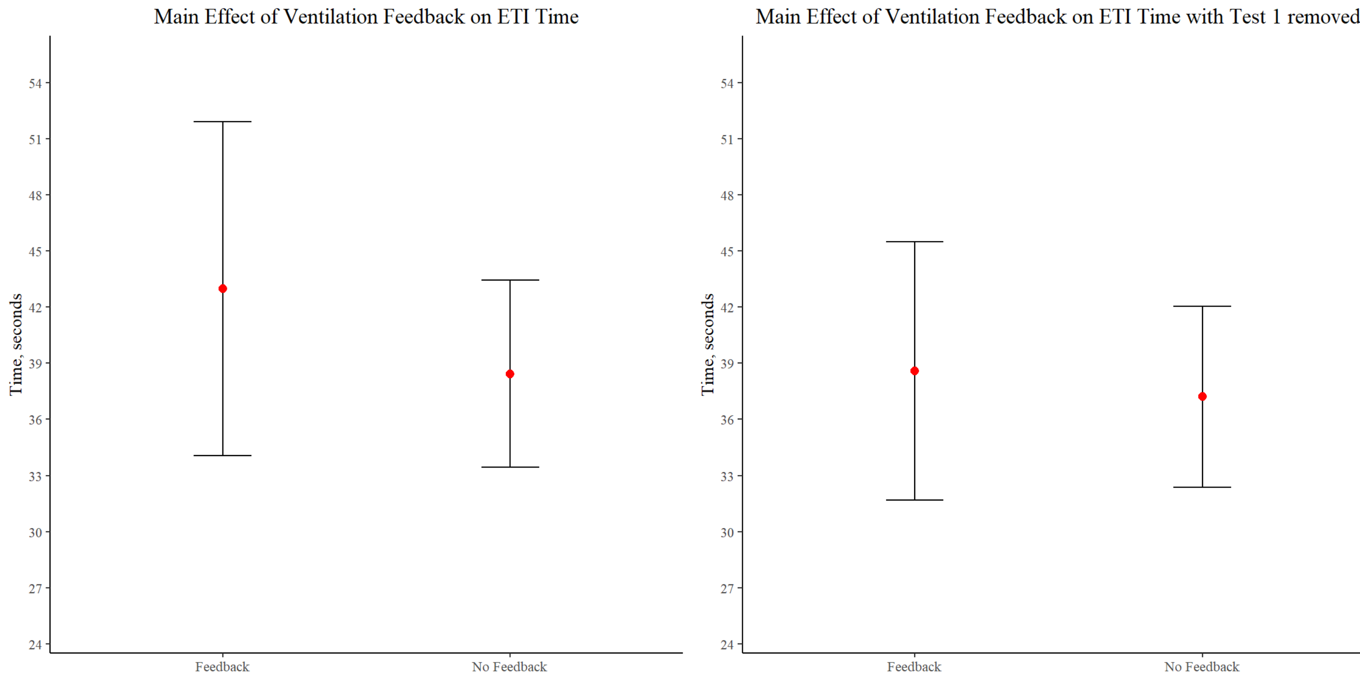
BVM size also seems to have an effect on ETI time. This is seen consistently across both plots, with a slight improvement in consistency with the Adult size BVM.





Main Effects - Ventilation Feedback

Ventilation feedback seems to have no discernible effect on total endotracheal intubation time.



Main Effects Summary:

Overall, the biggest main effects we see on total endotracheal intubation time are the stylets and BVM size. When we remove Test 1 from the data set, we see a larger shift in the Video Laryngoscope Systems - with consistent performance between the GlideScope Go and OneScope Pro. This may indicate that VLS system, in and of itself, is not necessarily a factor in determining which system to pursue based on performance alone, and instead other factors such as cost, provider comfort and preference, durability and maintainability, and technologic capability are more important considerations if a decision to pursue a new device is considered.

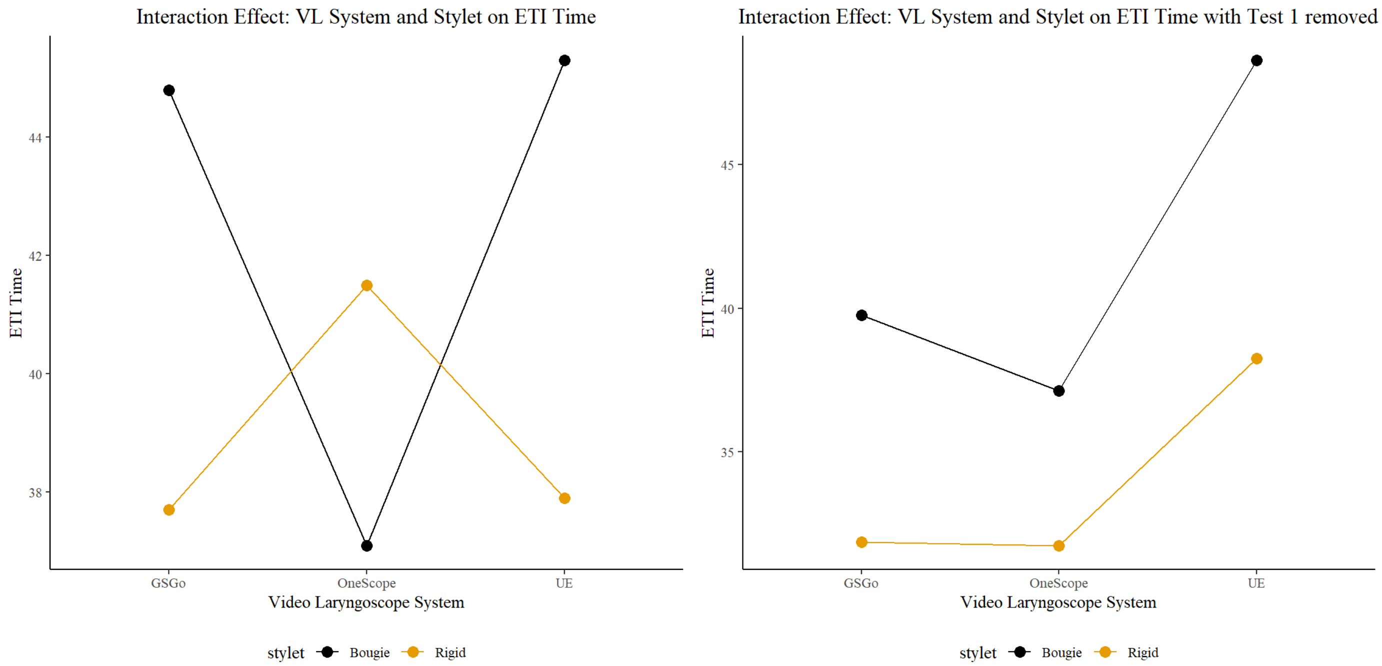
Interaction Effects:

Interaction effects are a critical aspect of factorial testing, as they reveal how factors interact to influence outcomes. Orthogonal Array Testing (OAT), a structured type of factorial test, supports the exploration of two-factor interactions depending on the resolution of the design. Higher-resolution arrays (e.g., Resolution IV or V) enable the independent estimation of two-factor interactions without confounding them with main effects or other interactions. In this study, the $\boldsymbol{L_{12}\ (3^1, 2^4)}$ design is used to examine patterns suggestive of interaction effects on total ETI time.

Although the Resolution III structure of the design does not allow for independent estimation of interactions due to confounding with main effects, this exploratory analysis aims to identify relationships that may warrant further investigation. By revealing how system elements may reinforce or counteract each other, this analysis informs future studies with higher-resolution designs to isolate these effects and investigate higher-order interactions. Ultimately, this approach provides a foundation for process optimization and more informed decision-making.

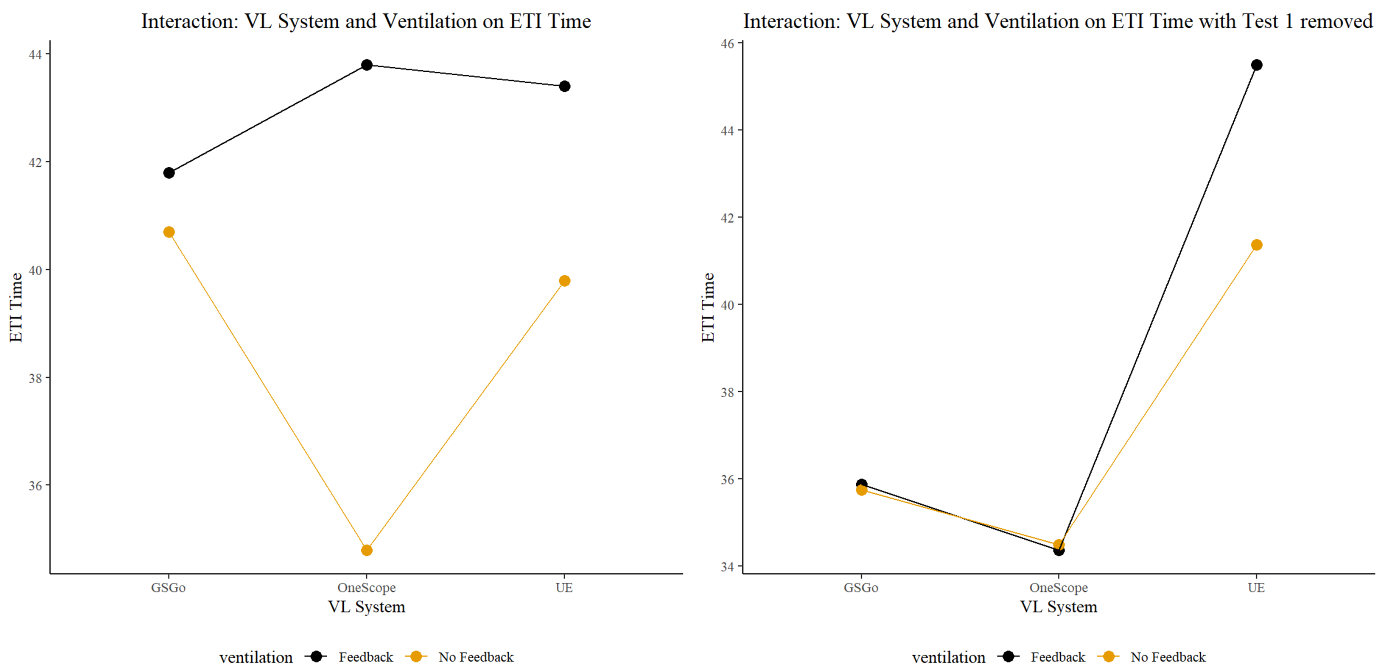
Interaction Effects - VLS System & Stylet

The effect of stylet with video laryngoscope system initially appears to show an interaction between the two factors. However, removing Test 1 from the data shows no interaction; indicating that providers themselves may have a stronger impact on the data.



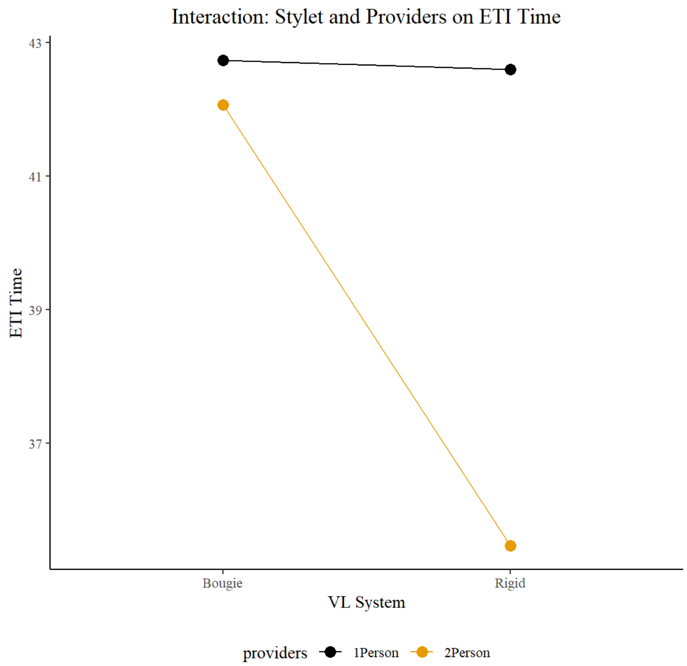
Interaction Effects - VLS System & Ventilation Feedback

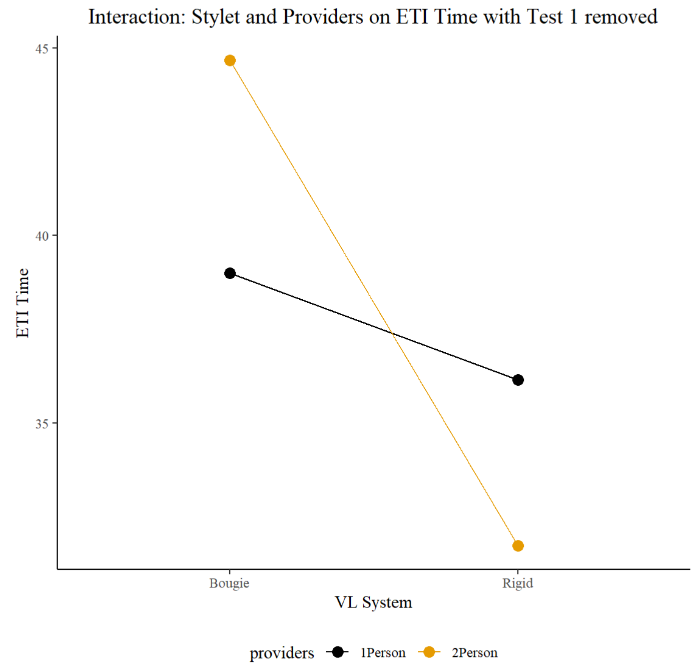
The effects of ventilation feedback and video laryngoscope systems seems to be reversed from data with the stylet, indicating that there may be an interaction between the the VLS systems and ventilation feedback.



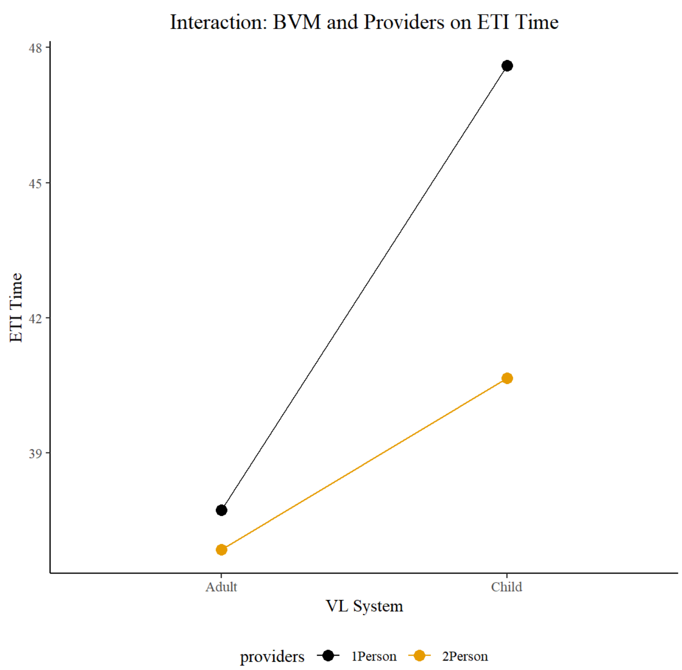
Interaction Effects - Stylet & Number of Providers

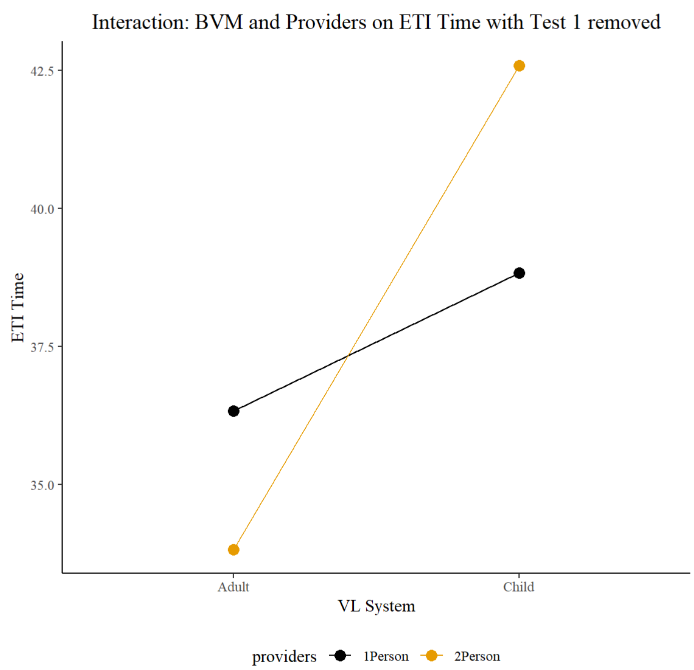
Interaction between stylets and number of providers suggests an interaction between the two. When removing Test 1 from the data again shows the sensitivity to paramedic bias. However, what's notable here the performance of the bougie stylet and 1-person ETI. The introduction of a second provider appears to increase the average total endotracheal intubation time; thus, may be an important factor of further study and research.





Interaction Effects - BVM Size & Number of Providers





Interaction Effects Summary:

In summary, the interaction effects of this study should be interpreted with caution given the Resolution III design, which does not address confounding issues with the main effects. However, there may be opportunities for further study on the relationship of the number of providers engaged in executing the endotracheal intubation skill and the potential impact it has not only on total endotracheal intubation time, but also on first-pass success rate and overall success rate.

Discussion:

Endotracheal intubation and advanced airway management more broadly, are complex processes that require a high level of skill to perform successfully without injuring or harming a patient during execution of the skill. What is often lacking in research is the understanding of how the process as a whole or known factors coincide to impact metrics like first-pass success rate and total intubation time. Our goal, in this PDSA cycle was to start to understand ETI holistically by combining known factor or suspected factors that impact total ETI time, as measured as the time difference between the last breath given pre-intubation, to the second breath given post intubation.

The total ETI time metric is major element in the suite of metrics used to assess performance. Extended ETI time is associated with worse outcomes due to the risks of hypoxia and hypotension as a result of failing to ventilate a patient. Therefore, the standard for performing endotracheal intubation is often set at 30 seconds. Throughout this experiment, we see an overall average ETI time of 40.7 seconds, and a median time of 35 seconds. This suggest that on the whole, providers are adequately able to execute the skill within an acceptable interval of time. The variability within the data suggests some level of consistency overall as well.

In an effort to understand performance of endotracheal intubation, we included a range of experienced paramedics within the Department, who also operate in other capacities other than front line providers. Two of the three participants, were experienced field providers who currently respond to calls. One field provider currently performs other community outreach work and does not actively work in an emergent response capacity. The final two, are officers holding the ranks of Captain and Sergeant were also included. Neither officer is actively engaged in field work. The purpose of this approach was to assess the capacity of any paramedic, regardless of experience or current assignment, and determine their ability to perform ETI in a simulated setting using various factors. The second run chart in this analysis reveals very different performance between paramedic field providers and paramedic non-field providers.

The choice of factors to include in the experiment were based on the required basic tools to perform the skill, in addition to the opportunity to test new Video Laryngoscope Systems for future incorporation into our system. Our experiment focused solely on the providers ability to use the various combination of tools to place an endotracheal tube within a certain amount of time under a ‘low-fidelity’ simulated condition. Other factors were not included, like the application of end-tidal CO_2 sensors, auscultation of lung and epigastric sounds, and visual confirmation of accurate tube placement. Including these factors in future experiments will be necessary to understand the process of ETI more holistically. The inclusion of these additional steps in the process only further adds to the complexity of the process and as a result, adds more cognitive workload and stress to the provider performing the skill.

With respect the predictions and hypotheses of this study: 1) 2-person ETI will be the factor that contributes the most to efficiency, 2) No significant difference between systems will be detected, 3) No real effect will be seen between stylets, 4) No real effect will be seen with ventilation feedback we can conclude the following.

1. 2-person ETI showed mixed results in efficiency in endotracheal intubation, and may be influenced by other factors such as stylet choice and ventilation feedback.

2. There were no real difference between video laryngoscope systems; however, removing the initial Test set from the data shows the UE Scope performed the worst. This also indicates paramedic skill may be an unmeasured factor throughout our study.

3. Stylets have a noticeable effect on ETI time, with the use of the bougie show an average increased effect on time over a rigid/malleable stylet.

4. We see no discernible effect of ventilation feedback on total endotracheal intubation time.

Overall, the factors that seem most important from this experiment are stylet choice, and the number of providers engaged in the insertion of a endotracheal tube. What was not directly measured, but may be indicated in our data is that the level of skill and exposure to performing endotracheal intubation may have on total ETI time. Our future studies will incorporate this to control for paramedic bias based on field/non-field working status. Additionally, incorporating additional factors and increasing the fidelity of simulation to better understand the process and effects of particular factors will be instrumental to optimizing our approach.

Limitations:

This study has several limitations. First, a power analysis was not conducted, meaning the significance of main and interaction effects cannot be used inferentially or predictively. However, quality improvement studies often prioritize empirical findings, making a power analysis less critical for generating actionable insights through direct observation. Second, Orthogonal Array Testing inherently limits the ability to analyze higher-order interactions, such as three- and four-factor interactions. The use of a Resolution III design further restricts the interpretability of two-factor interactions because they are confounded with main effects. While two-factor interactions can be cautiously explored, higher-order interactions remain unaccounted for, introducing variability that adds complexity to the models. Given the intricacy of the endotracheal intubation process, higher-order interactions may play a critical role in optimizing the procedure and configuration for successful intubation. Lastly, this study was designed to examine video laryngoscope systems and related factors within a controlled simulation environment, using an airway simulation head, predefined blade types and sizes, and a waist-height table setup. As a result, the findings should be interpreted as exploratory, identifying factors in the ETI process that warrant further investigation under high-fidelity, real-world conditions.

Summary:

In summary, we learned the following from this study:

- Paramedic skill was an unmeasured factor that warrants future study
- The bougie stylet was associated with an increased endotracheal intubation over rigid/malleable stylet
- Ventilation feedback did not have a direct effect on total endotracheal intubation time, however in the presence of other factors - did seem to demonstrate an interaction.
- BVM size was also associated with difference in total endotracheal intubation time - with the Child Size BVM being associated with a longer average time.
- Video Laryngoscope Systems may not effect the total overall intubation time to a certain extent; but may indicate that some systems/equipment are less desired or contribute to worse performance.
- While this study was not directly designed to account for interactions between factors, there are indications that particular interactions do exist and are worth further investigation.

Recommendations:

We recommend the following next steps:

1. Additional testing on factors associated with endotracheal intubation and include additional outcome variables including first pass success rate, and increase the fidelity of the simulations to simulate real-world scenarios.
2. Consider testing on the optimization of using the bougie stylet during the performance of endotracheal intubation. For example, pre-loading a bougie with a stylet prior to an attempt versus ‘rail roading’ or using a second provider to guide the tube over the device and handing it to the intubating provider.
3. Continue the use of Adult BVM in endotracheal intubation, in adult patients.
4. Consider testing endotracheal intubation performance with an EMT partner to assist the paramedic, instead of using a two paramedic model.
5. Consider expanding the exposure to additional paramedics of varying skills and experience throughout the Department to better understand system performance in a simulated setting.
6. Consider updating airway management policies and protocols based on what is learned from this, and future studies of this kind.

Works Cited:

Bonnette, Austin J., Tom P. Aufderheide, Jeffrey L. Jarvis, Jason A. Lesnick, Graham Nichol, Jestin N. Carlson, Matthew Hansen, Shannon W. Stephens, M. Riccardo Colella, and Henry E. Wang. 2021. "Bougie-Assisted Endotracheal Intubation in the Pragmatic Airway Resuscitation Trial." *Resuscitation* 158 (January): 215–19. https://doi.org/10.1016/j.resuscitation.2020.11.003.

Hellmann, Rafael von, Natalia Fuhr, Ian Ward A. Maia, Danielle Gerberi, Daniel Pedrollo, Fernanda Bellolio, and Lucas Oliveira J. e Silva. 2024. "Effect of Bougie Use on First-Attempt Success in Tracheal Intubations: A Systematic Review and Meta-Analysis." *Annals of Emergency Medicine* 83 (2): 132–44. https://doi.org/10.1016/j.annemergmed.2023.08.484.