OPER 688 Final Report

1. Recognition of and Statement of the Problem

A problem many amateur golfers deal with is their short game, particularly putting. One of the biggest differences between PGA Tour golfers and amateurs, like myself, is their ability to make mid-range putts. A 2019 Golf.com article states that PGA Tour players make roughly 52% of their putts from 8 feet. Anecdotally, I can tell you that amateurs fall well short of that mark. One thing you see on the Tour is a wide variety of putting techniques. What I would like to do is test some of those techniques and determine their influence on an amateur (myself) attempting 8 foot putts. The reasons for running this experiment include factor screen/characterization (which factors are important?) and optimization (what is the best combination of factors?).

2. Selection of the Response Variable

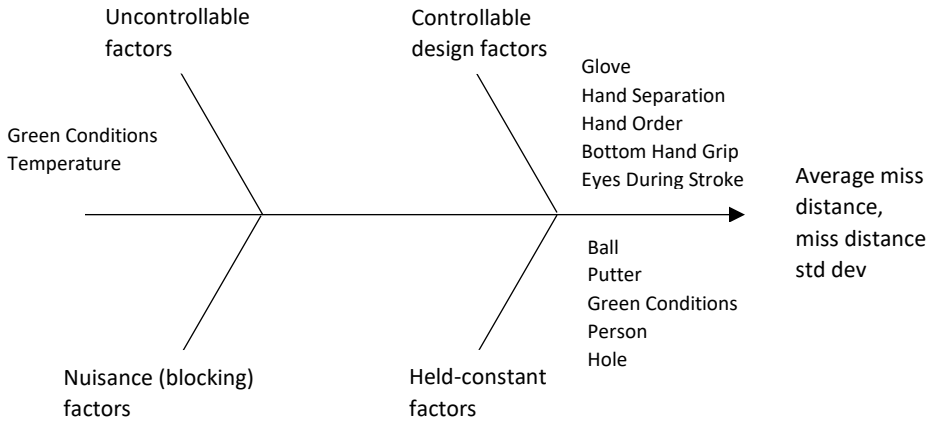
There are two response variables for this experiment. The first response variable is the Average Miss Distance of 5, 8-foot putts (5 repeated measures) per treatment combination per replication (measured in inches). The second response variable is the Miss Distance Standard Deviation per treatment combination per replication (inches).

3. Choice of Factors, Levels, and Range

The table below shows the five factors to be tested, as well as their respective levels (two each).

	Factor	Level
A	Glove	Off (-), On (+)
B	Hand Separation	Not Separated (-), Separated (+)
C	Hand Order	Standard (-), Reversed (+)
D	Bottom Hand Grip	Standard (-), Claw (+)
E	Eyes During Stroke	On Ball (-), On Cup (+)

Below is a cause-and-effect diagram for the experiment. I have categorized green conditions as both uncontrollable and held-constant factors. The reason for this is because I conducted all of the tests in one sitting. Because I ran all of the tests in a relatively small window of time, I am assuming that the green conditions are the same for all of the tests.



4. Choice of Experimental Design

A pilot study of trial runs was conducted in order to calculate the Anticipated RMSE for a power analysis. The pilot study consisted of 8 putt attempts each for 3 randomly selected treatment combinations (24 observations total). The putts were attempted from a relatively flat portion of the practice green. A point 8 feet from the hole was measured off and putts were attempted from there, all with the same ball. In order to minimize the "learning effect," a 10 minute warmup was conducted using various combinations of the factor levels.

The standard deviation of those observations was 6.848 inches. Since the study will be conducted using 5 repeated measures, the Anticipated RMSE is equal to $\frac{6.848}{\sqrt{5}} = 3.063$. The difference in response I would like to detect due to a change in a factor (δ) is 6 inches. In order to estimate all of the 2 factor interactions, as well as the main effects, the initial design was a Resolution V Fractional Factorial (0 replications). At a significance level of 0.05, the power for this design is 0.241. In order to increase the power of the analysis, the design was augmented with 1 replication. At a significance level of 0.05, the power for this design is 0.999. The JMP data table for the final design is attached.

5. Performing the Experiment

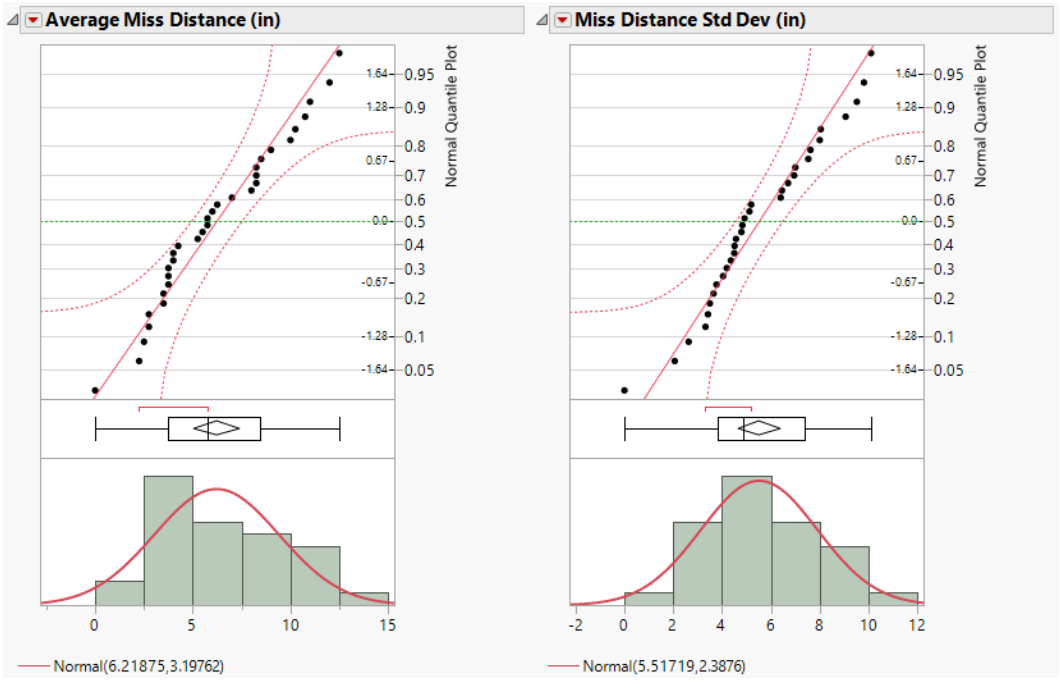
The experiment was conducted using the same method as the pilot study. A relatively flat portion of the practice green was selected, and a point 8 feet from the hole was measured off. After a 10 minute warmup, putts were attempted from that point using the same ball. After each attempt, the distance from the center of the hole to the ball was recorded (miss distance in inches). In order to reduce the effects of changing green conditions, all putts were attempted in one sitting.

6. Statistical Analysis of the Data

The data was imported into JMP, where a first-order model with interaction terms was used to describe the results. The responses that were modeled were the Average Miss Distance (inches) and the Miss Distance Standard Deviation (inches). Upon initial inspection, it was noted that two outliers were present in the Standard Deviation data. After investigating the outliers, it was determined that the data points made up by the first repeated measures were skewing the overall Average Miss Distance data as well as the Standard Deviation data.

Because it is the goal of this study to determine the effectiveness of different putting techniques as used in an 18-hole round of golf, it was decided to remove the data points that make up the first repeated measure for each experimental run. In a practical sense, this can be thought of as removing the variability in putting that would normally be eliminated by warming up. Now that only 4 repeated measures are being used, the new Anticipated RMSE is equal to 3.424, resulting in a power of 0.996.

Normality was checked by analyzing the distributions of both the Average Miss Distance data as well as the Miss Distance Standard Deviation data. The Normal Quantile Plots, Histograms, Box Plots, and Goodness-of-Fit Test Results for both data sets can be found below. Both data sets appear to be normal, therefore there is no need for transformations.



Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.960113	0.2766

Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.

Goodness-of-Fit Test

Shapiro-Wilk W Test

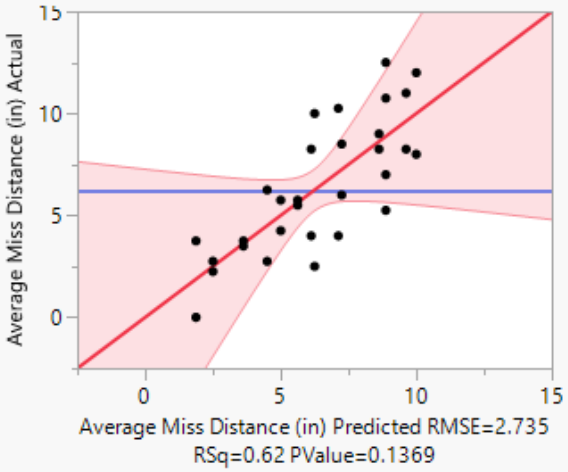
W	Prob<W
0.968054	0.4475

Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.

Below is the Actual by Predicted Plot, as well as the Effect Summary for the full Average Miss Distance Model.

Response Average Miss Distance (in)

Actual by Predicted Plot



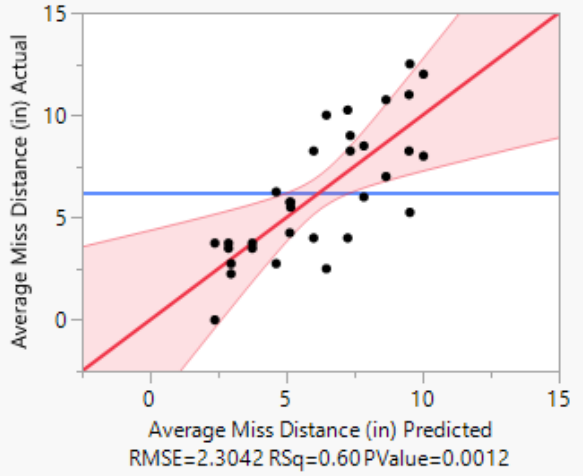
Effect Summary

Source	LogWorth	PValue
Glove*Eyes During Stroke	2.047	0.00897
Hand Separation*Eyes During Stroke	1.448	0.03563
Eyes During Stroke	1.312	0.04877 ^
Bottom Hand Grip	1.258	0.05518
Glove*Bottom Hand Grip	0.853	0.14040
Hand Order*Eyes During Stroke	0.229	0.59033
Hand Order*Bottom Hand Grip	0.198	0.63442
Hand Separation*Bottom Hand Grip	0.168	0.67999
Hand Separation*Hand Order	0.125	0.75075
Bottom Hand Grip*Eyes During Stroke	0.125	0.75075
Hand Order	0.084	0.82390 ^
Glove*Hand Separation	0.084	0.82390
Glove*Hand Order	0.034	0.92397
Hand Separation	0.011	0.97462 ^
Glove	0.000	1.00000 ^

The model was reduced so that only the significant ($\alpha = 0.05$) factors and interactions remained. The Actual by Predicted Plot, Effect Summary, Summary of Fit, and Analysis of Variance for the reduced Average Miss Distance Model can be found below. Eyes During Stroke, Bottom Hand Grip, Glove*Eyes During Stroke, Hand Separation*Eyes During Stroke, and Glove*Bottom Hand Grip were determined to be significant. Hand Separation and Glove were included in the reduced Average Miss Distance Model in order to maintain hierarchy. The model has an R^2 of 0.60 and a P Value of 0.0012.

Response Average Miss Distance (in)

Actual by Predicted Plot



Effect Summary

Source	LogWorth	PValue	
Glove*Eyes During Stroke	2.766	0.00171	
Hand Separation*Eyes During Stroke	1.926	0.01185	
Eyes During Stroke	1.737	0.01831	^
Bottom Hand Grip	1.663	0.02172	
Glove*Bottom Hand Grip	1.108	0.07797	
Hand Separation	0.013	0.96972	^
Glove	0.000	1.00000	^

Summary of Fit

RSquare	0.597999
RSquare Adj	0.480748
Root Mean Square Error	2.30418
Mean of Response	6.21875
Observations (or Sum Wgts)	32

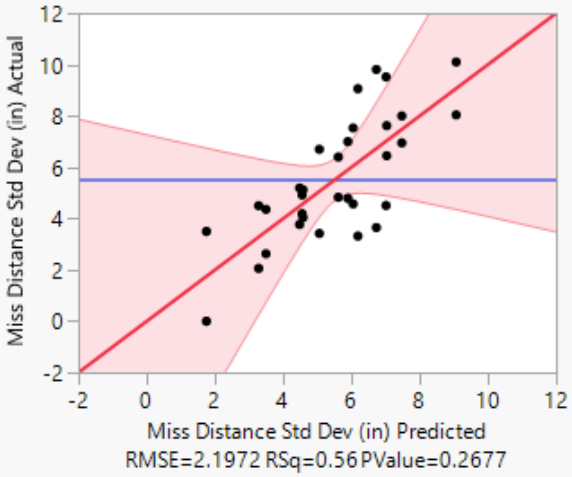
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	189.54688	27.0781	5.1002
Error	24	127.42188	5.3092	Prob > F
C. Total	31	316.96875		0.0012*

Below is the Actual by Predicted Plot, as well as the Effect Summary for the full Miss Standard Deviation Model.

Response Miss Distance Std Dev (in)

Actual by Predicted Plot



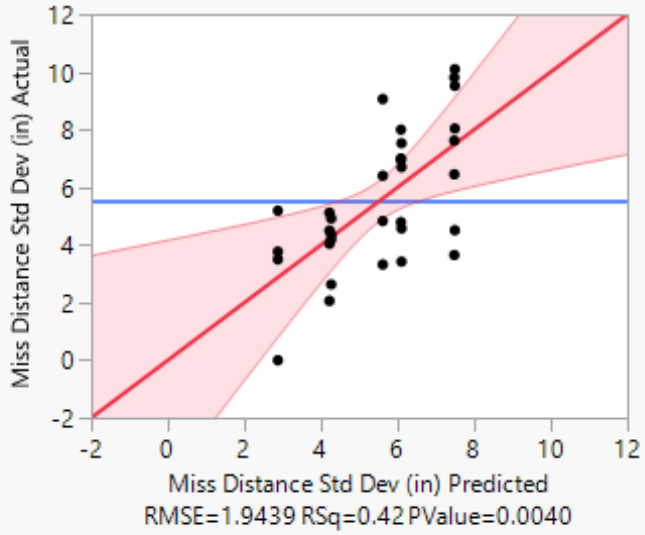
Effect Summary

Source	LogWorth	PValue	
Glove*Eyes During Stroke	2.327	0.00471	
Bottom Hand Grip	1.036	0.09211	
Hand Separation*Eyes During Stroke	0.607	0.24716	
Bottom Hand Grip*Eyes During Stroke	0.528	0.29663	
Eyes During Stroke	0.405	0.39391	^
Glove	0.393	0.40418	^
Hand Order*Eyes During Stroke	0.392	0.40505	
Hand Order	0.321	0.47707	^
Hand Separation*Bottom Hand Grip	0.286	0.51731	
Hand Separation	0.267	0.54070	^
Glove*Bottom Hand Grip	0.156	0.69804	
Hand Order*Bottom Hand Grip	0.141	0.72265	
Glove*Hand Order	0.109	0.77884	
Glove*Hand Separation	0.095	0.80438	
Hand Separation*Hand Order	0.022	0.95011	

The model was reduced so that only the significant ($\alpha = 0.05$) factors and interactions remained. The Actual by Predicted Plot, Effect Summary, Summary of Fit, and Analysis of Variance for the reduced Miss Standard Deviation Model can be found below. Bottom Hand Grip and Glove*Eyes During Stroke were determined to be significant. Eyes During Stroke and Glove were included in the reduced Miss Standard Deviation Model in order to maintain hierarchy. The model has an R^2 of 0.42 and a P Value of 0.0040.

Response Miss Distance Std Dev (in)

Actual by Predicted Plot



Effect Summary

Source	LogWorth	PValue
Glove*Eyes During Stroke	3.020	0.00095
Bottom Hand Grip	1.277	0.05284
Eyes During Stroke	0.480	0.33081 ^
Glove	0.467	0.34139 ^

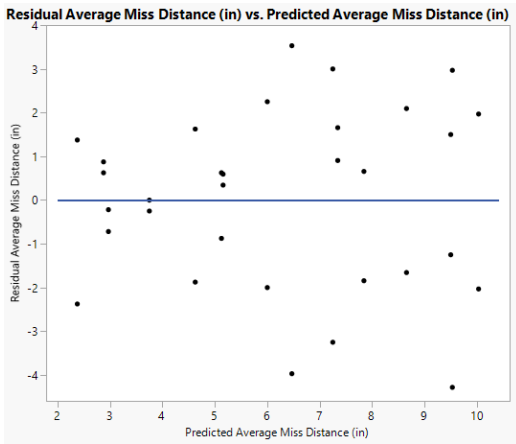
Summary of Fit

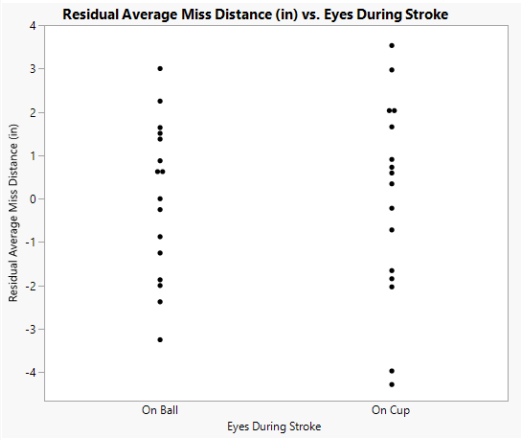
RSquare	0.422662
RSquare Adj	0.33713
Root Mean Square Error	1.943907
Mean of Response	5.517188
Observations (or Sum Wgts)	32

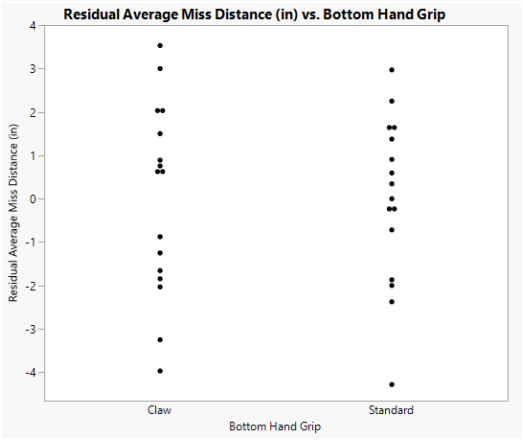
Analysis of Variance

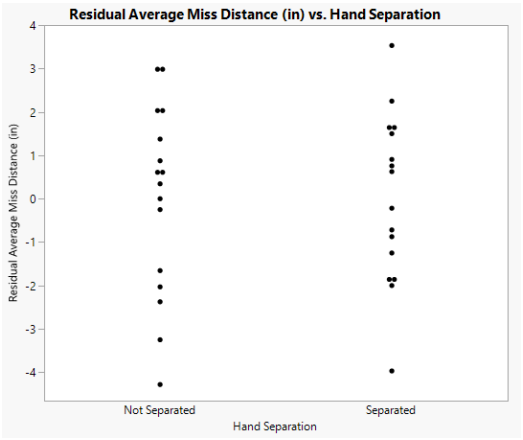
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	74.69251	18.6731	4.9416
Error	27	102.02693	3.7788	Prob > F
C. Total	31	176.71945		0.0040*

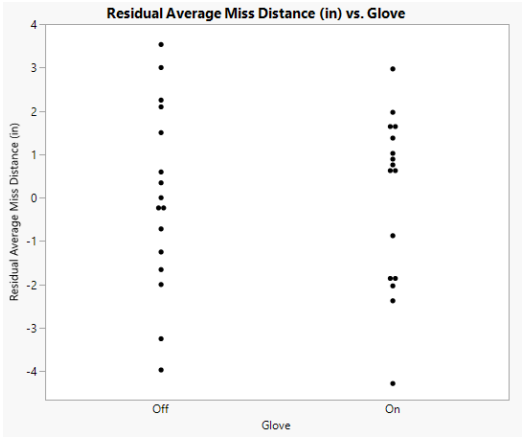
In addition to being normally distributed (assumption checked above), these data are also assumed to have constant variance.

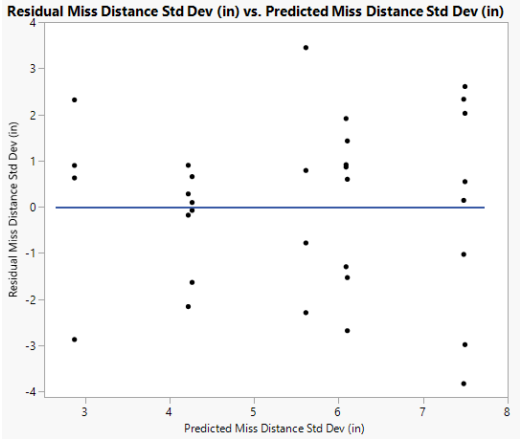


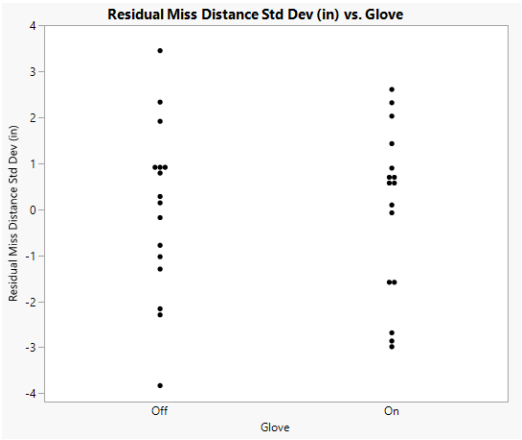






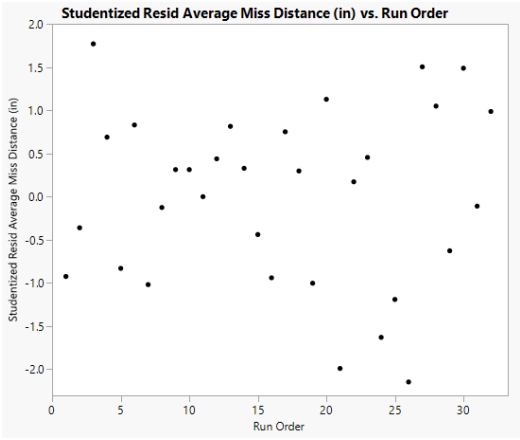


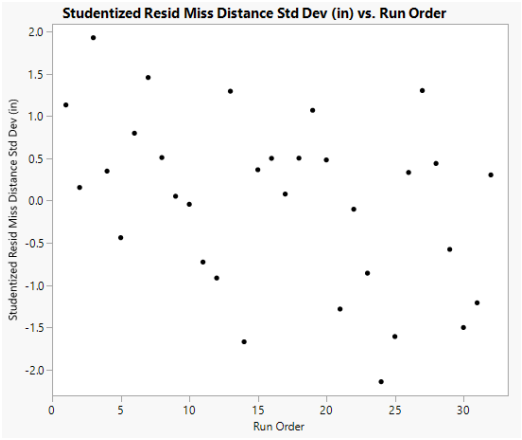




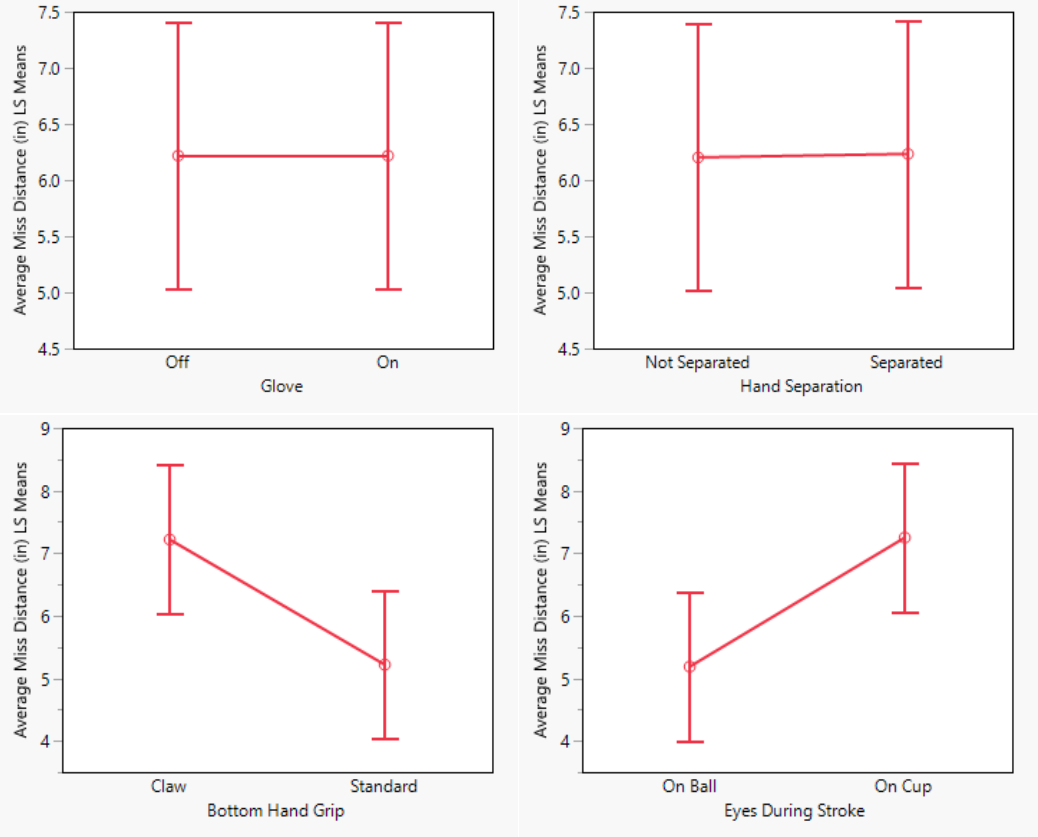
Based on the plots above, it appears that the constant variance assumption has been reasonably satisfied for both data sets (Average Miss Distance and Miss Distance Standard Deviation).

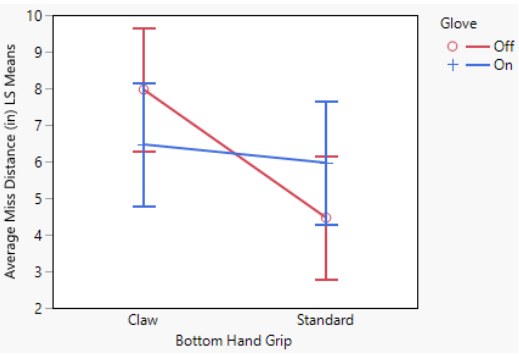
It is also important to ensure that the responses are independent of run order. Below are the studentized residuals for both data sets plotted against the run order. There does not appear to be an overt relationship between the studentized residuals and the run order.

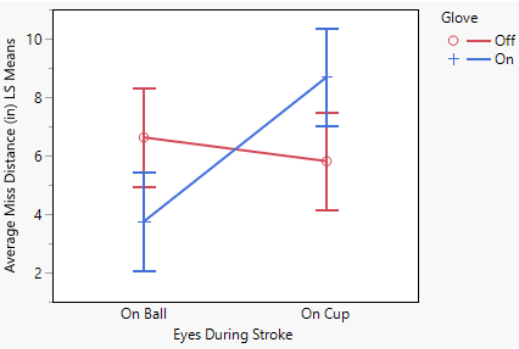


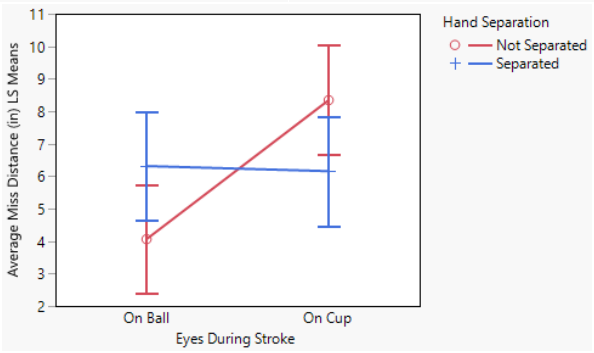


Below are the Least Squares Means Plots for the factors and significant interactions that were included in the reduced Average Miss Distance Model. Examining these plots, it is clear that on their own, Glove and Hand Separation have little to no effect on Average Miss Distance. However, Glove and Hand Separation do appear to be components in several interactions that are statistically significant.

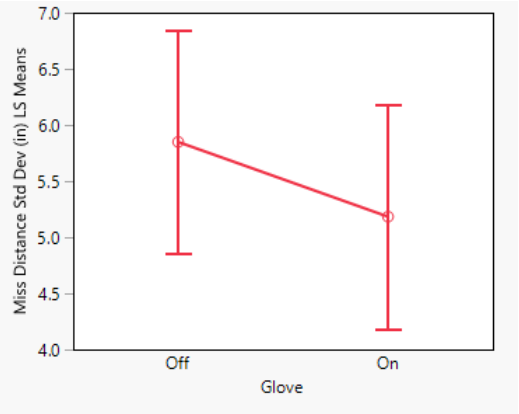


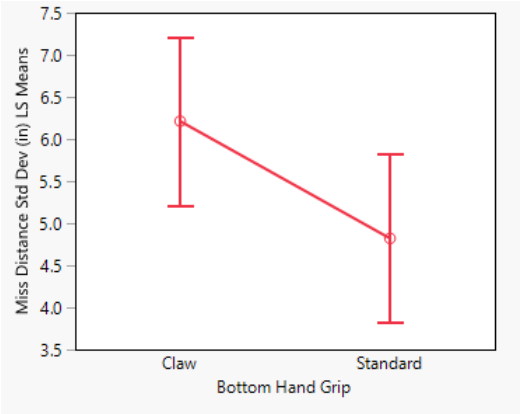


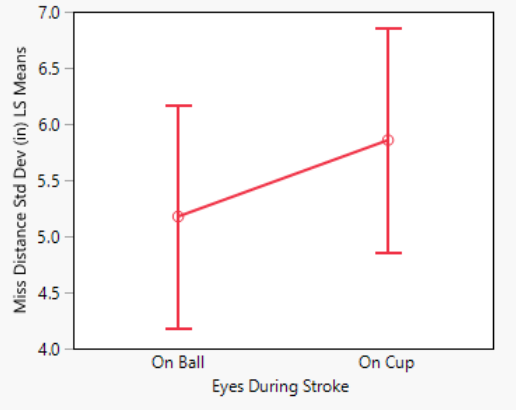


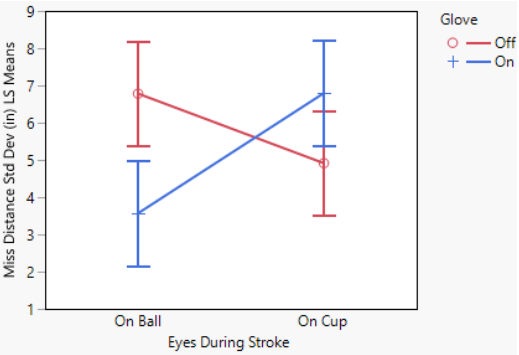


Below are the Least Squares Means Plots for the factors and significant interactions that were included in the reduced Miss Distance Standard Deviation Model. Although the individual factors do not appear to have an overtly significant effect (Bottom Hand Grip does have a P Value of 0.05284), it is clear that the Eyes During Stroke*Glove interaction significantly affects the Miss Distance Standard Deviation.

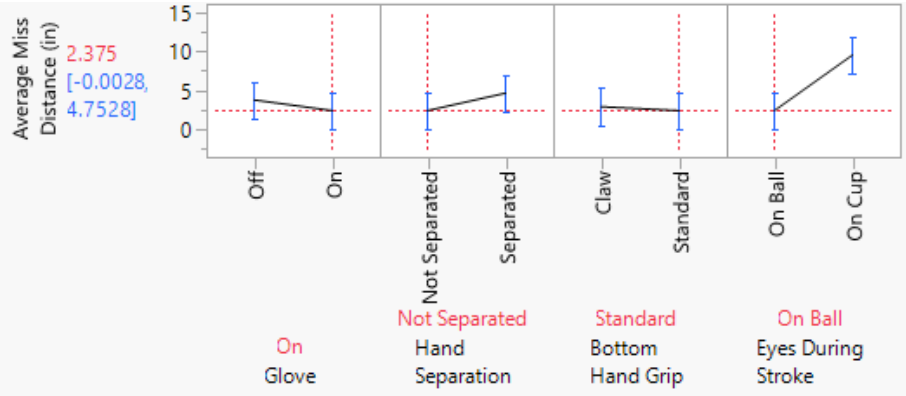




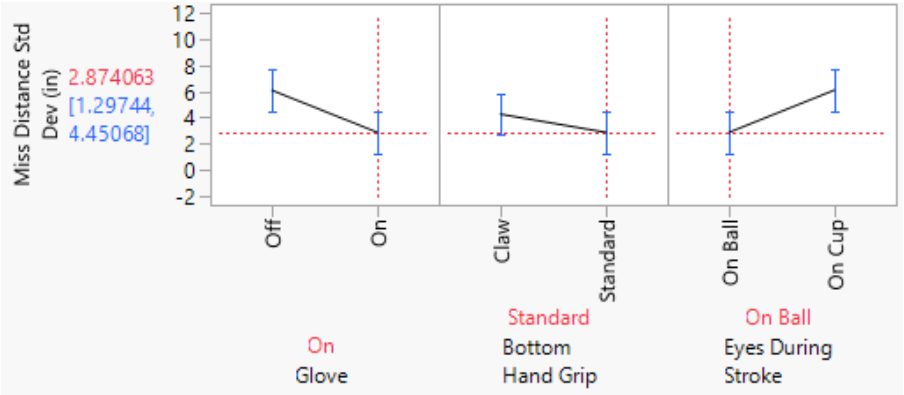

7.0
6.5
6.0
5.5
5.0
4.5
4.0
Miss Distance Std Dev (in) LS Means
On Ball
On Cup
Eyes During Stroke


9
8
7
6
5
4
3
2
1
Miss Distance Std Dev (in) LS Means
On Ball
On Cup
Eyes During Stroke
Glove
Off
On

Below are the Prediction Profilers showing the combinations that result in the minimum Average Miss Distance and the minimum Miss Distance Standard Deviation. The top four factor combinations for each response can be found below as well.



Glove	Hand Separation	Bottom Hand Grip	Eyes During Stroke	Predicted Response (Miss)	95% CI Lower	95% CI Upper
On	Not Separated	Standard	On Ball	2.4	0.0	4.8
On	Not Separated	Claw	On Ball	2.9	0.5	5.3
Off	Separated	Standard	On Cup	3.0	0.6	5.3
Off	Not Separated	Standard	On Ball	3.8	1.4	6.1



Glove	Bottom Hand Grip	Eyes During Stroke	Predicted Response (Std Dev)	95% CI Lower	95% CI Upper
On	Standard	On Ball	2.9	1.3	4.5
Off	Standard	On Cup	4.2	2.6	5.8
On	Claw	On Ball	4.3	2.7	5.8
Off	Standard	On Ball	6.1	4.5	7.7

7. Conclusions and Recommendations

It is important to point out that putting and putting techniques are very specific to individual golfers. In other words, the technique that works best for me could be terrible for you. Therefore, the conclusions and recommendations to follow should not necessarily be viewed as being applicable to all golfers. Instead, they should be viewed as general guidelines focused on a specific individual (me).

It is clear that Eyes During Stroke is the factor with the greatest effect on the Average Miss Distance. In general, for the best results, no matter what levels are chosen for the other factors, the eyes should always be on the ball during the stroke.

Bottom Hand Grip had the second largest effect, as a single factor, on the Average Miss Distance. Bottom Hand Grip was also the factor with the greatest effect on the Miss Distance Standard Deviation. For best results, a standard grip should be used instead of a claw.

The other factors, Glove, Hand Separation, and Hand Order, as well as the significant interactions had effects that were not so intuitive. While some of the interactions were statistically significant, it is not necessarily true that they are practically significant. For example, within 6 inches, being an extra inch closer to the hole probably will not make much of a difference in the success rate of the following tap-in putt. Additionally, it is worth noting that the standard golf hole radius is 2.125 inches. Therefore, predicted Average Miss Distances that are less than or equal to 2.125 inches can be thought of as being practically the same as a miss distance of 0 inches (a made putt).

Taking all of this into account, it is recommended to have eyes on the ball during the stroke and to employ a standard bottom hand grip. For the other three factors, it is best to choose levels that are most comfortable. One of the most important, but hard to quantify aspects of the game of golf is the mental aspect. A round of golf with great putting still has a golfer attempting close to 30 putts. Being comfortable and at ease during those 30 putts goes a long way in lowering your score.

Moving forward I will putt with the following factor levels:

Eyes During Stroke	Bottom Hand Grip	Glove	Hand Separation	Hand Order
On Ball	Standard	Off	No Separation	Standard