September 26, 2017
From: Shanglun Li, Caihui Xiao, Kiera Murphy
To: Royal National Hospital for Rheumatic Diseases in Bath
Re: Ankylosing Spondylitis

ANKYLOSING SPONDYLITIS AND THE BENEFIT OF STRETCHING EXERCISES

Abstract. This project used linear mixed effects model to analyze if doing additional daily stretch exercises of tissues around the hip joints would help patients with Ankylosing Spondylitis (AS) to get more movement in their hip joints.

Contents

1. Project Description

The Royal National Hospital for Rheumatic Diseases in Bath, England conducted a study to see if daily stretching of tissues around the hip joints would help patients with Ankylosing Spondylitis (AS) to get more movement in their hip joints. Ankylosing Spondylitis is a form of arthritis which limits the motion of the spine and muscles, which affects 1.3% of the population. It is an incurable, painful disease which usually affects people between the ages of 17- 45.

How the data was collected and reviewed: The Royal National Hospital for Rheumatic Diseases surveyed 39 consecutive patients with 'typical' Ankylosing

Spondylitis and randomly assigned 12 to the control group, and 27 to the treatment group. The control group received the standard stretching routine, and the treatment group received additional stretching exercises. The 39 patients were then measured on the day of admission into the study, and three week later they reported back to the hospital and were measured again. The hospital measured the extent of flexion, and lateral rotation (in degrees) of the hips of the subjects. Although Ankylosing Spondylitis primarily affects the spine, this study focused on the hip joints, which also can be affected by Ankylosing Spondylitis. Measuring improvements in the hip joints is much easier than measuring improvements in the spine. They measured left hips and right hips individually. The degrees range from 0-180 degrees, 0 being no stretch at all, and 180 being completely stretched. An increase in degree represents an improvement in stretching ability.

What was asked of us: The client provided raw data from the samples of patients and they requested we analyze the data to provide answers to their research questions and statistical questions which can be viewed in the next sections 1.1 and 1.2. The results will be beneficial for the hospital to use proper exercises to relief the sickness of Ankylosing Spondylitis patients.

1.1. Research Questions.

The client is targeting the following research questions:

- **Q1:** Has the stretched group improved significantly more than the control group?

1.2. Statistical Questions.

To answer the client's research question, we investigated the following statistical question:

- **Q1:** Does treatment group influence the improvement of hip flexion degree more than control group?
- **Q2:** Does treatment group influence the improvement of hip rotation degree more than control group?

1.3. Variables of Interest.

After being imported from NotePad to Microsoft Excel, the data has been modified by rearranging the variables; patients, the treatment group (stretching exercises or not), left or right hip, the rotation degree before and after three week period, the improvement of rotation degree during the three week period (by taking difference of the rotation degree before and after the three week period), the flexion degree before and after the three week period, and the improvement of flexion degree during the three week period (by taking difference of the flexion degree before and after the three week period), which we named Subject, Stretch, Hip, Before_Rotation, After_Rotation, Diff_Rotation, Before_Flexion, After_Flexion, and Diff_Flexion, respectively (For more detailed description of variables, refer to the table below). According to the client's interest, the explanatory variables used in our analysis were the treatment level, different individual subjects, left and right hip, the improvement of flexion degree before and after the three week period, and the improvement of rotation degree before and after the three week period were used as the response variables (see Appendix A for raw and modified data set). Table 1 provides the name and a brief description of each variable in two data sets that were created, including the associated levels and the type and usage of the variables in the future analysis (Refer to explanations in Section 2 and 3).

Variable Attributes

Variable	**Description**	**Levels**	**Comments**
Subject	Represents different patients in this study	No.1-39	Explanatory variable; Random effect
Stretch	Represents if the patient did the stretching exercise during the three week period	C - control group; T - treatment group	Explanatory variable; Fixed effect
Hip	Represents the observation is on the left hip or right hip	L - left hip; R - right hip	Explanatory variable; Replicates
Before_Flexion	The flexion degree of hip before the three week period	Range from 0 to 180	
Before_Rotation	The rotation degree of hip before the three week period	Range from 0 to 180	Used for descriptive statistics
Before_Flexion	The flexion degree of hip after the three week period	Range from 0 to 180	Used for descriptive statistics
Before_Rotation	The rotation degree of hip after the three week period	Range from 0 to 180	Used for descriptive statistics
Diff_Flexion	The improvement of flexion degree of hip during the three week period	Range from -180 to 180	Response variable
Diff_Rotation	The improvement of rotation degree of hip during the three week period	Range from -180 to 180	Response variable

Table 1: *The table includes the name, description, levels, comments for each variable. Explanatory variable, response variable, and variable type are noted in the comments.*

2. Exploratory Data Analysis (EDA)

The data was reviewed and modified prior to the statistical analysis followed by the procedure stated in the former section (see Appendix A for modified data set). There were no notable errors or missing values. We looked at the descriptive statistics of some variables with respect to the whole sample and some variables with respect to treatment groups that were meaningful, shown in Table 2 (Refer to Appendix B for SAS code with output) and Table 3, respectively (Refer to Appendix C for manipulation procedure to get the statistics in Table 3 using Excel).

Descriptive Statistics for Variables with respect to the Whole Sample

Variable	N	Mean	Standard Deviation	Minimum	Maximum
Before_Rotation	78	24.84615	8.76842	2.0	48.0
After_Rotation	78	29.70513	9.13124	2.0	50.0
Diff_Rotation	78	4.85897	6.50619	-9.0	22.0
Before_Flexion	78	114.48718	11.83846	77.0	135.0
After_Flexion	78	120.83333	10.07171	88.0	139.0
Diff_Flexion	78	6.34615	9.18614	-11.0	49.0

Table 2: *The table displays some variables with respect to the whole sample that were meaningful to include. There were a total of 78 observations across the study. The table also displays additional information pertaining to the mean, standard deviation, maximum and minimum for each variable.*

As shown in Table 2, there exists some extreme values in our dataset that should be taken care of in future analysis.

Descriptive Statistics for Variables with respect to treatment group

Variable	N	Mean	Standard Deviation	Minimum	Maximum
Difference_Flexion _Control	24	3.7916	6.70186	-5.0	11.0
Difference_Flexion _Treatment	54	7.4815	9.80692	-11.0	49.0
Difference_Rotation _Control	24	0.9583	4.99566	-9.0	16.0
Difference_Rotation _Treatment	54	6.5926	6.28496	-8.0	22.0

Table 3: *The table displays some variables with respect to treatment groups that were meaningful to include. There was a total of 24 observations for the control group. There was a total of 54 observations for the treatment group. The table also displays additional information pertaining to the mean, standard deviation, maximum and minimum for each variable.*

In Table 3, Difference_Flexion_Control is the difference of hip flexion degrees before and after the three week period in the control group. Difference_Flexion_Treatment is the difference of hip flexion degrees before and after the three week period in the treatment group. Difference_Rotation_Control is the difference of hip rotation degrees before and after the three week period in the control group. Difference_Rotation_Treatment is the difference of hip rotation degrees before and after the three week period in the treatment group.

We explored the difference in the before and after measurements of rotation and flexion for different hips from table 3. Means of the difference of hip flexion/rotation degrees during the three week period in the treatment group are more than the means of the difference of hip flexion/rotation degrees during the three week period in the control group. It appears that because of the treatment, flexion and rotation might have improved.

Next, we looked at the boxplot of improvement of hip rotation degrees in each stretch group and improvement of hip flexion degrees in each stretch group, as shown in Figure 1 and Figure 2. It is notable that from the boxplots, the spreads of the improvement of hip rotation degrees in the treatment group and the control group are roughly the same. The hip flexion degrees in the treatment group and the control group are roughly the same. In addition, the mean difference of hip flexion/rotation degrees in the treatment group is larger than the mean difference of hip flexion/rotation degrees in the control group. It appears that the extra stretching exercises that the treatment grouped received may have influenced the improvement of hip flexion and rotation more than control group. We will further discuss this in the Statistical Analysis section later on.

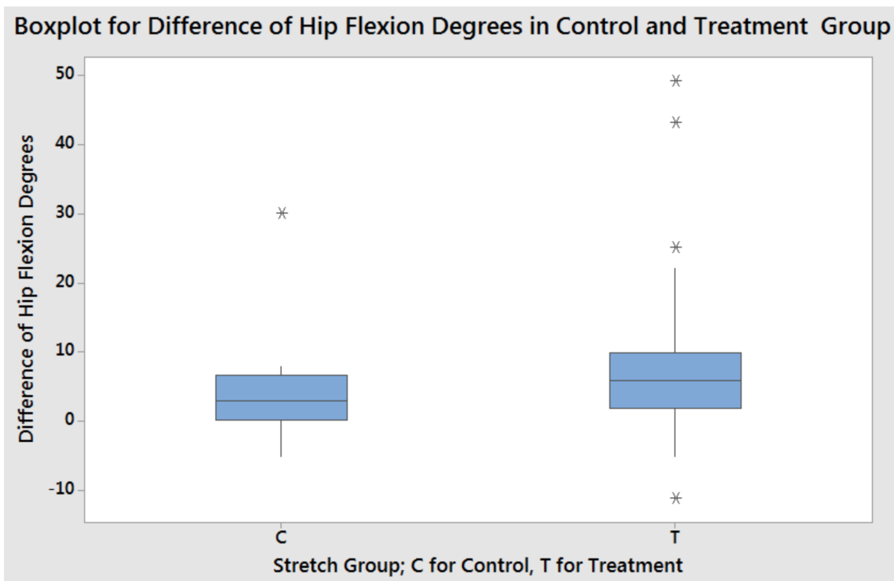

Figure 1. *Boxplot for difference of hip flexion degrees in control and treatment group generated in Minitab.*

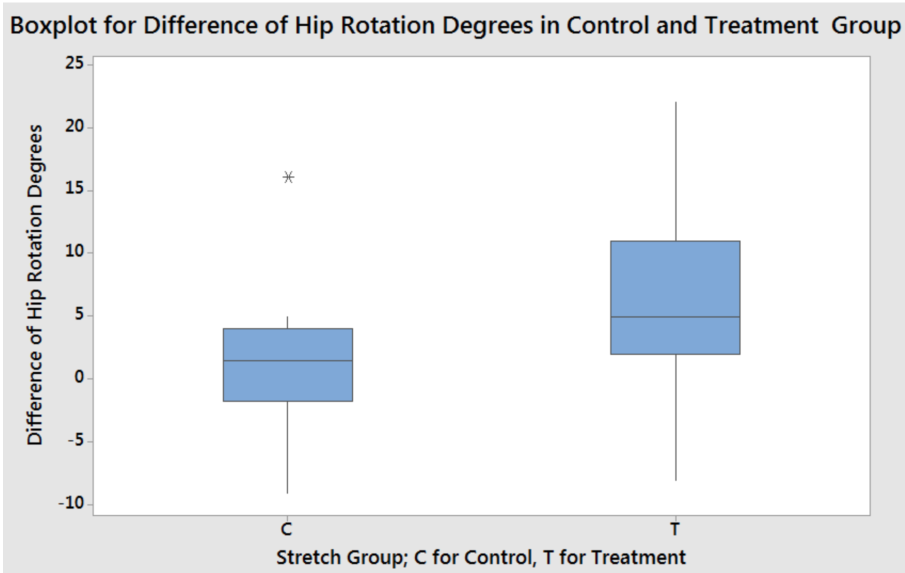

Figure 2. *Boxplot for difference of hip rotation degrees in control and treatment group generated in Minitab.*

Then, we looked at the boxplot of improvement of hip rotation degrees in each hip (left and right) and improvement of hip flexion degrees in each hip, as shown in Figure 3 and Figure 4. The left hip and right hip did not seem to have an influence on the improvement of the flexion/rotation degrees. Thus, we would treat them as simply replicates in the data set.

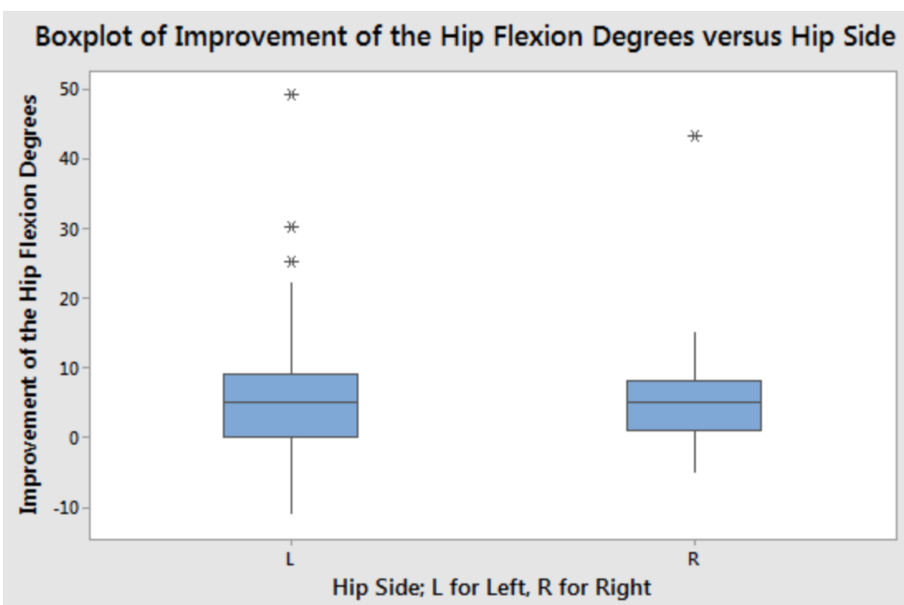

Figure 3. *Boxplot for difference of hip flexion degrees in left and right hip groups generated in Minitab.*

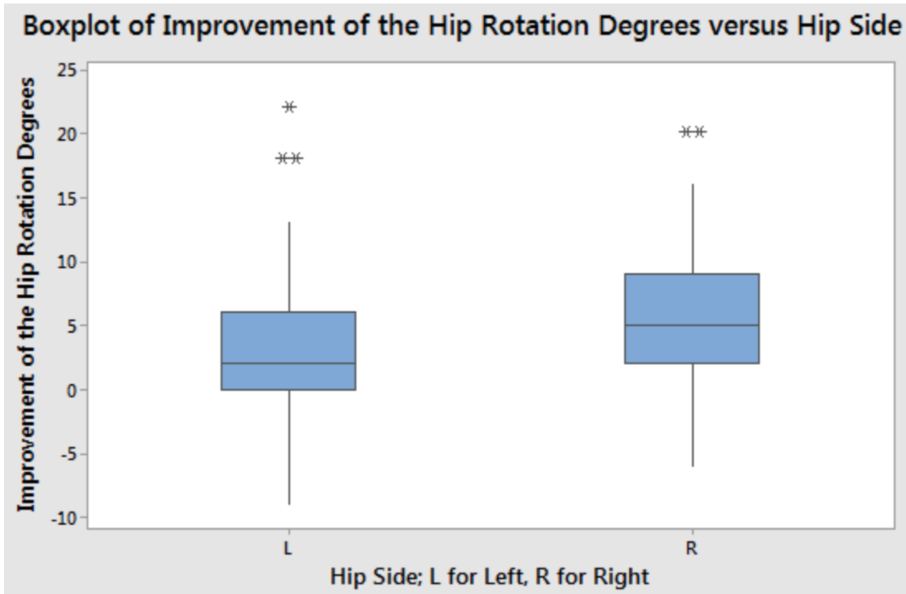

Figure 4. *Boxplot for difference of hip rotation degrees in left and right hip groups generated in Minitab.*

Then, we drew the scatterplot for the improvement of hip flexion degrees versus the improvement of hip rotation degrees using Minitab, as shown in Figure 5. No strong relationship between the two variables was found in the plot. Thus, we might consider that there is no correlation between the improvement of hip flexion degrees and the improvement of hip rotation degrees. This means that if we can prove this statistically, we could use two separate models to analyze the data later on.

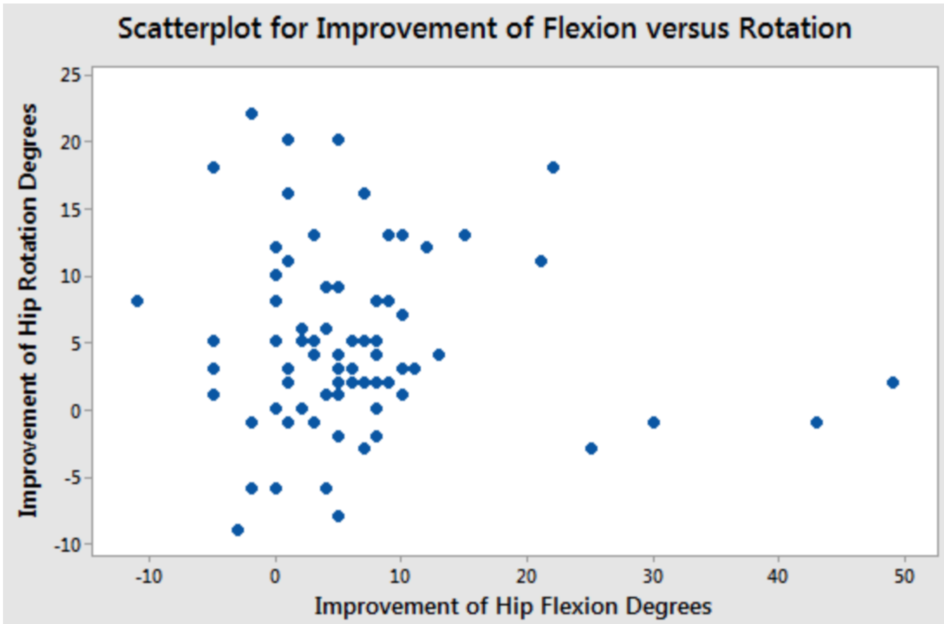

Figure 5. *Scatterplot for the improvement of hip flexion degrees versus the improvement of hip rotation degrees generated in Minitab.*

3. Statistical Analysis

To answer the clients' question, as stated in section 2, we want to first test the correlation between the improvement of hip rotation degrees and the improvement of hip flexion degrees. After we conduct the Fisher's test, which is an appropriate test to see if two variables are correlated, we found that the p-value of the test is greater than 0.05, which implies that there is no significant correlation between the improvement of hip rotation degrees and the improvement of hip flexion degrees. P-value is the probability that for a given test, when the null hypothesis is true, the statistical summary (in this case, the correlation between two improvement variables) would equal to a specific value (zero in this case), and the generally accepted cut-off value is 0.05. Thus, two separate mixed effect models with difference of hip flexion degrees and difference of hip rotation degrees as response variables were used in the study. The linear mixed effects model is a model to test whether there exists an effect of the treatment variable on the response variable, taking both fixed and random effects into consideration. In the study, subject appeared to be the random effect, since the variation of the improvement of flexion/rotation degrees differs from patient to patient; we want to take this variation into account. On the other hand, the stretching treatment group was considered to be the fixed effect, since that is the variable we want to investigate the effect on the improvement of flexion and rotation degrees. In addition, the pre-measurement of the flexion and rotation degrees were taken into consideration in the model and treated as a fixed effect, since we have a limited range of movement, which will make the model more precise. Therefore, the stretch treatment factor (Stretch), patients (Subject), and the hip flexion degrees before the three week period (Before_Flexion) were determined to be the explanatory variables, and the improvement of hip flexion degrees (Diff_Flexion) was treated as the response variable in the first model. In the second model, the stretch treatment factor (Stretch), patients (Subject), and the hip rotation degree before the three week period (Before_Rotation) were determined to be the explanatory variables with the improvement of hip rotation degrees (Diff_Rotation) as the response variable (See Appendix D for assumption check).

Since there is no universal way to calculate the p-value in the linear mixed effects model, the comparison between the models with and without the stretching treatment group variable was applied to both models to figure out the significance of the stretching treatment group variable (See Appendix E for R code and output). According to the comparison output in both rotation and flexion models, the models including stretching treatment group variable as the explanatory variable appeared to be the better models. Thus, the stretching treatment group variable has been proven to be the significant factor in this study, which means the influence of stretch variable is not likely to occur by chance.

After fitted the model and did the summary, Table 4 and 5 shown below had been generated:

Statistical Summary for Model 1

Parameter	**Coefficient**	**Standard Error**
Intercept	64.82090	8.29816
Pre-measurement of hip flexion degrees	-0.55502	0.07356
Stretching treatment group	7.32058	2.27623

Table 4: *The table displays the coefficient of parameters in model 1 in the R summary output that were meaningful to include. The table also displays additional information pertaining to the standard error for each variable.*

In the table, the coefficient for the intercept is 64.82090, which implies that the expected improvement of hip flexion degrees is 64.82090 when the pre-measurement of hip flexion degree is 0 and the patient does not have the stretching treatment. The coefficient for the pre-measurement of hip flexion degrees is -0.55502, which implies that when fixing other variables, the improvement of hip flexion degrees will decrease 0.55502 degree for each unit degree increase in the pre-measurement of hip flexion degree. The coefficient for stretching treatment group is 7.32058, which implies that when fixing the other variables, the improvement of hip flexion degrees will increase 7.32058 if the patient has had the stretching treatment.

Statistical Summary for Model 2

Parameter	**Coefficient**	**Standard Error**
Intercept	6.33367	2.19951
Pre-measurement of hip rotation degrees	-0.21501	0.06426
Stretching treatment group	5.58648	1.80576

Table 5: *The table displays the coefficient of parameters in model 2 in the R summary output that were meaningful to include. The table also displays additional information pertaining to the standard error for each variable.*

In the table, the coefficient for the intercept is 6.33367, which implies that the expected improvement of hip rotation degrees is 6.33367 when the pre-measurement of hip rotation degree is 0 and the patient does not have the stretching treatment. The coefficient for the pre-measurement of hip rotation degrees is -0.21501, which implies that when fixing other variables, the improvement of hip rotation degrees will decrease 0.21501 degree for each unit degree increase in the pre-measurement of hip rotation degree. The coefficient for stretching treatment group is 5.58648, which implies that when fixing the other variables, the improvement of hip rotation degrees will increase 5.58648 if the patient has had the stretching treatment.

Standard error (in Table 4 and 5) is a measure of how precise the estimate of the parameters is. In addition, almost all possible variations of the parameter are within three standard errors away from the estimation value for the parameter.

Intraclass Correlation Coefficient (ICC) was calculated for each model that was established in the study. For model 1 (with improvement of hip flexion degrees as response variable), the intraclass correlation coefficient was 0.6490876, which implies that 64.9% of the variation in the improvement of hip flexion degrees is due to the randomness of subject. For model 2 (with improvement of hip rotation degrees as response variable), the intraclass correlation coefficient was 0.654551, which implies that 65.5% of the variation in the improvement of hip rotation degrees is due to the randomness of subject. Thus, we want to account for the variability due to the subjects in the model.

Note that potential outliers were found in both models. We would not remove them, since we did not have enough information for the extreme observations.

4. Recommendations

The client's research question was: Has the stretched group improved significantly more than the control group?

The answer is yes, since from the analysis in section 3, we found that it was necessary to include the stretching treatment group factor in the model for both the improvement of hip flexion degrees and the improvement of hip rotation degrees. In addition, the coefficient is positive, which implies that doing additional stretching exercises is beneficial for the Ankylosing Spondylitis patients. Furthermore, after we analyzed the coefficient in section 3, we found that the improvement is profound. Therefore, we would recommend Ankylosing Spondylitis patients to do the additional daily stretching exercises.

5. Resources

R, SAS and Microsoft Excel were used to modify and analyze the data. The functions below can be used to reproduce the results. The code used to transform the data and the outputs from the analysis are provided in Appendix E. The open source R software can be downloaded via the link: https://www.r-project.org

To import the data set that was in excel form, read_excel() was used in R. This function is part of the readxl package that can be downloaded using the install.packages(-"readxl") command in R. More information on this function can be found via the link: https://cran.r-project.org/web/packages/readxl/readxl.pdf

To perform the Linear Mixed Effects Model, lmer() was used in R. This function is part of the lme4 package that can be downloaded using the install.packages("lme4") command in R. More information on this function can be found via the link: https://cran.r-project.org/web/packages/lme4/lme4.pdf.

To manipulate the data set that was in .txt format, excel is a good software tool to choose.

LaTeX was used to write up the report.

The following additional resources were also used to complete the study:

Analytics, Business Intelligence and Data Management. (n.d.). Retrieved September 26, 2017, from https://www.sas.com/en_us/home.html

LaTeX. (n.d.). Retrieved September 13, 2017, from https://en.wikibooks.org/wiki/LaTeX/

Linear Mixed-Effects Models using 'Eigen' and S4 [R package lme4 version 1.1-14]. (n.d.). Retrieved October 03, 2017, from https://cran.r-project.org/web/packages/-lme4/index.html

Statistical Soup: ANOVA, ANCOVA, MANOVA, & MANCOVA. (n.d.). Retrieved October 02, 2017, from http://www.statsmakemecry.com/smmctheblog/stats-soup-anova-ancova-manova-mancova

Read Excel Files [R package readxl version 1.0.0]. (n.d.). Retrieved October 03, 2017, from https://cran.r-project.org/web/packages/readxl

RStudio Team (2015). RStudio: Integrated Development for R. RStudio, Inc., Boston, MA URL http://www.rstudio.com/.

SAS/STAT 9.22 User's Guide. (2010, June 22). Retrieved September 27, 2017, from https://support.sas.com/documentation/cdl/en/statug/63347/HTML/default/viewer.htm#titlepage.htm

6. Considerations

There are several additional considerations to help to fully understand this study:

- According to the data analysis in section 2, left hip and right hip were roughly the same. However, if instead of using left and right hip, we use dominant hip and non-dominant hip to be the factors, we may get a significant difference between dominant hip and non-dominant hip. If there is enough informations about that, it is worth a try.

- As stated in the data set, the hospital surveyed 39 consecutive patients with 'typical' Ankylosing Spondylitis. Thus, we cannot say if these 39 consecutive patients are representative of all Ankylosing Spondylitis patients. We also do not know the relationship among these patients. If there are patients that are correlated to each other, then we should take that into consideration when doing analysis. In addition, the clients did not provide a rigorous definition of what a 'typical' Ankylosing Spondylitis patient is in this study. More details would be helpful for the study.
- As mentioned in the former analysis, we can see that there are potential outliers in the data set. However, we cannot remove them because we do not have enough information about these observations. We do not know what happened to these hips (like injuries, genetics, etc). Thus, more information about the patients would be helpful to the study.
- When analyzing the research question that has the stretched group improved significantly more than the control group, we figured out two possible approaches to get new variables from the raw data set to represent the improvement of hip flexion degrees and hip rotation degrees. One is taking the difference of before and after hip flexion/rotation degrees. However, note that the flexion and rotation degrees are all bounded, which implies that there might be a difference in meanings for the same amount of improvement on different starting points. Another approach is calculating the percentage difference of before and after hip flexion/rotation degrees. However, some very small improvements that have happened at a low start level would become extreme observations with a high percentage, which will become unreasonably influential in the data set. Thus, after considering both approaches carefully, we choose to take the difference directly to represent the improvement, and include the pre-measurement of hip flexion/rotation degrees in the model. It may be helpful to figure out a more reasonable way to represent the improvement.

Acknowledgments. It is a pleasure to thank our mentor, Matthew Beckman, and our Teaching Assistant, Christian Schmid, for providing helpful suggestions about constructing model and information related to the data set during the process of finishing this project.

Appendix A: Raw and Modified Data Set

The raw data sets and modified data sets combined and used in this study can be found at the following link:
https://drive.google.com/drive/folders/0B2yD3RBHbfMAc1RBbWxWSzV5cGc?usp=sharing
The raw data sets are embedded below:

Data_set_raw

Ankylosing_Spondilitus_data.txt

The data set embedded below is the modified data set as described in the main report. This data set is provided such that the client can reproduce the analysis discussed in this report, as needed:

Data_set_modified

Appendix B: SAS Code and Correlation Test Output

SAS Code:

```
options ls = 78;
DATA AS_Data;
input Subject Stretch $ Hip $ Before_Rotation After_Rotation Diff_Rotation Before_Flexion
After_Flexion Diff_Flexion;
datalines;
1 C R 23 17 -6 100 100 0
1 C L 18 12 -6 105 103 -2
2 C R 21 24 3 114 115 1
2 C L 28 27 -1 115 116 1
3 C R 25 29 4 123 126 3
3 C L 26 27 1 126 121 -5
4 C R 35 33 -2 105 110 5
4 C L 33 24 -9 105 102 -3
5 C R 25 30 5 120 123 3
5 C L 22 27 5 123 118 -5
6 C R 20 36 16 95 96 1
6 C L 26 30 4 112 120 8
7 C R 27 30 3 108 113 5
7 C L 15 14 -1 111 109 -2
8 C R 26 25 -1 108 111 3
8 C L 14 13 -1 81 111 30
9 C R 22 24 2 114 121 7
9 C L 26 26 0 112 120 8
10 C R 36 41 5 103 110 7
10 C L 33 36 3 105 111 6
11 C R 32 35 3 113 118 5
11 C L 27 31 4 112 115 3
12 C R 36 30 -6 116 120 4
12 C L 4 2 -2 113 121 8
13 T R 25 36 11 125 126 1
```

13 T L 35 37 2 120 127 7
14 T R 28 40 12 135 135 0
14 T L 24 34 10 135 135 0
15 T R 26 30 4 100 113 13
15 T L 24 26 2 110 115 5
16 T R 22 42 20 122 123 1
16 T L 24 37 13 122 125 3
17 T R 29 29 0 124 126 2
17 T L 28 31 3 124 135 11
18 T R 22 38 16 113 120 7
18 T L 12 34 22 122 120 -2
19 T R 30 35 5 130 138 8
19 T L 30 27 -3 105 130 25
20 T R 33 42 9 123 127 4
20 T L 34 40 6 125 129 4
21 T R 18 27 9 123 128 5
21 T L 26 32 6 126 128 2
22 T R 20 40 20 115 120 5
22 T L 22 40 18 125 120 -5
23 T R 7 20 13 120 135 15
23 T L 10 28 18 105 127 22
24 T R 25 28 3 120 130 10
24 T L 25 26 1 110 120 10
25 T R 35 39 4 127 135 8
25 T L 25 29 4 125 130 5
26 T R 30 43 13 128 138 10
26 T L 33 45 12 124 136 12
27 T R 26 34 8 115 124 9
27 T L 40 42 2 116 124 8
28 T R 20 21 1 106 110 4
28 T L 16 17 1 111 116 5
29 T R 10 12 2 113 114 1
29 T L 11 14 3 105 115 10
30 T R 14 23 9 100 105 5
30 T L 2 10 8 99 88 -11
31 T R 48 50 2 113 119 6
31 T L 35 35 0 126 126 0
32 T R 22 30 8 102 110 8
32 T L 13 24 11 94 115 21
33 T R 22 25 3 116 111 -5
33 T L 20 25 5 112 114 2
34 T R 30 35 5 122 128 6
34 T L 33 35 2 122 128 6
35 T R 22 30 8 118 127 9
35 T L 25 27 2 115 124 9
36 T R 32 39 7 115 125 10
36 T L 12 25 13 118 127 9
37 T R 35 34 -1 78 121 43

```
37 T L 30 32 2 77 126 49
38 T R 36 44 8 129 129 0
38 T L 33 25 -8 127 132 5
39 T R 10 15 5 127 127 0
39 T L 39 36 -3 132 139 7
;
RUN;

PROC PRINT data = AS_Data;
title 'Ankylosing Spondylitis Data';
RUN;

PROC corr data = AS_Data cov;
var Before_Rotation After_Rotation Diff_Rotation Before_Flexion After_Flexion Diff_Flexion;
RUN;

PROC corr data = AS_Data cov fisher(alpha = .5 biasadj = no);
var Before_Rotation After_Rotation Diff_Rotation Before_Flexion After_Flexion Diff_Flexion;
RUN;
```

Descriptive Statistic Output:

Simple Statistics						
Variable	N	Mean	Std Dev	Sum	Minimum	Maximum
Before_Rotation	78	24.84615	8.76842	1938	2.00000	48.00000
After_Rotation	78	29.70513	9.13124	2317	2.00000	50.00000
Diff_Rotation	78	4.85897	6.50619	379.00000	-9.00000	22.00000
Before_Flexion	78	114.48718	11.83846	8930	77.00000	135.00000
After_Flexion	78	120.83333	10.07171	9425	88.00000	139.00000
Diff_Flexion	78	6.34615	9.18614	495.00000	-11.00000	49.00000

Figure B1. *Descriptive statistic table.*

Fisher's Correlation Test Output:

Ankylosing Spondylitis Data

The CORR Procedure

2 Variables:	Diff_Rotation Diff_Flexion

Covariance Matrix, DF = 77		
	Diff_Rotation	Diff_Flexion
Diff_Rotation	42.33050283	-3.82067932
Diff_Flexion	-3.82067932	84.38511489

Simple Statistics						
Variable	N	Mean	Std Dev	Sum	Minimum	Maximum
Diff_Rotation	78	4.85897	6.50619	379.00000	-9.00000	22.00000
Diff_Flexion	78	6.34615	9.18614	495.00000	-11.00000	49.00000

Pearson Correlation Coefficients, N = 78 Prob > |r| under H0: Rho=0		
	Diff_Rotation	Diff_Flexion
Diff_Rotation	1.00000	-0.06393 0.5782
Diff_Flexion	-0.06393 0.5782	1.00000

Pearson Correlation Statistics (Fisher's z Transformation)							
Variable	With Variable	N	Sample Correlation	Fisher's z	95% Confidence Limits		p Value for H0:Rho=0
Diff_Rotation	Diff_Flexion	78	-0.06393	-0.06401	-0.282439	0.160893	0.5793

Figure B2. *Fisher's correlation test result.*

Appendix C: Excel Procedure to Get Descriptive Statistics

We used excel to calculate the values described in Table 3 in section 2. The following functions will be helpful to reproduce the result:

- COUNT to calculate N
- AVERAGE to calculate Mean
- STDEC.P to calculate Standard Deviation
- Min to calculate Minimum
- Max to calculate Maximum

Appendix D: ANOVA Model Assumption Check

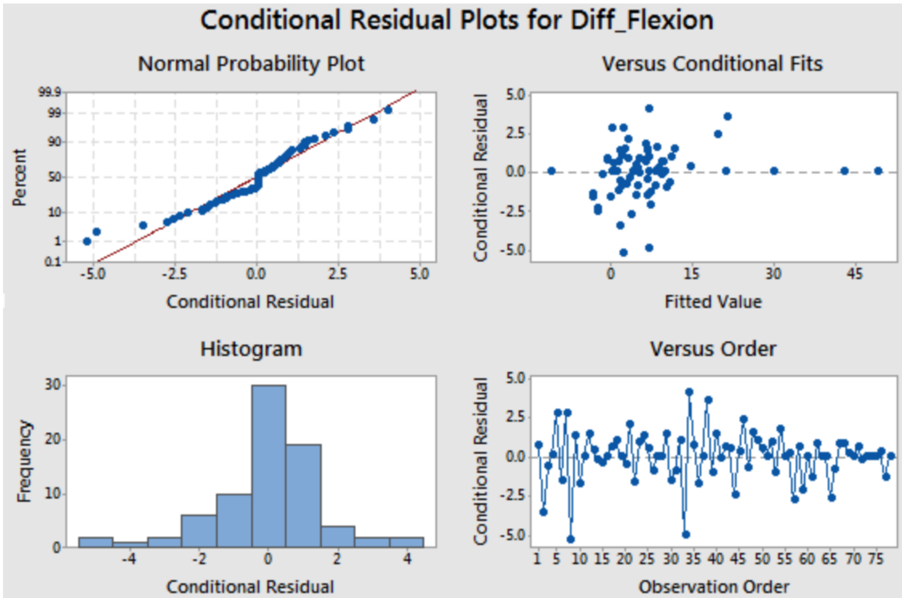

Figure D1. *Minitab output for the residual plots of the hip flexion degrees model.*

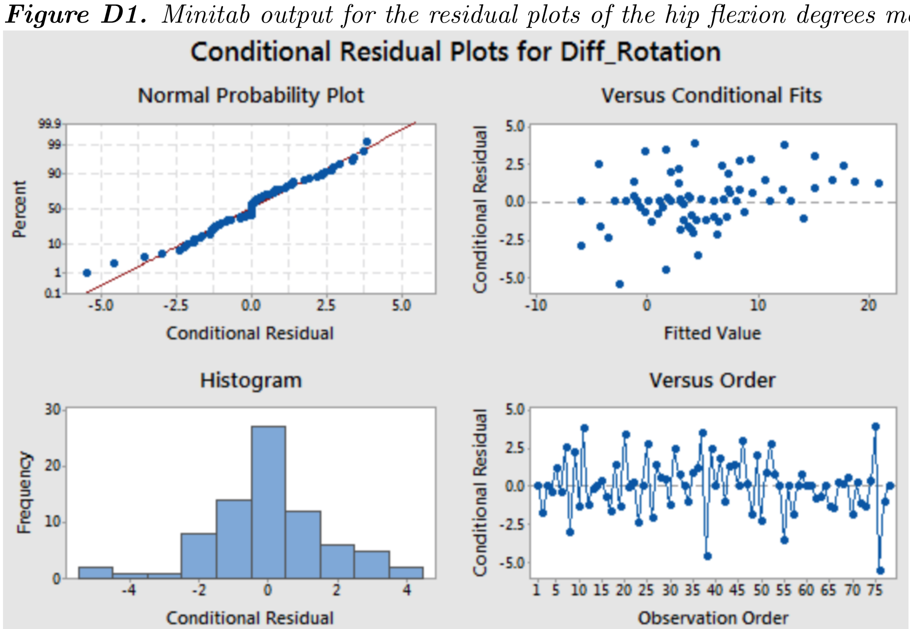

Figure D2. *Minitab output for the residual plots of the hip rotation degrees model.*

The assumptions for a mixed effects model are:

- **<u>The errors have constant variance:</u>**
  For the first model (with improvement of hip flexion degree as response):
  From Figure D1, we can see that from the Versus Conditional Fits plot, the variances of the residuals are roughly the same.

For the second model (with improvement of hip rotation degree as response):
From Figure D2, we can see that from the Versus Conditional Fits plot, the variances of the residuals are roughly the same.

- **The errors are independent:**
For the first model (with improvement of hip flexion degree as response):
From Figure D1, we can see that from the Versus Order plot, no pattern exists. Thus, the residuals are independent to each other.
For the second model (with improvement of hip rotation degree as response):
From Figure D2, we can see that from the Versus Order plot, no pattern exists. Thus, the residuals are independent to each other.

- **The errors are Normally distributed:**
For the first model (with improvement of hip flexion degree as response):
From Figure D1, we can see that from the Normal Probability Plot, the residuals roughly lie on the straight line, which implies that the residuals are roughly normally distributed. In addition, from the histogram, we can also see that the residuals are roughly normally distributed. Thus, the residuals are normally distributed.
For the second model (with improvement of hip rotation degree as response):
From Figure D2, we can see that from the Normal Probability Plot, the residuals roughly lie on the straight line, which implies that the residuals are roughly normally distributed. In addition, from the histogram, we can also see that the residuals are roughly normally distributed. Thus, the residuals are normally distributed.

Appendix E: R Code and Output

R Code:

```
library(readxl)
library(”lme4”, lib.loc=”/Library/Frameworks/R.framework/Versions/3.3/Resources/library”)
Data_set_modified <- read_excel(” /Documents/2017 fall/STAT 470W/case study 2/Data_set_modified.xlsx”)
model.flexion <- lmer(Diff_Flexion Before_Flexion + Stretch + (1|Subject), data = Data_set_modified)
model.flexion.null <- lmer(Diff_Flexion Before_Flexion + (1|Subject), data = Data_set_modified, REML=FALSE)
anova(model.flexion.null,model.flexion)
summary(model.flexion)
model.rotation <- lmer(Diff_Rotation Before_Rotation + Stretch + (1|Subject), data = Data_set_modified)
model.rotation.null <- lmer(Diff_Rotation Before_Rotation + (1|Subject), data = Data_set_modified, REML=FALSE)
anova(model.rotation.null,model.rotation)
summary(model.rotation)
```

R Output:

```
> anova(model.flexion.null,model.flexion)
refitting model(s) with ML (instead of REML)
Data: Data_set_modified
Models:
model.flexion.null: Diff_Flexion ~ Before_Flexion + (1 | Subject)
model.flexion: Diff_Flexion ~ Before_Flexion + Stretch + (1 | Subject)
                   Df    AIC    BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
model.flexion.null  4 519.74 529.17 -255.87   511.74
model.flexion       5 511.87 523.65 -250.93   501.87 9.8762      1   0.001674 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure E1. *R output for comparison of the model with stretch treatment factor and the model without the stretch treatment factor. The two models both use the improvement of hip flexion degrees as the response variable.*

```
> anova(model.rotation.null,model.rotation)
refitting model(s) with ML (instead of REML)
Data: Data_set_modified
Models:
model.rotation.null: Diff_Rotation ~ Before_Rotation + (1 | Subject)
model.rotation: Diff_Rotation ~ Before_Rotation + Stretch + (1 | Subject)
                    Df    AIC    BIC  logLik deviance  Chisq Chi Df Pr(>Chisq)
model.rotation.null  4 485.63 495.06 -238.81   477.63
model.rotation       5 478.59 490.37 -234.29   468.59 9.0397      1   0.002642 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure E2. *R output for comparison of the model with stretch treatment factor and the model without the stretch treatment factor. The two models both use the improvement of hip rotation degrees as the response variable.*

```
> summary(model.flexion)
Linear mixed model fit by REML ['lmerMod']
Formula: Diff_Flexion ~ Before_Flexion + Stretch + (1 | Subject)
   Data: Data_set_modified

REML criterion at convergence: 500

Scaled residuals:
     Min       1Q   Median       3Q      Max 
-2.99179 -0.38550  0.07522  0.38524  1.81806 

Random effects:
 Groups   Name        Variance Std.Dev.
 Subject  (Intercept) 32.37    5.689   
 Residual             17.50    4.183   
Number of obs: 78, groups:  Subject, 39

Fixed effects:
               Estimate Std. Error t value
(Intercept)    64.82090    8.29816   7.811
Before_Flexion -0.55502    0.07356  -7.545
StretchT        7.32058    2.27623   3.216

Correlation of Fixed Effects:
            (Intr) Bfr_Fl
Before_Flxn -0.975       
StretchT     0.025 -0.211
```

Figure E3. *R output for the summary of the model with the improvement of hip flexion degrees as the response variable.*

```
> summary(model.rotation)
Linear mixed model fit by REML ['lmerMod']
Formula: Diff_Rotation ~ Before_Rotation + Stretch + (1 | Subject)
   Data: Data_set_modified

REML criterion at convergence: 467.8

Scaled residuals:
     Min       1Q   Median       3Q      Max
-2.75381 -0.49063  0.01304  0.42701  2.19475

Random effects:
 Groups   Name        Variance Std.Dev.
 Subject  (Intercept) 21.43    4.629
 Residual             11.31    3.364
Number of obs: 78, groups:  Subject, 39

Fixed effects:
                Estimate Std. Error t value
(Intercept)      6.33367    2.19951   2.880
Before_Rotation -0.21501    0.06426  -3.346
StretchT         5.58648    1.80576   3.094

Correlation of Fixed Effects:
            (Intr) Bfr_Rt
Before_Rttn -0.730
StretchT    -0.574  0.008
```

Figure E4. *R output for the summary of the model with the improvement of hip rotation degrees as the response variable.*

Appendix F: Intraclass Correlation Coefficient (ICC) Calculation

ICC.subject.flexion = 32.37 / (32.37 + 17.50)
ICC.subject.rotation = 21.43 / (21.43 + 11.31)

```
> ICC.subject.flexion
[1] 0.6490876
> ICC.subject.rotation
[1] 0.654551
```