이화여자대학교

Handwriting Analysis for
Fine Motor Skill Classification

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Background

What is Fine Motor Skill ?

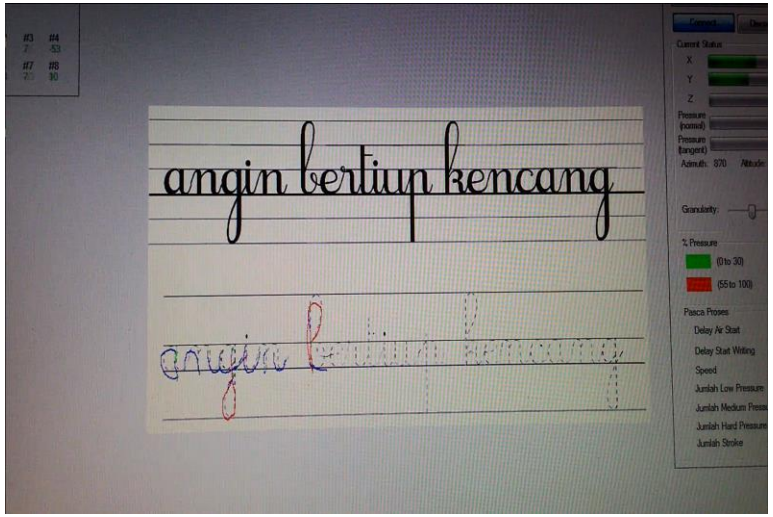
- The ability to make movements using the small muscles in our hands and fingers.
- The development of these skills is crucial for handwriting because it requires the precise movements of the fingers to grip and control a pencil or pen
- As children develop fine motor skills, they improve in their ability to manage writing tools, which can lead to better handwriting quality
- Practicing handwriting can also help in refining fine motor skill.

❖ Handwriting analysis can be valuable tool for assessing fi ne motor skill

Data Collection and Dataset

1	29:05.5	316	276	1023	0	1110	530
2	29:05.5	316	276	1023	0	1110	530
3	29:05.5	316	276	1023	0	1110	530
4	29:05.6	316	276	1023	0	1110	530
5	29:05.6	316	276	1023	0	1110	530
6	29:05.6	316	276	1023	0	1110	530
7	29:05.6	316	276	1023	0	1110	530
8	29:05.6	316	276	1023	0	1110	530
9	29:05.6	316	276	1023	0	1110	530
10	29:05.6	316	276	1023	0	1110	530
11	29:05.6	316	276	1023	0	1110	530
12	29:05.6	316	276	1023	0	1110	530

student1.csv



https://youtu.be/yYyPT5sProw

Patten :

“ Angin bertiup kencang”

“바람이 세차게 불었습니다”

Dataset : FMS2.csv

	log_time	x_pos	y_pos	z_pos	p_pos	altitude	azimuth	person	label
2	44:41.5	347	307	1023	0	1290	520	1	1
3	44:41.5	347	307	922	0	1280	530	1	1
4	44:41.5	348	307	938	0	1280	530	1	1
5	44:41.5	348	308	922	0	1280	530	1	1
6	44:41.5	349	308	906	0	1280	530	1	1
7	44:41.5	350	308	890	0	1280	530	1	1
8	44:41.5	350	308	858	0	1280	530	1	1
9	44:41.6	352	308	858	0	1270	530	1	1
10	44:41.6	353	308	842	0	1270	530	1	1
11	44:41.6	354	308	826	0	1270	530	1	1
12	44:41.6	355	308	794	0	1270	530	1	1

```
> head(dataset)
  log_time x_pos y_pos z_pos p_pos altitude azimuth person label
1  44:41.5   347   307  1023     0     1290     520      1     1
2  44:41.5   347   307   922     0     1280     530      1     1
3  44:41.5   348   307   938     0     1280     530      1     1
4  44:41.5   348   308   922     0     1280     530      1     1
5  44:41.5   349   308   906     0     1280     530      1     1
6  44:41.5   350   308   890     0     1280     530      1     1
```

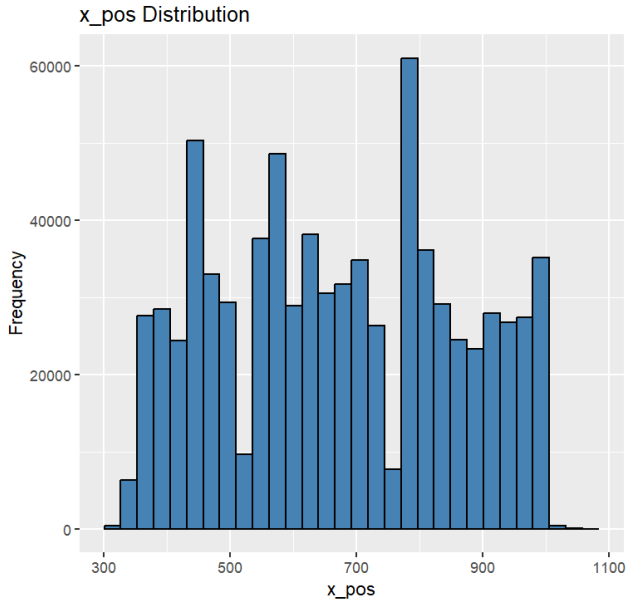
```
> tail(dataset)
       log_time x_pos y_pos z_pos p_pos altitude azimuth person label
786608  38:58.1   989   297  1023     0     1310     480     40     1
786609  38:58.1   989   297  1023     0     1310     480     40     1
786610  38:58.2   989   297  1023     0     1310     480     40     1
786611  38:58.2   989   297  1023     0     1310     480     40     1
786612  38:58.2   989   297  1023     0     1310     480     40     1
786613  38:58.2   989   297  1023     0     1310     480     40     1
```

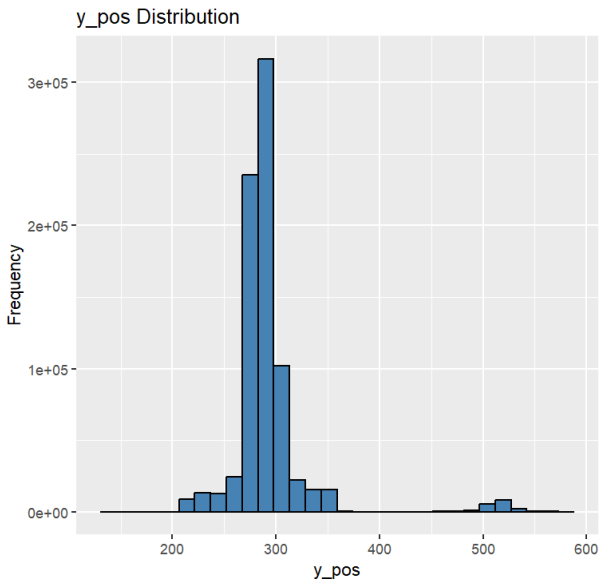
Labeling by Psychologist : good (1) and bad (0)
-> Use Bender Gestalt Test

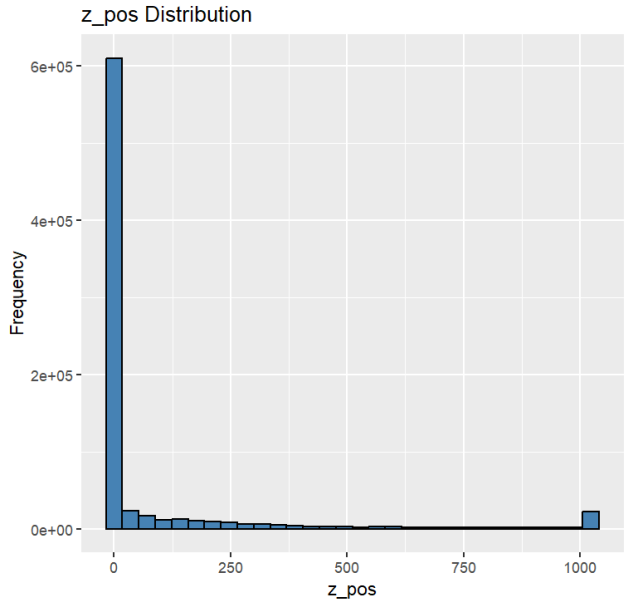
Objective

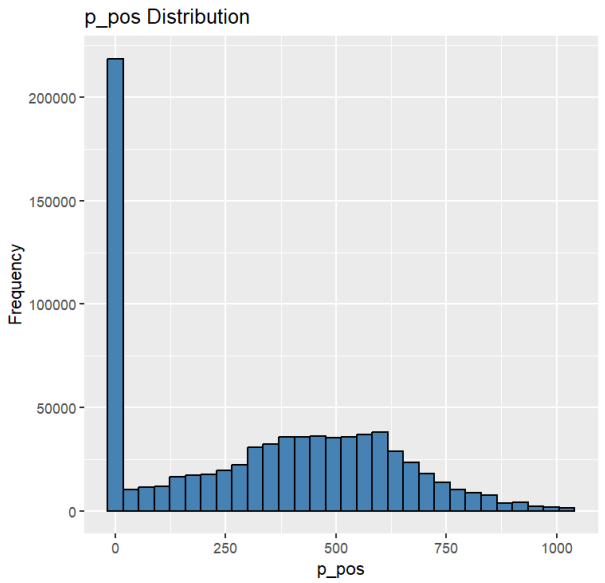
- Explore potential features that can be use to determine the level of fine motor skill
- Identify the most appropriate model for the handwriting data

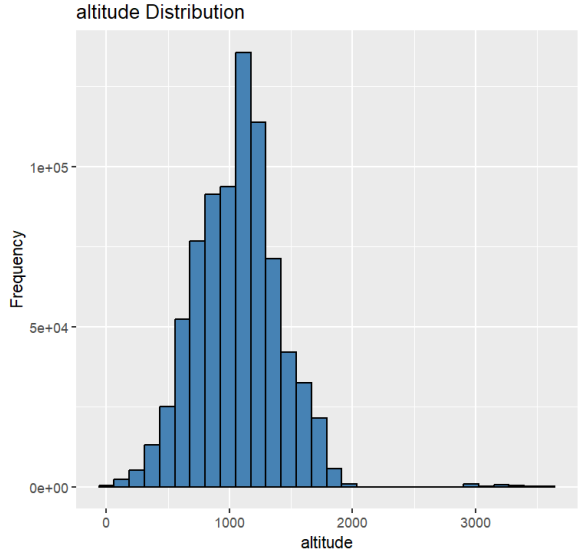
Exploring Data _ The Distribution Plot

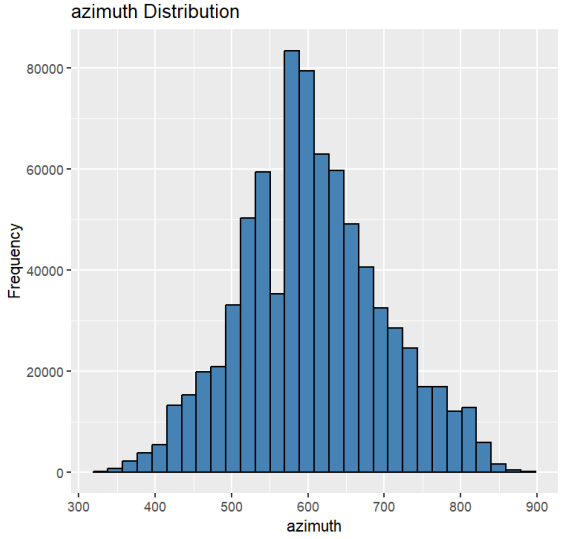












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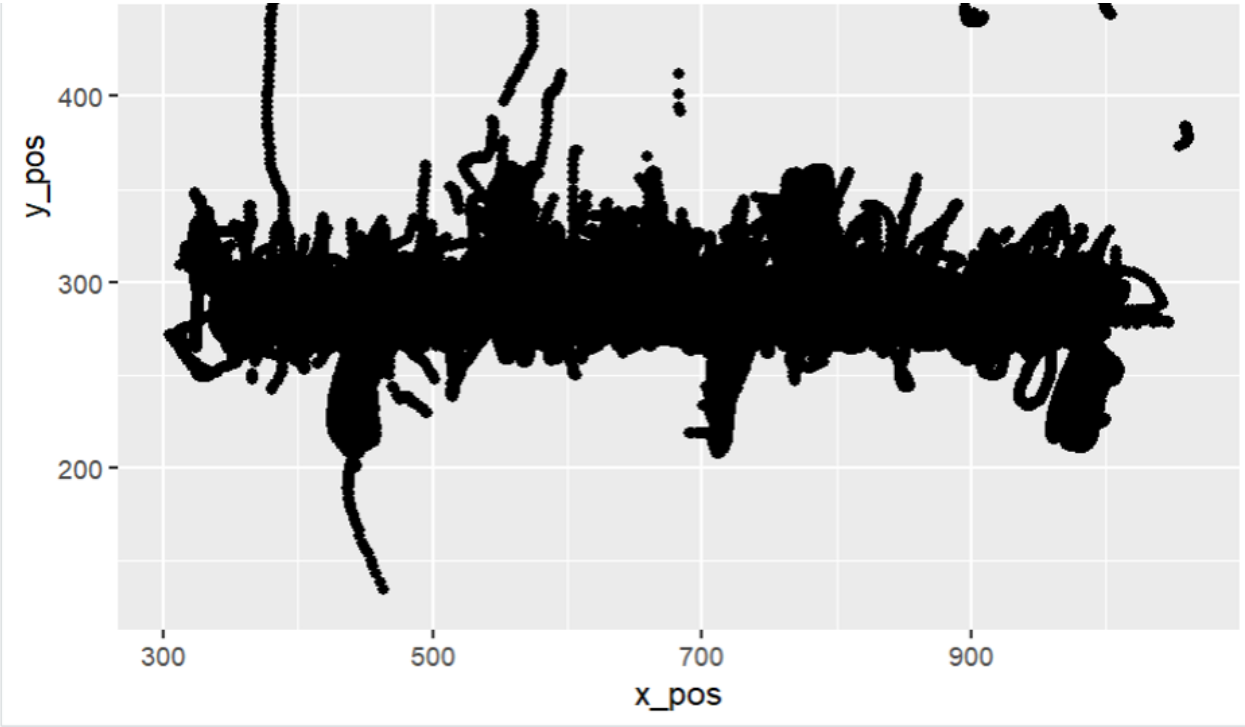
Exploring Data _ Scatter Plot of x_pos vs y_pos



- Represent the movement of a pen on a surface
- Represent specific letter or whole words
- Represent density of data points
  -> could indicate slower or quicker movement of the pen
- Indicate an outlier or noise

Project's Scenario

Features :
- acceleration derived from x_pos and y_pos
- pressure (p_pos)

Features :
- Speed
- x_pos, y_pos, z_pos, p_pos
- Altitude, Azimuth

Features with acceleration & pressure

- Acceleration : changes in speed → writer's ability to smoothly start or stop and transition between movement
- Pressure : how firmly a person write or interacts with a writing instrument → indicator of motor skill and control

- T-Test and Box-plot with max_acceleration & pressure

Features with acceleration & pressure

```
        Welch Two Sample t-test

data:  features$max_acceleration by features$skill_level
t = 4.7828, df = 32.571, p-value = 3.593e-05
alternative hypothesis: true difference in means between group Bad and group Good is not equal to 0
95 percent confidence interval:
 207.3959 514.7306
sample estimates:
 mean in group Bad mean in group Good
          576.3835           215.3203
```

```
        Welch Two Sample t-test

data:  features$avg_pressure by features$skill_level
t = -2.2227, df = 32.863, p-value = 0.03323
alternative hypothesis: true difference in means between group Bad and group Good is not equal to 0
95 percent confidence interval:
 -155.67038   -6.86745
sample estimates:
 mean in group Bad mean in group Good
          312.0624           393.3313
```

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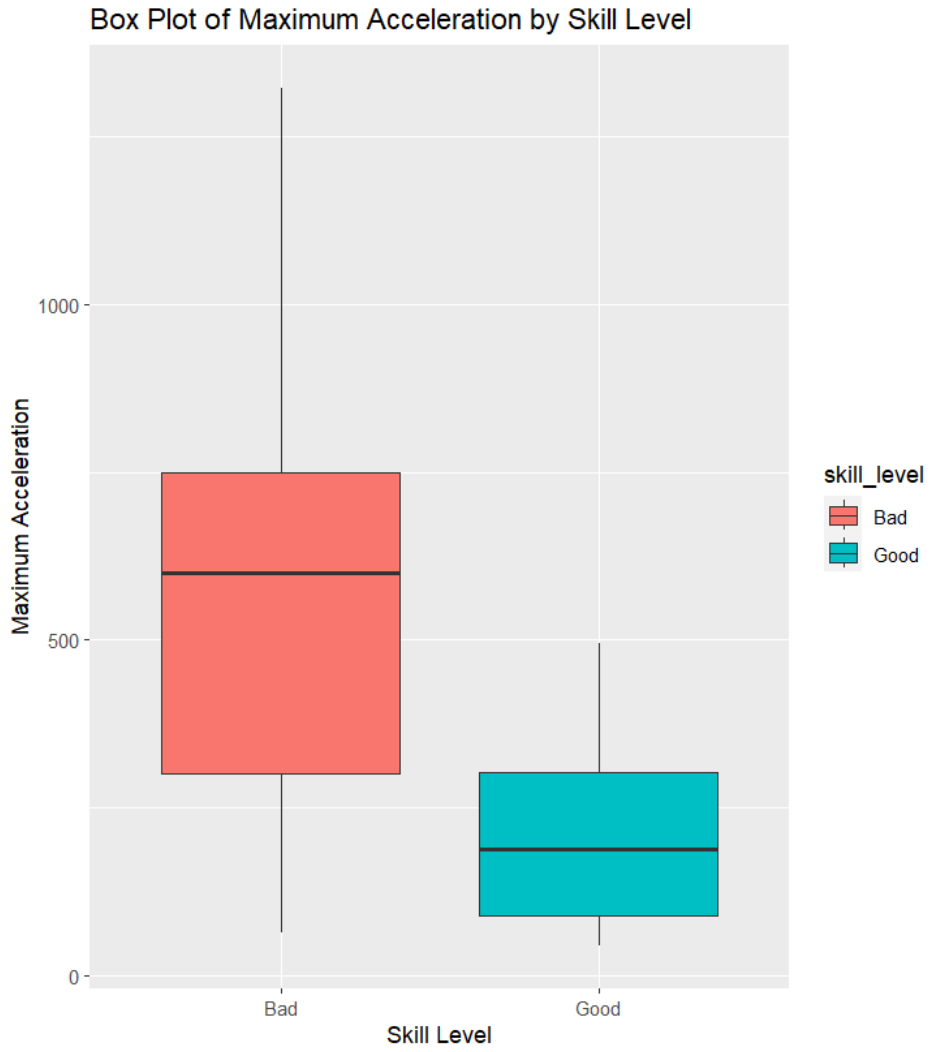
Features with acceleration & pressure



- Lower max_acceleration in 'Good' skill → more controlled and steady movements
- High max_acceleration in 'Bad' skill → less control or consistency in movements

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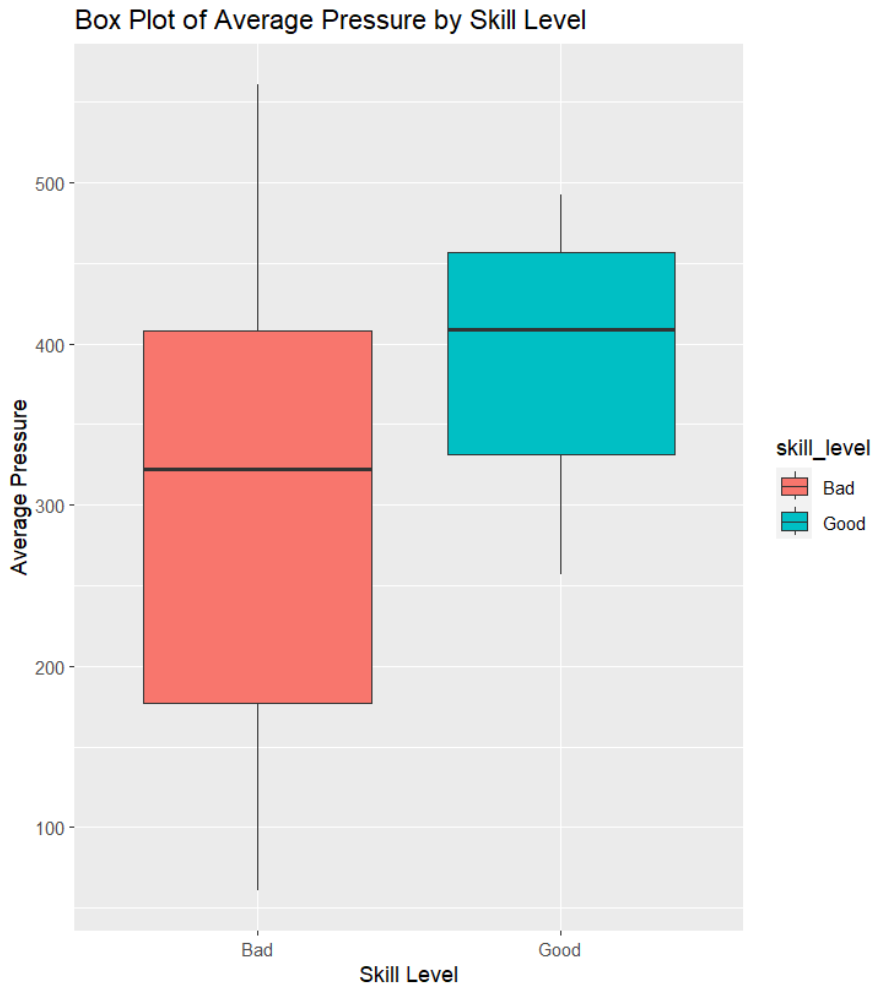
Features with acceleration & pressure



- Good skill Level → consistent & high pressure
- Big range of IQR → more variability in the pressure applied by individuals with poorer fine motor skills

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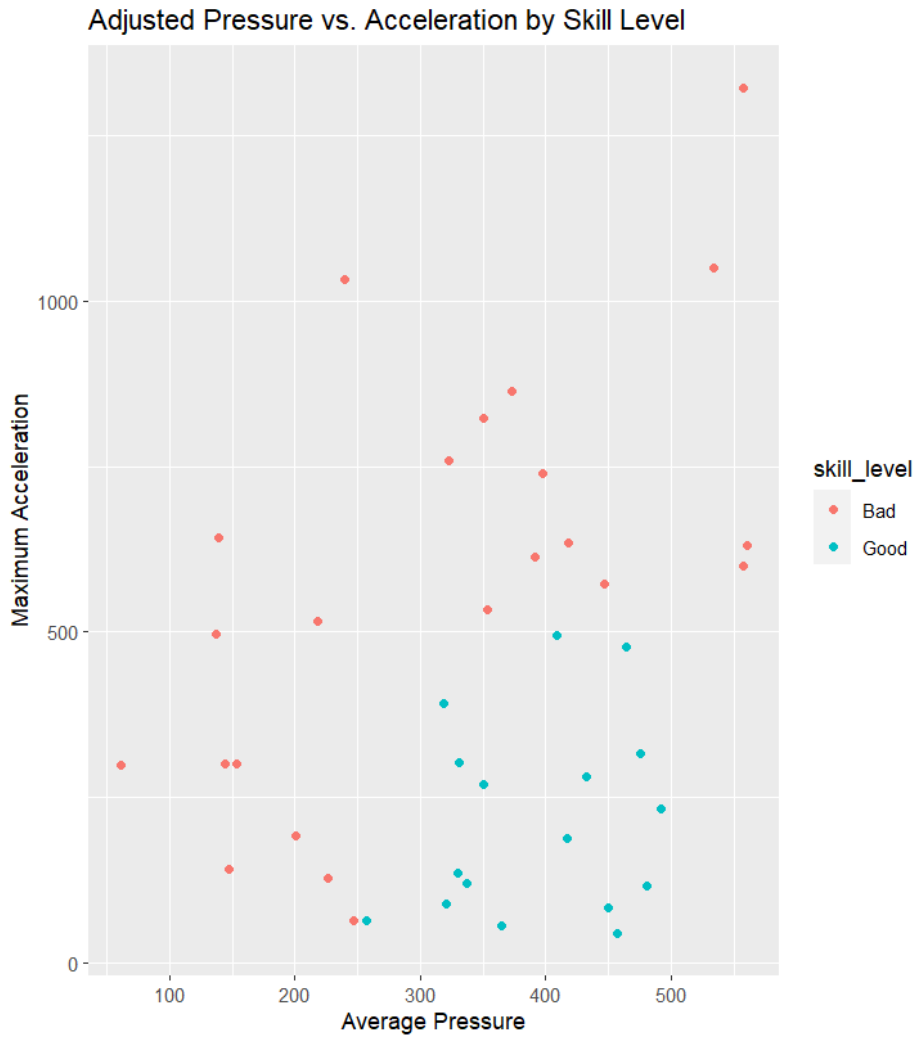
Features with acceleration & pressure



- Good skills → lower acceleration → consistent & controlled movement
- Bad skills → higher acceleration → irregular pressure patterns → lack of consistency and control

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Features with acceleration & pressure

```
33 samples
 2 predictor
 2 classes: 'Bad', 'Good'

No pre-processing
Resampling: Cross-Validated (5 fold)
Summary of sample sizes: 26, 26, 26, 26, 28
Resampling results:

  ROC        Sens  Spec
  0.9666667  0.95  0.8666667
```

```
RMSE: 0.6546537
>
```

- Small data set → data augmentation about 500
- Train : Test = 8 : 2
- Use 3 model for train data set → Random Forest, SVM, GBM
- Compare RMSE

Features with acceleration & pressure

```
Confusion Matrix and Statistics

          Reference
Prediction Bad Good
      Bad   54    0
      Good   0   46

               Accuracy : 1
                 95% CI : (0.9638, 1)
    No Information Rate : 0.54
    P-Value [Acc > NIR] : < 2.2e-16

                  Kappa : 1

 Mcnemar's Test P-Value : NA

            Sensitivity : 1.00
            Specificity : 1.00
         Pos Pred Value : 1.00
         Neg Pred Value : 1.00
             Prevalence : 0.54
         Detection Rate : 0.54
   Detection Prevalence : 0.54
      Balanced Accuracy : 1.00
```

- Model : Random Forest
- Accuracy : 1
- RMSE : 0

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Features with acceleration & pressure

```
Confusion Matrix and Statistics

          Reference
Prediction Bad Good
      Bad   53    6
      Good   1   40

               Accuracy : 0.93
                 95% CI : (0.8611, 0.9714)
    No Information Rate : 0.54
    P-Value [Acc > NIR] : <2e-16

                  Kappa : 0.858

 Mcnemar's Test P-Value : 0.1306

            Sensitivity : 0.9815
            Specificity : 0.8696
         Pos Pred Value : 0.8983
         Neg Pred Value : 0.9756
             Prevalence : 0.5400
         Detection Rate : 0.5300
   Detection Prevalence : 0.5900
      Balanced Accuracy : 0.9255
```

- Model : SVM
- Accuracy : 0.93
- RMSE : 0.2645751

Features with acceleration & pressure

```
Confusion Matrix and Statistics

          Reference
Prediction Bad Good
      Bad   54    0
      Good   0   46

               Accuracy : 1
                 95% CI : (0.9638, 1)
    No Information Rate : 0.54
    P-Value [Acc > NIR] : < 2.2e-16

                  Kappa : 1

 Mcnemar's Test P-Value : NA

            Sensitivity : 1.00
            Specificity : 1.00
         Pos Pred Value : 1.00
         Neg Pred Value : 1.00
             Prevalence : 0.54
         Detection Rate : 0.54
   Detection Prevalence : 0.54
      Balanced Accuracy : 1.00
```

- Model : GBM
- Accuracy : 1
- RMSE :0

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Features with acceleration & pressure

- Most Fitted Model : Random Forest or GBM

- SVM is the lowest accuracy and RMSE
- Random Forest & GBM is the highest accuracy as 1 and lowest RMSE as 0

2 All features + speed

- Delta : the movement of the pen in three-dimensional space → direction and magnitude of pen movements → crucial for understanding handwriting patterns
- Speed : how quickly the pen moves between points → capture fluidity and control of handwriting

- Train : Test = 8 : 2
- Use 6 models (Logistic Regression, Decision Tree, Random Forest, GBM, XGBoost, Light GBM)

2 All features + speed

```
Confusion Matrix and Statistics

          Reference
Prediction     0     1
         0 19353 11001
         1  9204 15207

               Accuracy : 0.6311
                 95% CI : (0.627, 0.6351)
    No Information Rate : 0.5214
    P-Value [Acc > NIR] : < 2.2e-16

                  Kappa : 0.2587

 Mcnemar's Test P-Value : < 2.2e-16

            Sensitivity : 0.6777
            Specificity : 0.5802
         Pos Pred Value : 0.6376
         Neg Pred Value : 0.6230
             Prevalence : 0.5214
         Detection Rate : 0.3534
   Detection Prevalence : 0.5543
      Balanced Accuracy : 0.6290
```

- Logistic Regression

```
Confusion Matrix and Statistics

          Reference
Prediction     0     1
         0 17954  6355
         1 10603 19853

               Accuracy : 0.6903
                 95% CI : (0.6865, 0.6942)
    No Information Rate : 0.5214
    P-Value [Acc > NIR] : < 2.2e-16

                  Kappa : 0.3837

 Mcnemar's Test P-Value : < 2.2e-16

            Sensitivity : 0.6287
            Specificity : 0.7575
         Pos Pred Value : 0.7386
         Neg Pred Value : 0.6519
             Prevalence : 0.5214
         Detection Rate : 0.3278
   Detection Prevalence : 0.4439
      Balanced Accuracy : 0.6931
```

- Decision Tree

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2 All features + speed

```
> print(model_rf$bestTune)
  mtry
3    4
> # Make predictions on the test set
> predictions_rf <- predict(model_rf, newdata=datasetTest)
> # Evaluate the model
> confusionMatrix(predictions_rf, datasetTest$label)
Confusion Matrix and Statistics

          Reference
Prediction     0     1
         0 28491    39
         1    66 26169

               Accuracy : 0.9981
                 95% CI : (0.9977, 0.9984)
    No Information Rate : 0.5214
    P-Value [Acc > NIR] : < 2e-16

                  Kappa : 0.9962

 Mcnemar's Test P-Value : 0.01117

            Sensitivity : 0.9977
            Specificity : 0.9985
         Pos Pred Value : 0.9986
         Neg Pred Value : 0.9975
             Prevalence : 0.5214
         Detection Rate : 0.5202
   Detection Prevalence : 0.5210
      Balanced Accuracy : 0.9981

       'Positive' Class : 0
```

- Random Forest

```
Confusion Matrix and Statistics

          Reference
Prediction     0     1
         0 25066  2693
         1  3491 23515

               Accuracy : 0.8871
                 95% CI : (0.8844, 0.8897)
    No Information Rate : 0.5214
    P-Value [Acc > NIR] : < 2.2e-16

                  Kappa : 0.774

 Mcnemar's Test P-Value : < 2.2e-16

            Sensitivity : 0.8778
            Specificity : 0.8972
         Pos Pred Value : 0.9030
         Neg Pred Value : 0.8707
             Prevalence : 0.5214
         Detection Rate : 0.4577
   Detection Prevalence : 0.5069
      Balanced Accuracy : 0.8875

       'Positive' Class : 0
```

- GBM

2 All features + speed

```
Confusion Matrix and Statistics

          Reference
Prediction     0     1
         0 28557     0
         1     0 26208

               Accuracy : 1
                 95% CI : (0.9999, 1)
    No Information Rate : 0.5214
    P-Value [Acc > NIR] : < 2.2e-16

                  Kappa : 1

 Mcnemar's Test P-Value : NA

            Sensitivity : 1.0000
            Specificity : 1.0000
         Pos Pred Value : 1.0000
         Neg Pred Value : 1.0000
             Prevalence : 0.5214
         Detection Rate : 0.5214
   Detection Prevalence : 0.5214
      Balanced Accuracy : 1.0000

       'Positive' Class : 0
```

- XGBoost

```
Confusion Matrix and Statistics

          Reference
Prediction     0     1
         0 28557     0
         1     0 26208

               Accuracy : 1
                 95% CI : (0.9999, 1)
    No Information Rate : 0.5214
    P-Value [Acc > NIR] : < 2.2e-16

                  Kappa : 1

 Mcnemar's Test P-Value : NA

            Sensitivity : 1.0000
            Specificity : 1.0000
         Pos Pred Value : 1.0000
         Neg Pred Value : 1.0000
             Prevalence : 0.5214
         Detection Rate : 0.5214
   Detection Prevalence : 0.5214
      Balanced Accuracy : 1.0000

       'Positive' Class : 0
```

- Light GBM

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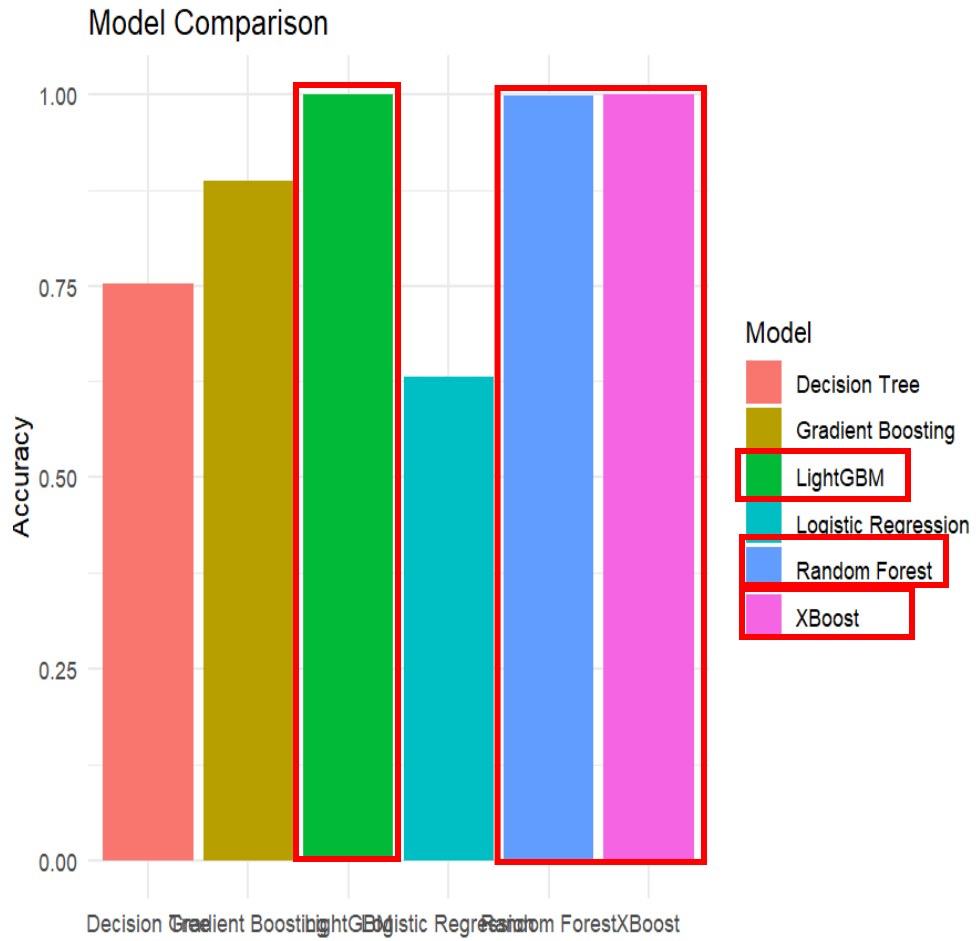
2 All features + speed



- Logistic Regression : 63.11%
- Decision Tree : 75.33%
- Gradient Boosting : 88.71%
- Random Forest : 99.81%
- Light GBM : 100%
- XGBoost : 100%

- XGBoost, Light GBM has same accuracy
- Random Forest almost 100

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Insight

- 어린이들의 소근육 발달을 위한 교육적 도구 개발에 활용
- 효과적인 교육 및 재활(훈련) 프로그램 개발 → 효율성 증대
- 로봇이 인간의 fine motor skills를 모방하거나 대체할 수 있는 기술을 개발하는 데 있어 중요한 기초 자료 제공 → 정밀한 작업 수행하는 로봇 개발 가능
- 운동 선수나 음악가, 예술가들의 트레이닝 프로그램 개발에 활용 → 자신의 기술을 정교하게 다듬고 퍼포먼스 향상 기대

Thank You For Listening

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