Analysis of Hand Arrangement Effectiveness in Ultrasound-Guided Regional Anesthesia

STAT400/DATA419A/DATA500
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Project Goal

The primary objective of this study is to evaluate the effectiveness of different hand arrangements in ultrasound-guided regional anesthesia procedures, particularly focusing on the time efficiency and accuracy of needle placement. This involves analyzing the performance of participants using either their dominant or non-dominant hand for needle control in a simulated environment. The goal is to determine if the choice of hand arrangement impacts the learning curve and overall proficiency in these medical procedures. This analysis will provide valuable insights into the best practices for training in ultrasound-guided anesthesia techniques. Additionally, the project will analyze other factors, such as age, gender, hand dominance, and participants' backgrounds, to help identify key factors influencing the learning and performance of the procedure.

Data Description

The dataset for this study consists of two main files: participant information and time values.

Participant Information (`info.csv`)

This dataset includes detailed information about the participants in the study. The key attributes are as follows:

- **PARTICIPANT**: Unique identifier for each participant.
- **DOMINANCE**: Dominant hand of the participant (R for right, L for left).
- **PICKS UP PROBE IN**: Hand used by the participant to pick up the ultrasound probe (DH for Dominant Hand, NDH for Non-Dominant Hand).
- **STARTING ARRANGEMENT**: Initial hand arrangement used in the procedure (DHP for Dominant Hand Probe, DHN for Dominant Hand Needle).
- **SUBJECTIVE EASIER**: Participant's subjective opinion on which hand arrangement was easier.
- **GENDER**: Gender of the participant.
- **AGE**: Age of the participant.
- **BACKGROUND**: Professional background of the participant (Student, Nurse, Orderly).

Time Values (`timeval.csv`)

This dataset records the time taken for each trial in the experiment. The columns include:

- **TIMES**: Unique identifier correlating with the participant number.
- **HANDS**: Type of hand arrangement used in each trial Dominant Hand Probe (DHP) or Dominant Hand Needle (DHN).
- **1st to 10th**: Time values (in seconds) for each of the ten trials performed by the participants.

Data Exploration

A merged DataFrame, `merged_df`, was created to combine relevant information from both `info.csv` and `timeval.csv`

	PARTICIPANT	DOMINANCE	PICKS UP PROBE IN	STARTING ARRANGEMENT	SUBJECTIVE EASIER	GENDER	AGE	BACKGROUND	HANDS	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
0	1	R	NDH	DHP	DHP	F	23	STUDENT	DHP	97	78	46	52	62	76	46	48	18	26
1	1	R	NDH	DHP	DHP	F	23	STUDENT	DHN	281	159	125	68	91	54	66	47	46	57
2	2	R	DH	DHN	DHP	F	28	NURSE	DHP	28	16	10	7	5	46	11	11	6	7
3	2	R	DH	DHN	DHP	F	28	NURSE	DHN	31	13	8	45	8	22	10	11	12	7
4	3	R	NDH	DHP	DHP	F	24	NURSE	DHP	32	10	31	10	7	24	8	13	23	7

Figure 1: The merged DataFrame.

Descriptive Statistics

The following table displays the descriptive statistics for the time taken (in seconds) for ten attempts of a certain procedure. The table summarizes the data with measures of central tendency and dispersion, such as mean, standard deviation, and percentiles, indicating the consistency and variability of the procedure's duration.

	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
count	40.000000	40.000000	40.000000	40.000000	40.000000	40.000000	40.000000	40.000000	40.000000	40.000000
mean	101.350000	76.975000	54.125000	75.350000	52.950000	37.325000	30.550000	30.550000	21.775000	18.550000
std	91.590099	69.461477	57.355029	97.800307	52.789349	36.139606	29.417377	26.755253	19.355629	13.999908
min	9.000000	5.000000	4.000000	2.000000	3.000000	8.000000	3.000000	7.000000	2.000000	5.000000
25%	31.750000	20.750000	13.250000	13.750000	14.000000	12.000000	10.000000	10.750000	8.500000	7.000000
50%	74.500000	64.500000	30.500000	35.500000	26.500000	23.500000	20.000000	19.000000	17.500000	12.000000
75%	155.500000	108.750000	73.250000	90.000000	73.750000	46.000000	37.500000	43.250000	24.000000	26.750000
max	424.000000	310.000000	240.000000	444.000000	195.000000	170.000000	150.000000	118.000000	82.000000	57.000000

Figure 2: Descriptive statistics for the time taken for ten attempts of the procedure. The table includes count, mean, standard deviation (std), minimum (min), percentiles (25%, 50%, and 75%), and maximum (max) values for each attempt.

Participant Demographics

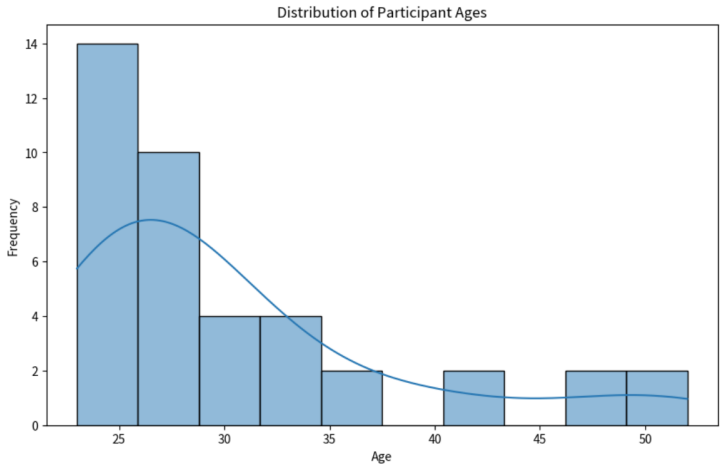

Figure 3: The histogram below illustrates the age distribution of participants in the study. The x-axis represents the age groups, while the y-axis shows the frequency of participants within each age group. The distribution appears to be right-skewed, with a higher concentration of participants in the younger age ranges, particularly in the 25-30 year age group, and fewer participants as age increases.. This suggests that the study may have a younger demographic profile, which should be considered when interpreting the results.

The figure below shows a bar chart of gender distribution among participants, Male (M) and Female(F).

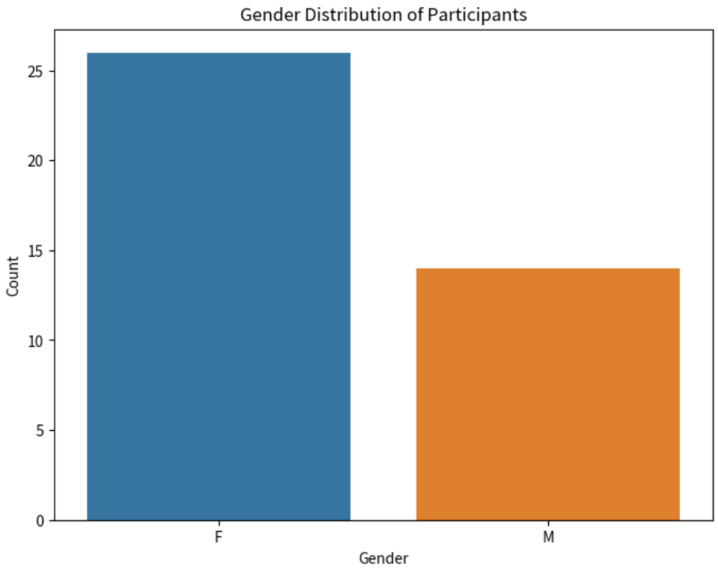

Figure 4: The chart indicates a higher number of female participants compared to male participants, which may reflect the target population of the study or may suggest a gender bias in the recruitment process.

The figure below shows a bar chart depicting the count of participants from different professional or educational backgrounds (Students, Nurses and Orderlies).

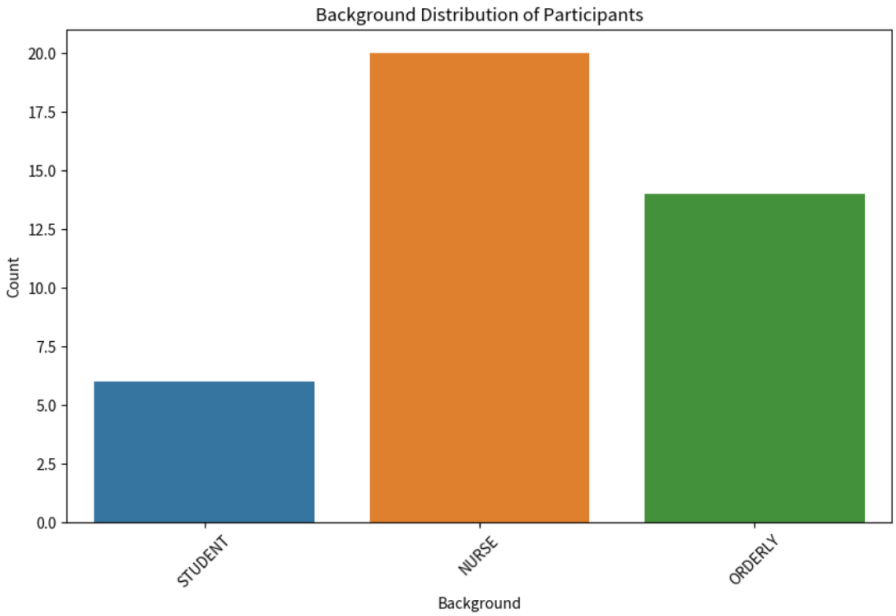

Figure 5: The most represented group is the nurses, followed by orderlies, and then students. This distribution may influence the study's results and should be considered when generalizing the findings.

The bar chart below shows the distribution of dominant hand preference among participants

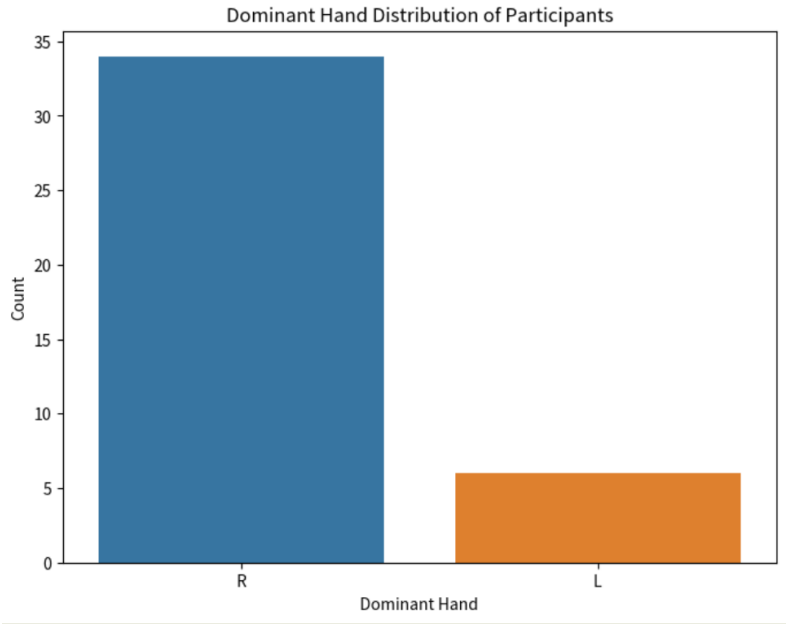

Figure 6: A significantly larger number of participants are right-handed (R) as compared to left-handed (L). This reflects the commonality of right-hand dominance in the general population and may need to be considered in the design and analysis of the study, especially if hand dominance is a relevant factor.

With the boxplot below, we were able to identify any outliers in the data that might skew the results or indicate data entry errors, which are not present. Null values were dropped.

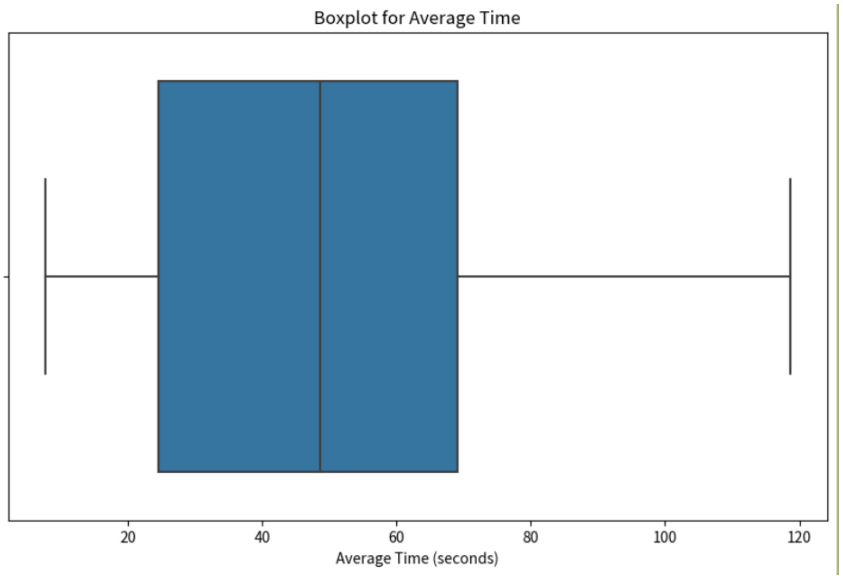

Figure 7: Boxplot for Average Time. The boxplot shows the distribution of average times taken for a certain task. It indicates the median, quartiles, and potential outliers.

Analytical Questions

During this EDA we may want to address the following analytical questions and try to answer with plots:

- Does the dominant hand of participants significantly impact their performance (time taken) in the ultrasound-guided needle procedure?
- How does the starting hand arrangement affect the learning curve over successive attempts?
- Are there any noticeable trends in performance based on the participants' professional background (e.g., student, nurse)?
- Does the subjective ease with which participants handle the equipment correlate with the objective performance data?
- How does age influence the ability to learn and perform the ultrasound-guided procedure?

Data Analysis

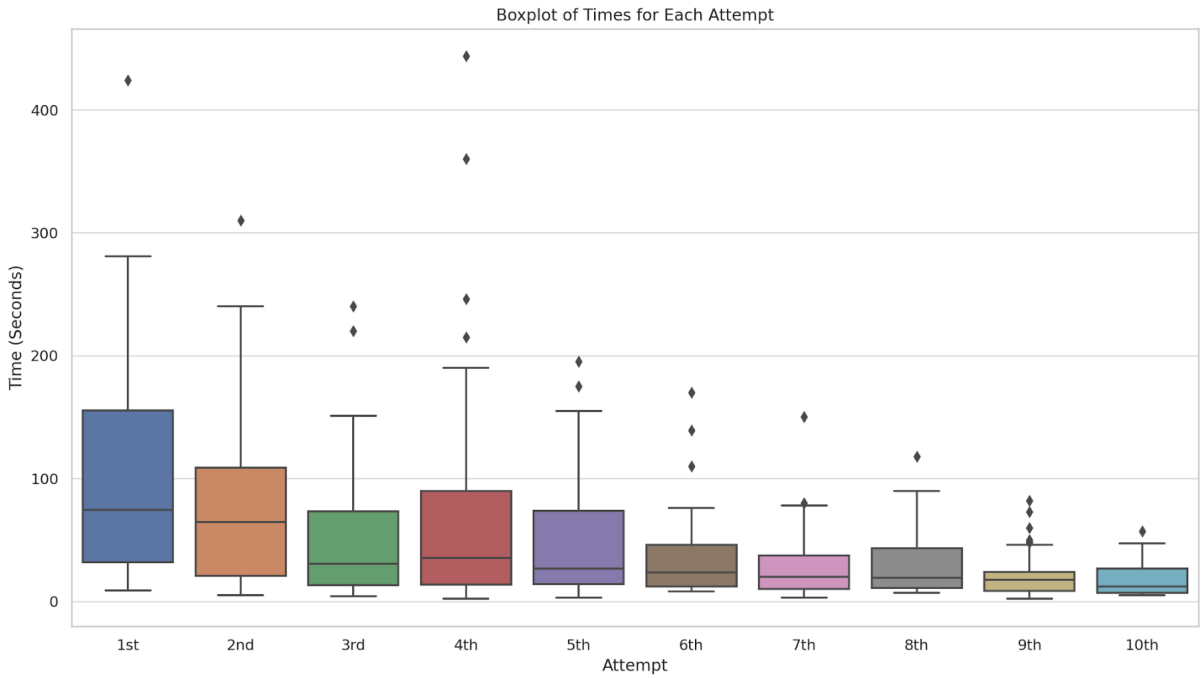

Figure 8: Boxplot of times for each attempt. This plot provides a graphical representation of the distribution of times across multiple attempts at a task.

- **Decreasing Median Times:** There is a visible trend of decreasing median times (the line inside the box) from the 1st to the 10th attempt, suggesting an improvement in performance and efficiency with practice.
- **Reducing Variability:** The size of the boxes (representing the interquartile range) and the range of the whiskers (indicating the overall spread of the data) generally decrease over the attempts. This reduction in variability indicates that participants became more consistent in their performance.
- **Outliers:** The presence of outliers (indicated by the dots outside the boxes) in earlier attempts is notable, suggesting that some participants took significantly longer times initially. These outliers become less frequent in later attempts.

Boxplot of Times (DHP vs. DHN)

Comparing the performance of participants with their dominant hand probe (DHP) versus dominant hand needle (DHN), we observe the following trends in median times:

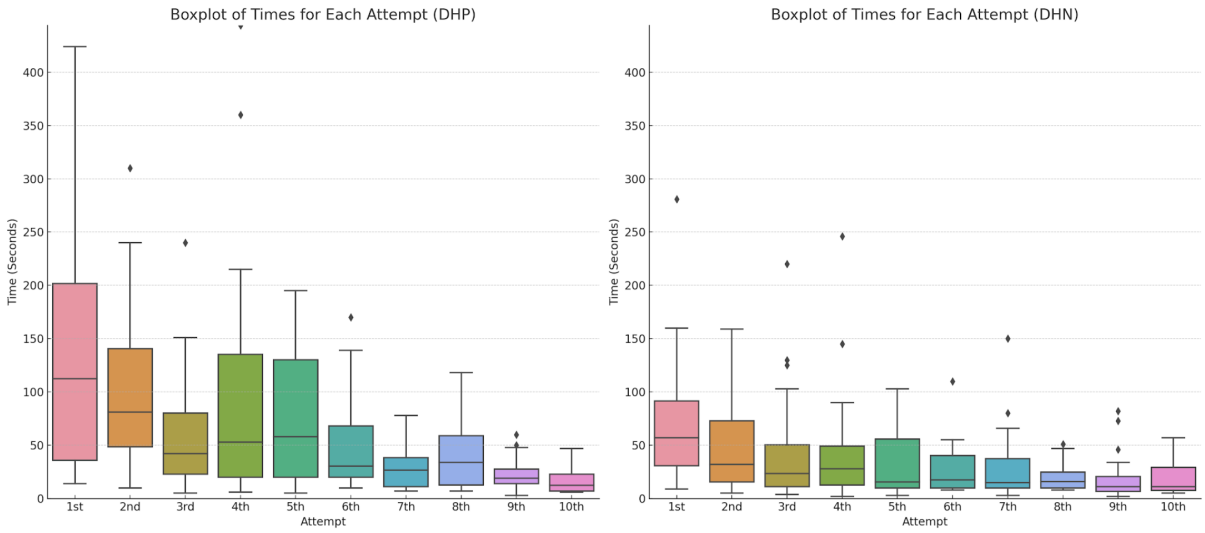

Figure 9: Comparative boxplots of times for each attempt with Dominant Hand Present (DHP) and Dominant Hand Not Present (DHN). The boxplots depict the distribution of times taken to complete a task across multiple attempts for each condition.

- The median times for DHP are generally higher across all attempts, suggesting that participants took longer to complete the task when using their dominant hand.
- In contrast, the median times for DHN are lower, indicating quicker task completion when participants did not use their dominant hand.
- Consistent with learning effects, both conditions show a decrease in median times over successive attempts, but the decrease is more pronounced for DHN.

Median Time per Attempt by Hand Arrangement

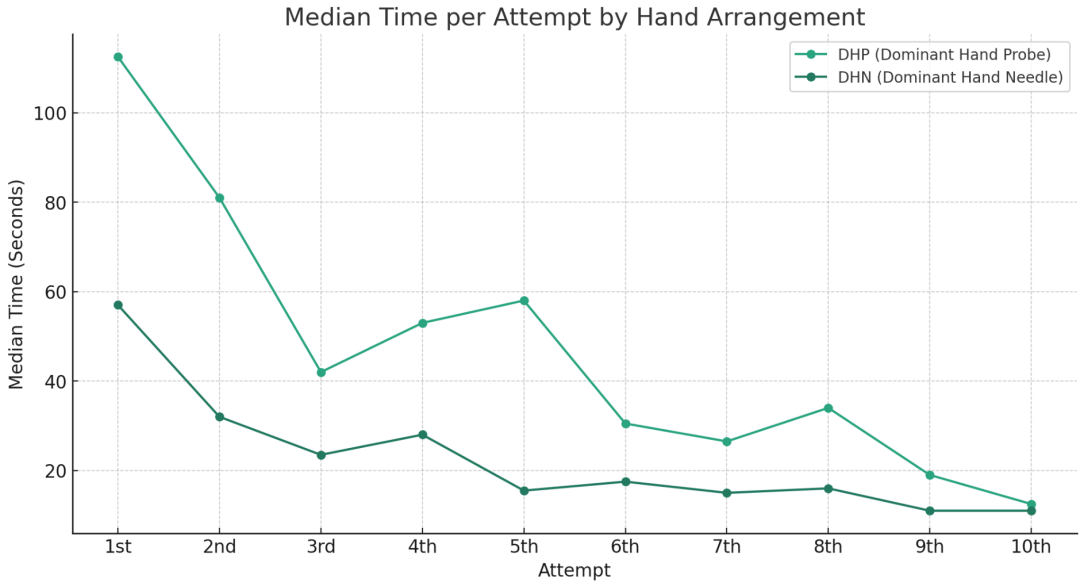

Figure 10: Scatter plot of median time per attempt by hand arrangement, comparing Dominant Hand Probe (DHP) and Dominant Hand Needle (DHN).

The scatter plot makes it easier to visualize differences in the median than Figure 9. The following observations can be made from the plot:

- The median times for DHP are initially higher than for DHN, indicating that participants initially took longer to perform the task when their dominant hand was holding the probe.

- There is a notable decrease in median time for DHP from the first to the second attempt, suggesting a quick adaptation or learning effect.
- For DHN, the median times fluctuate less dramatically and generally decrease as the attempts increase, indicating a more consistent performance and gradual improvement.
- By the final attempts (9th and 10th), the median times for both DHP and DHN converge, suggesting that participants have reached a similar efficiency level regardless of hand arrangement.

Average Time by Hand Arrangement

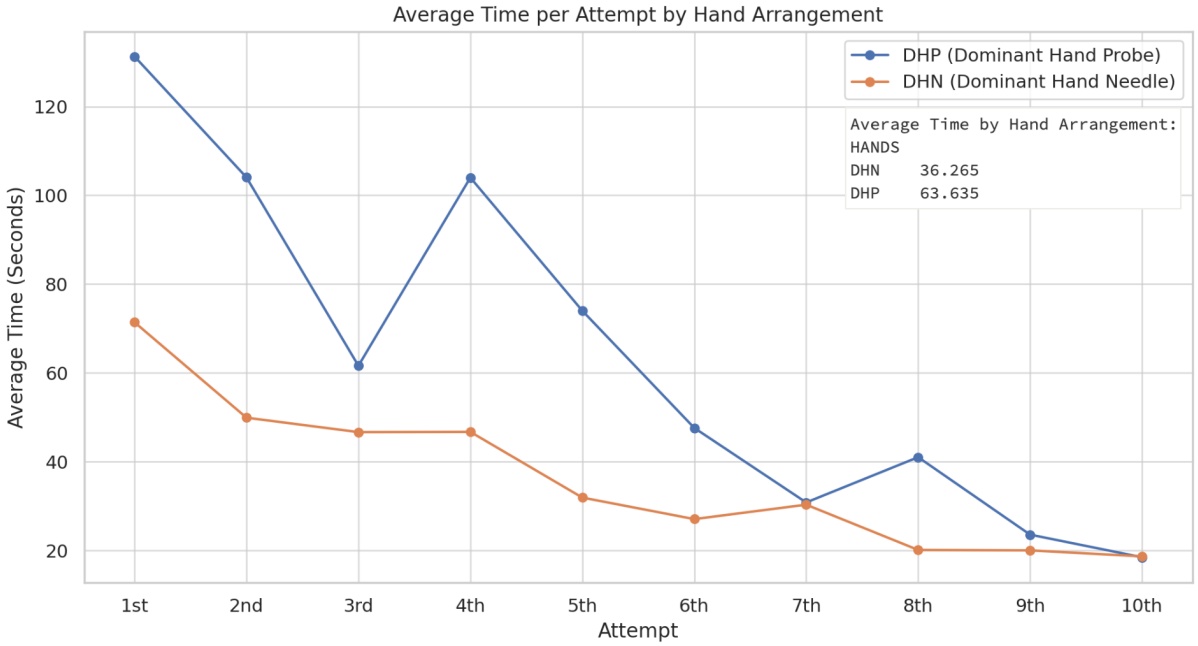

Figure 11: Scatter plot of the average time per attempt by hand arrangement, comparing Dominant Hand Probe (DHP) and Dominant Hand Needle (DHN).

The graph shows the following trends:

- The average time for DHP starts higher than for DHN and remains consistently higher throughout the attempts.
- There is a significant decrease in average time from the 1st to the 2nd attempt for DHP, which then fluctuates and tends to decrease overall in subsequent attempts.
- DHN starts with a lower average time and shows a general decrease as attempts continue, with minor fluctuations. The learning curve appears to be more stable for DHN.
- By the 10th attempt, both DHP and DHN show convergence in average time, although DHP still takes slightly longer.
- The summary table included in the graph highlights that the overall average time for DHN across all attempts is lower than for DHP, suggesting that participants were quicker on average when the dominant hand was used for the needle rather than the probe.

Average Time per Attempt by Gender

The graph shows the following trends:

- Female participants start with higher times on the first attempt compared to male participants.
- Both genders show a decrease in average time from the first to the second attempt, indicating a quick adaptation or learning effect.

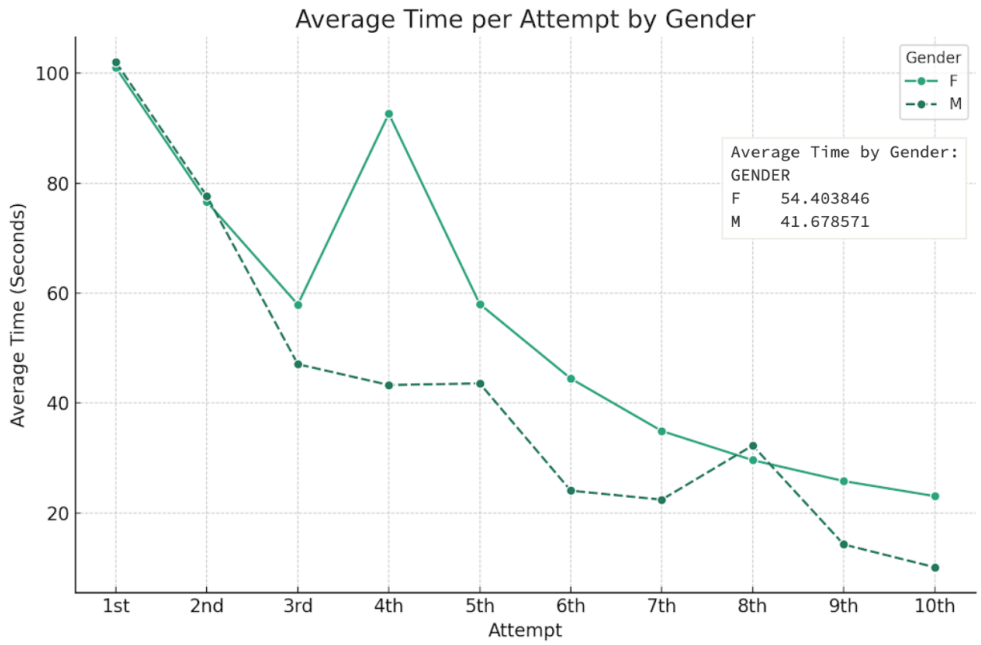

Figure 12: Scatter plot comparing the average time per attempt between female (F) and male (M) participants.

- Female participants have a peak at the fourth attempt, suggesting a possible challenge or variation in that attempt.
- Overall, male participants show a consistent decrease across attempts, finishing with a lower average time by the 10th attempt.
- The summary inset indicates that the overall average time for male participants is lower than that for female participants, which may suggest faster completion times for males in this particular task.

Average Time by Age Group

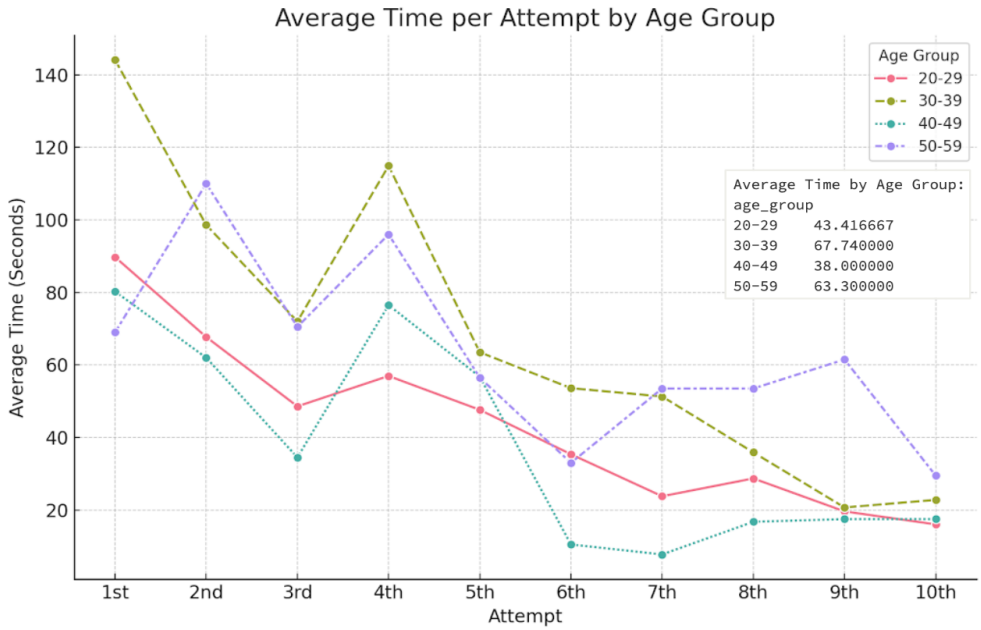

Figure 13: Scatter plot of the average time per attempt for different age groups.

The graph shows the following trends:

- The 20-29 age group starts with a lower average time, indicating quicker task completion, and shows a significant decrease in time by the second attempt, maintaining the quickest times throughout.
- The 30-39 age group begins with a higher average time, sees improvement by the third attempt, but then fluctuates, suggesting variable performance.
- Participants aged 40-49 have the best performance at the start, with the lowest time on the first attempt, but their time increases on subsequent attempts before decreasing and levelling out.
- The 50-59 age group shows a gradual decrease in average time, indicating a consistent improvement with each attempt, despite starting with higher times.
- According to the summary table, the 40-49 age group has the lowest overall average time, suggesting that this group was, on the whole, the fastest, despite fluctuations in individual attempts.

Average Time by Hand Dominance

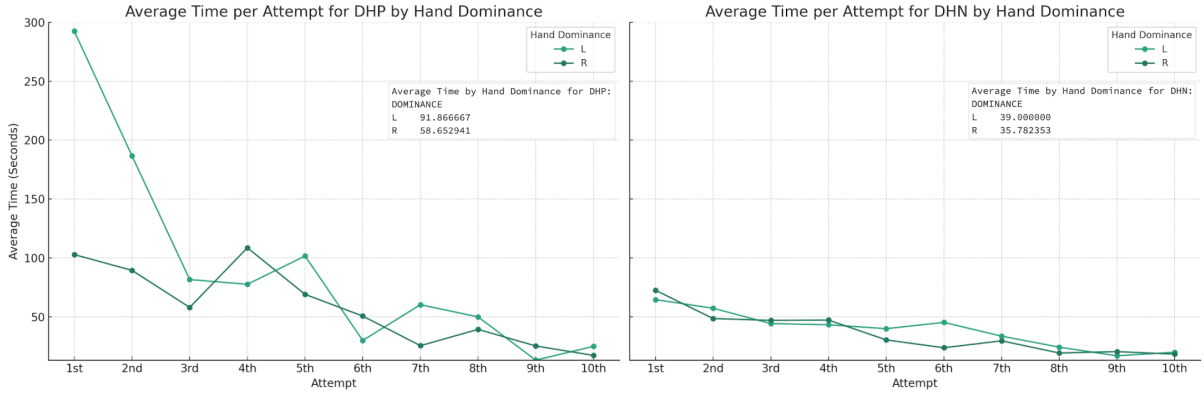

Figure 14: Scatter plots showing the average time per attempt for tasks with Dominant Hand Probe (DHP) versus Dominant Hand Needle (DHN) by hand dominance (left-hand L, right-hand R).

The graphs present a clear comparison between left- and right-hand dominant participants in their average completion times for tasks involving either a probe (DHP) or a needle (DHN):

- In the DHP task, right-hand dominant participants start with a significantly lower average time than left-hand dominant participants. Over the attempts, both groups show an overall decrease, but the right-hand dominant group consistently maintains a lower average time.
- For the DHN task, the times are closer between the hand dominance groups, with right-hand dominant participants again showing a slight edge in average time. Both groups demonstrate a downward trend, suggesting improvement with practice.
- The final average times across all attempts indicate that right-hand dominant participants are quicker on average for both DHP and DHN tasks.

Average Time by Subjective Hand Arrangement Preference

The graph below shows the following trends:

- Participants with a preference for DHN generally show a quicker average completion time across all attempts compared to those preferring DHP.
- Both groups improve their performance over time, with DHN showing a more pronounced and steady decline in average time, indicating a steeper learning curve or more efficient adaptation.
- The gap in average times between the two preferences narrows as the attempts progress, suggesting that with practice, the initial preference impact diminishes.
- The overall average time calculated across all attempts shows that participants with a DHN preference perform the task more quickly than those with a DHP preference.

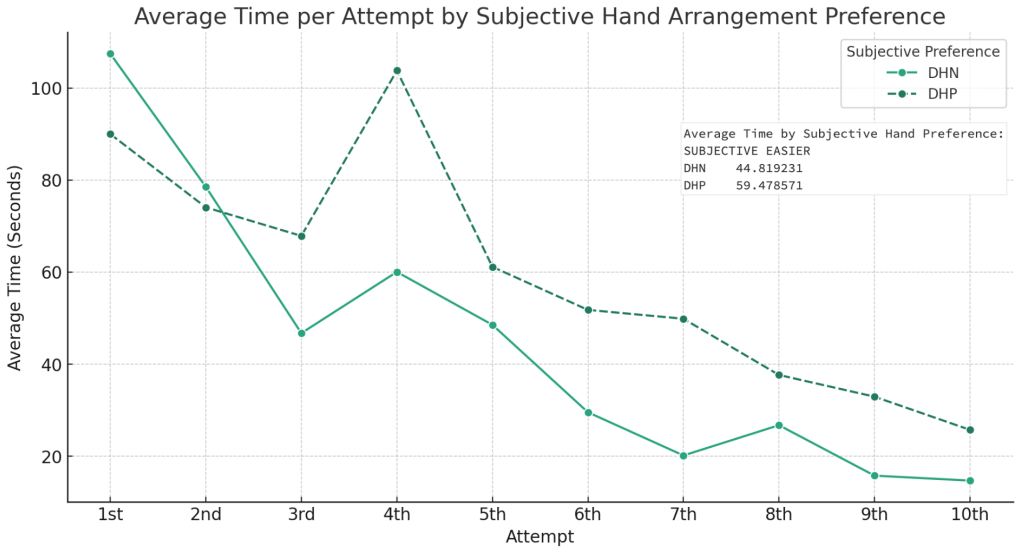

Figure 15: Scatter plot showing the average time per attempt according to the participants' subjective preference for using their dominant hand for the needle (DHN) or the probe (DHP).

The plot result is not a total indication that the Subjective Hand Arrangement is affecting the time performance of the task. Anyhow, we can see that DHN preference is associated with faster task completion in this instance too.

Learning Curve by Starting Hand Arrangement

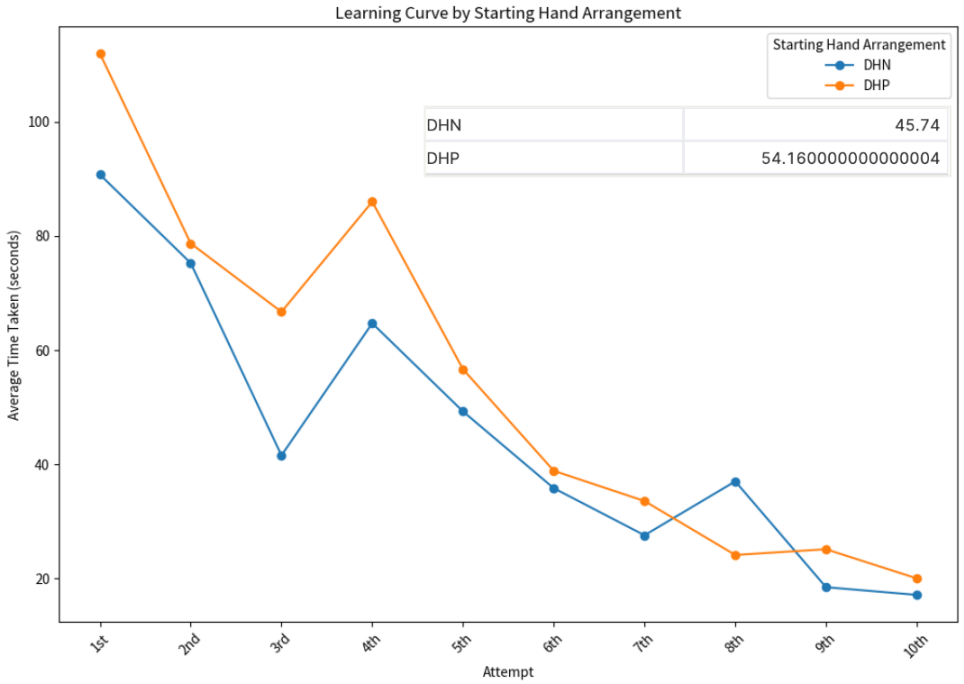

Figure 16: Scatter plot showing the learning curve for average time taken per attempt, comparing starting hand arrangements: Dominant Hand Needle (DHN) and Dominant Hand Probe (DHP).

- Both DHN and DHP groups show a significant decrease in the average time taken from the first to the second attempt, indicating a rapid adaptation to the task.
- The DHN group begins with a lower average time than the DHP group, suggesting initial quicker task completion when the dominant hand is used for the needle.

- Throughout the attempts, the DHN group maintains a generally lower average time than the DHP group, although the difference between the two decreases as participants gain more practice.
- Both groups show variability in performance, with some fluctuations in average time, but the overall trend for both is a downward slope, reflecting improvement over time.
- By the 10th attempt, the average times for both groups converge closely, with the DHP group showing a slight improvement over the DHN group in the final attempts.

Performance by Professional Background

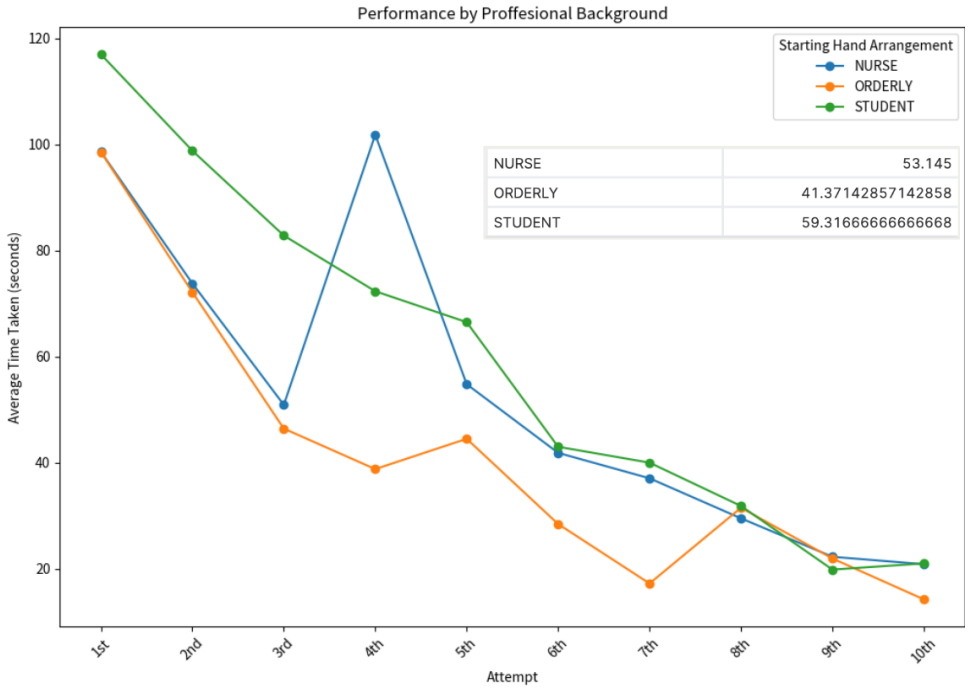

Figure 17: Scatter plot showing the average time taken per attempt, segmented by professional background: Nurse, Orderly, and Student.

The graph indicates the learning curve across ten attempts for different professional backgrounds:

- Orderlies have a relatively consistent performance with a gradual decrease in average time, with the lowest average time among the three groups.
- Students show a volatile performance with significant fluctuations in average time, potentially due to variability in familiarity with the tasks or learning styles.

These trends may reflect the difference in experience levels, with Nurses and Orderlies likely having more practical experience that translates into quicker task completion. The fluctuations in the Students' times suggest a steeper learning curve which stabilizes over time as they gain experience.

Distinctive Insights from Exploratory Data Analysis

The analysis of performance across various factors indicates the following:

1. **Dominant Hand Efficiency with Diminishing Discrepancy:** The data suggests that participants using their dominant hand for needle handling (DHN) consistently outperformed those using their dominant hand for the probe (DHP) in the initial attempts. However, this advantage becomes less pronounced with successive attempts. While initial observations across the majority of graphs lean towards a better performance by DHN considering all variables, the performance gap between DHN and DHP narrows as participants gain experience, which could imply that the initial hand preference advantage may be mitigated by practice and familiarity with the procedure. We want to build a model to see if there is an actual significant difference between DHP and DHN.

2. **Learning Curve and Performance Convergence:** A universal learning curve is evident, showing improvement in average completion times as the number of attempts increases. Despite initial performance differences that could be attributed to dominant hand preference, the average times of DHN and DHP tend to converge as participants continue to practice. By the 10th attempt, the learning curve for most participants leads to an approximate equalization of results. This suggests that while dominant hand preference impacts performance times in initial ultrasound-guided procedures, its influence may be largely a function of time, with practice playing a more substantial role in determining proficiency.

Building the Model

From the exploratory data analysis (EDA), we observed trends and patterns suggesting differences in performance between the two hand arrangements used in ultrasound-guided procedures: Dominant Hand Probe (DHP) and Dominant Hand Needle (DHN). However, to statistically find out the real difference between these two arrangements, it is crucial to consider the oher factors that might be influencing these differences.

Given the nature of our dataset, which includes repeated measures from the same participants across multiple attempts, the most suitable model for this analysis is a *mixed-effects model*. This model is particularly suitable because:

1. **Longitudinal Data Structure**: Our dataset consists of multiple time-point measurements from the same participants. This leads to a natural correlation within each participant's set of observations. Mixed-effects models are really good at handling such correlated data, which is a common characteristic of longitudinal or repeated-measures studies.

2. **Inclusion of Random Effects**: The mixed-effects model allows us to incorporate random effects, accounting for the individual variability among participants. This is crucial, as each participant's inherent ability, learning curve, and other unobserved factors (age, gender, background, subjective easier, etc) could significantly impact their performance. By including participants as random effects, the model can isolate the influence of the hand arrangements (fixed effects) from these individual differences.

3. **Assessment of Fixed Effects**: Our primary interest lies in comparing the DHP and DHN arrangements. Mixed-effects models enable the inclusion of these hand arrangements as fixed effects, allowing us to quantify their impact on performance while controlling the random effects.

Mixed-Effects Model Results and Analysis

```
Linear mixed model fit by REML. t-tests use Satterthwaite's method ['lmerModLmerTest']
Formula: Time ~ HANDS + (1 | PARTICIPANT)
   Data: data_long

REML criterion at convergence: 4388.8

Scaled residuals:
    Min      1Q  Median      3Q     Max
-1.5473 -0.5496 -0.2438  0.1515  6.2157

Random effects:
 Groups        Name        Variance Std.Dev.
 PARTICIPANT   (Intercept) 347.9    18.65
 Residual                  3322.9   57.64
Number of obs: 400, groups:  PARTICIPANT, 20

Fixed effects:
            Estimate Std. Error df t value Pr(>|t|)
(Intercept) 36.265   5.832      33.094 6.219 5.02e-07 ***
HANDSDHP    27.370   5.764      379.000 4.748 2.92e-06 ***
---
Signif. codes:  0 '***' 0.001 '***' 0.01 '**' 0.05 '*' 0.1 ' ' 1
```

```
Correlation of Fixed Effects:
            (Intr)
HANDSDHP    -0.494
```

Below is a summary of the mixed-effects linear model output analysis

Fixed Effects

- The Intercept (representing the average time for the reference group, presumably when HANDS is not DHP) is estimated at 36.265 seconds, with a standard error of 5.832 seconds. The t-value is 6.219, and the associated p-value is extremely small (5.02e-07), indicating that the intercept is significantly different from zero.
- The coefficient for HANDSDHP is 27.370 seconds with a standard error of 5.764 seconds. The t-value is 4.748, and the associated p-value is 2.92e-06, which is also extremely small. This provides strong evidence that the average time for attempts using the Dominant Hand Probe (DHP) is significantly longer than for the reference hand arrangement (DHN).

Random Effects

- The variance for the PARTICIPANT random intercept is 347.9, with a standard deviation of 18.65 seconds. This indicates substantial between-participant variability in the times for the procedures.
- The residual variance of 3322.9 and the standard deviation of 57.64 seconds tell us how much the procedure times vary from one attempt to another within the same person, after taking into account the type of hand arrangement used and the individual differences of the participants. The significant residual variance in our model indicates that there are additional factors influencing procedure times beyond hand arrangement and individual participant differences.

These results support the hypothesis that hand arrangement has a significant impact on the performance of ultrasound-guided procedures, with individual variability also playing a considerable role. There is enough statistical evidence to say that DHP is different from DHN.

Conclusion

The experiment was designed to investigate the effectiveness of two hand arrangements—Dominant Hand Probe (DHP) and Dominant Hand Needle (DHN)—during ultrasound-guided procedures. The data analysis revealed a consistent trend: procedures involving the DHP arrangement generally took longer to complete than those with the DHN arrangement. These findings are substantiated by significant statistical evidence from the mixed-effects modeling approach, affirming the impact of hand arrangement on procedural performance.

Visual data analysis through various graphs further supports this conclusion, showing a pattern of increased time required for the DHP group across several trials. The analysis also highlights the necessity of acknowledging individual differences when considering the efficacy of clinical procedures. The insights gained from this study provide a valuable perspective on optimizing hand arrangement to enhance the efficiency and effectiveness of medical practices.