

# Homework Assignment 01

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## Data

In this assignment we use a data set “experiment\_data”. The data give number of dots (number of hits) inside rings with different diameters that a testee was able to draw during 10 seconds. The data were collected from the results of four students. The data set consisting of 36 observations of 4 variables.

- BLOCK -
- HITS\_SUM - total number of hits;
- DIAMETER - the diameter of the ring in cm, a categorical variable with three levels “1”, “3”, “5”;
- HAND - the hand or hands used to perform the experiment, a categorical variable with three levels, “D” - dominant hand, “N” - non-dominant hand , “B” - both hands;

## Mean values and variances

The following table provides the summary of the data set:

##	BLOCK	HITS_SUM	DIAMETER	HAND
##	1:9	Min. : 9.00	1:12	B:12
##	2:9	1st Qu.:15.75	3:12	D:12
##	3:9	Median :22.00	5:12	N:12
##	4:9	Mean :21.75		
##		3rd Qu.:26.00		
##		Max. :44.00		

The following tables provide the mean values and variances for each variable.

BLOCK	1	2	3	4
mean value	19.00	19.67	22.00	26.33
variance	30.75	31.00	40.75	100.75

HAND	Both	Dominant	Non-Dominant
mean value	19.00	25.42	20.83
variance	29.82	82.45	38.70

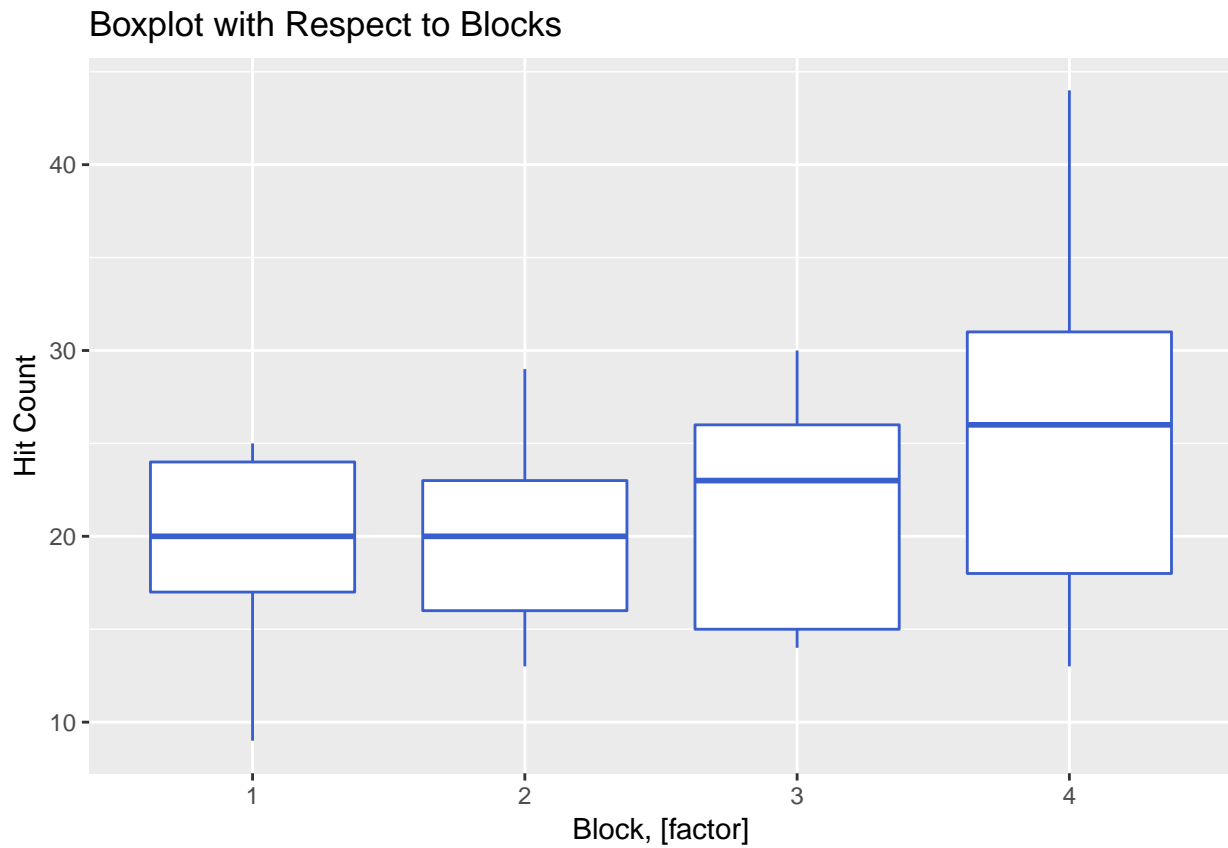
DIAMETER	1 cm	3 cm	5 cm
mean value	14.17	24.67	26.42
variance	5.42	20.97	52.63

We can see that mean values for each of the blocks are slightly different. However, the 4th block shows an outstanding behavior. As a result, further investigation is needed. Regarding circle diameters, the data shows, that with bigger diameter the number of hits increases. Turning to mean values with respect to the

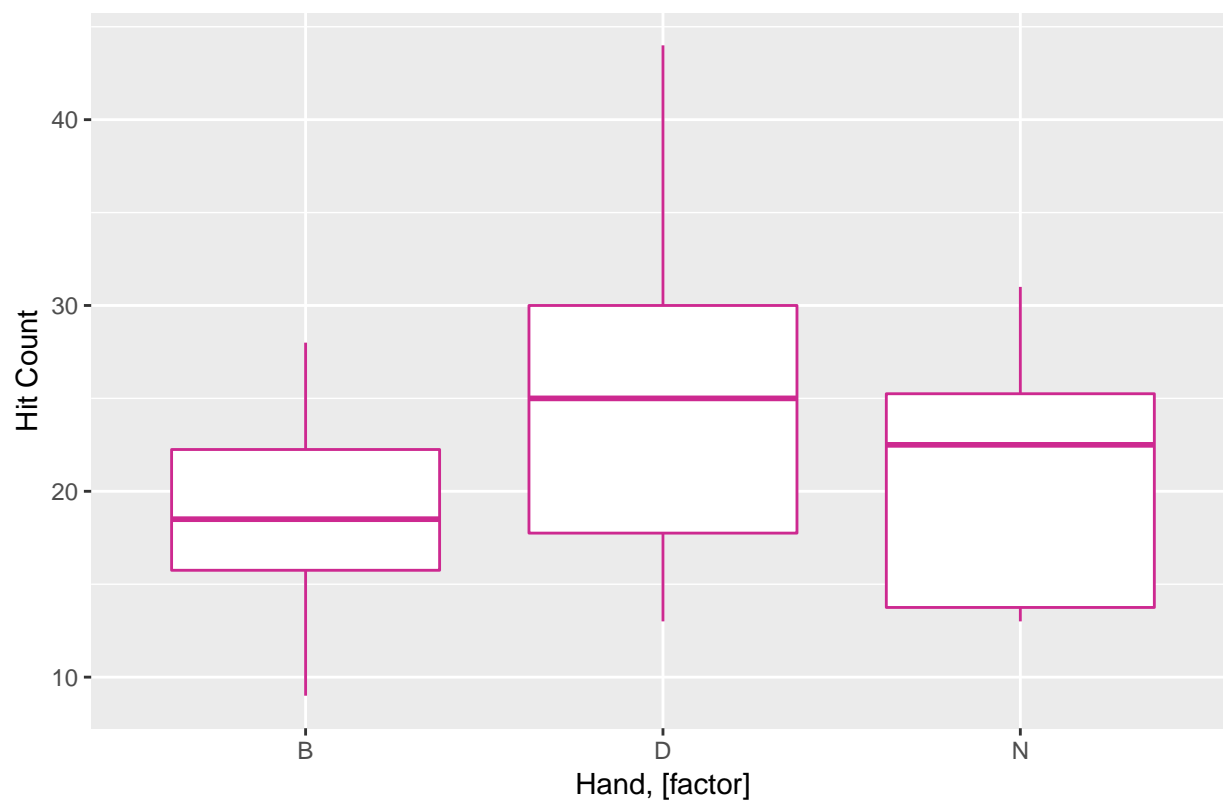
hand, as expected, the number of hits made by the dominant hand is significantly larger than that of the non-dominant and both hands. The variance shows the same behavior as that of mean values. Once again, the 4th block displays outlying behavior performance.

## Data visualization

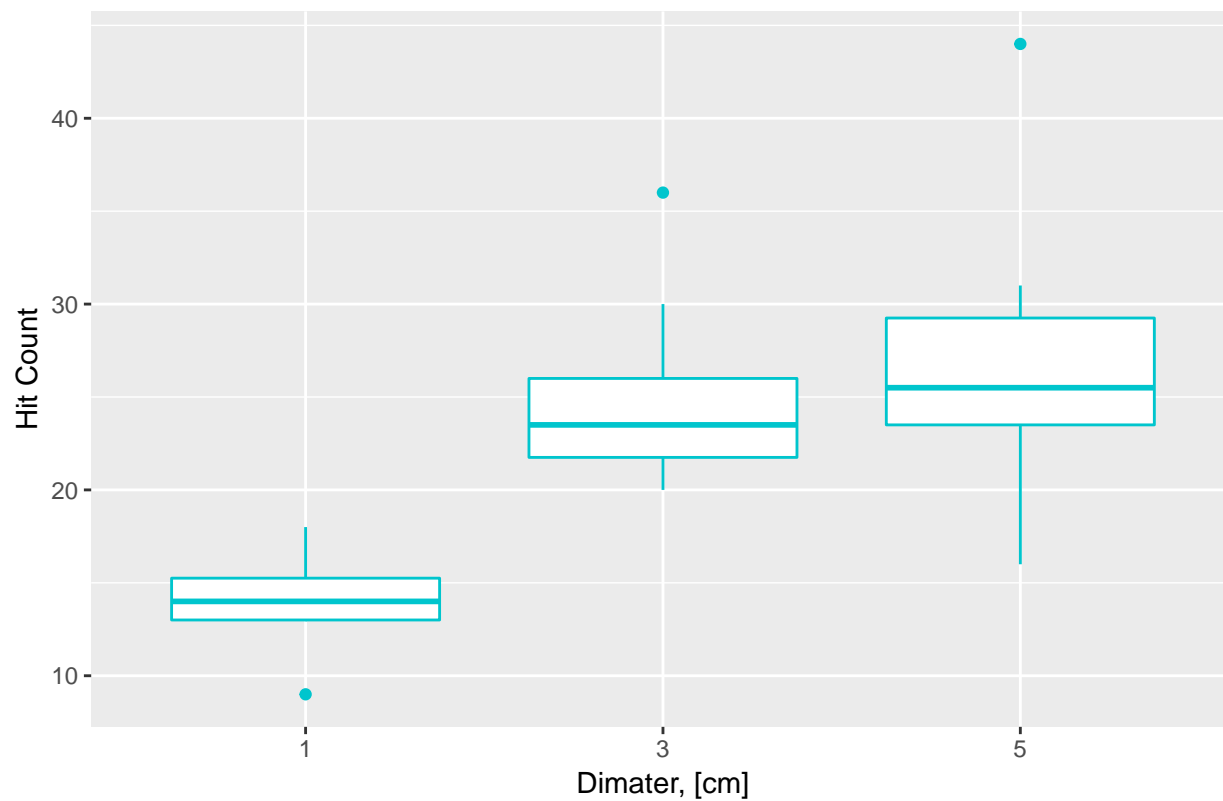
Let's visualize the dataset using boxplots.



Boxplot with Respect to Hand

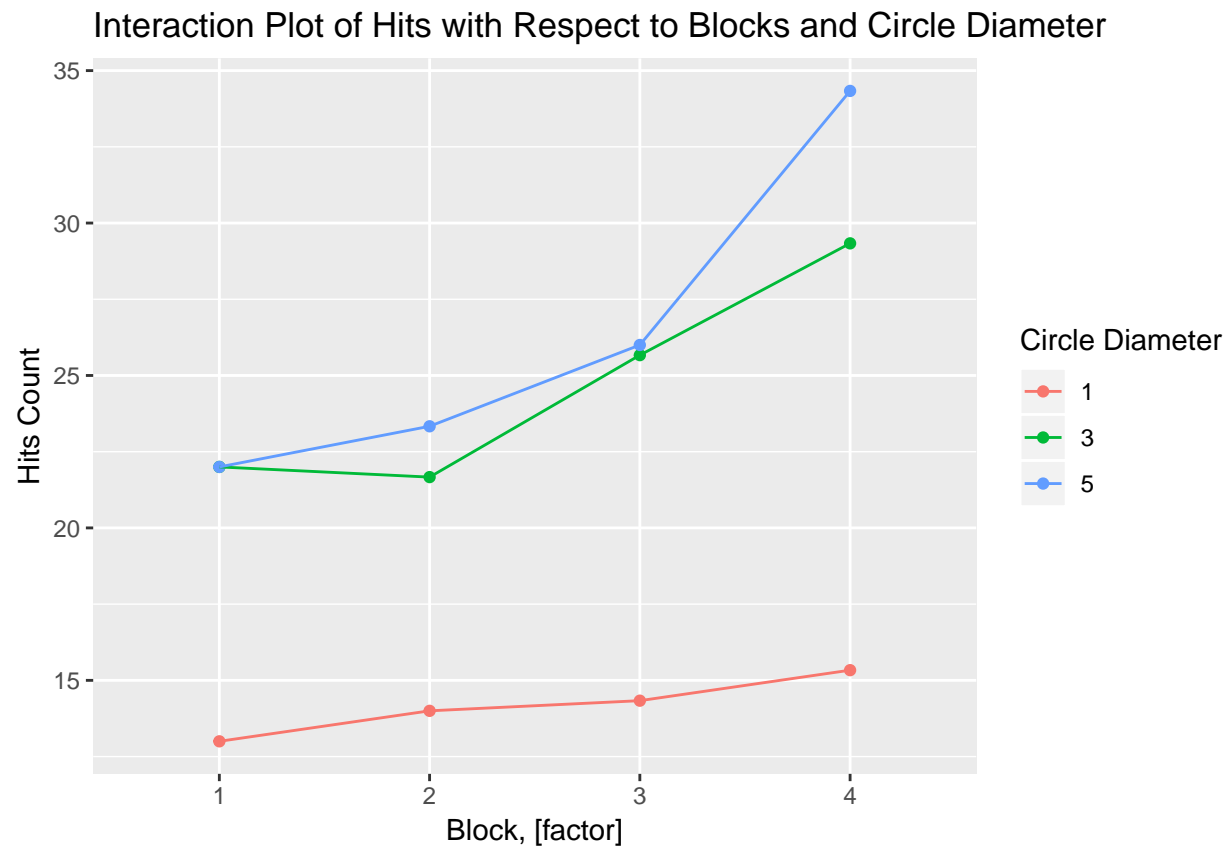


Boxplot with Respect to Circle Diameter

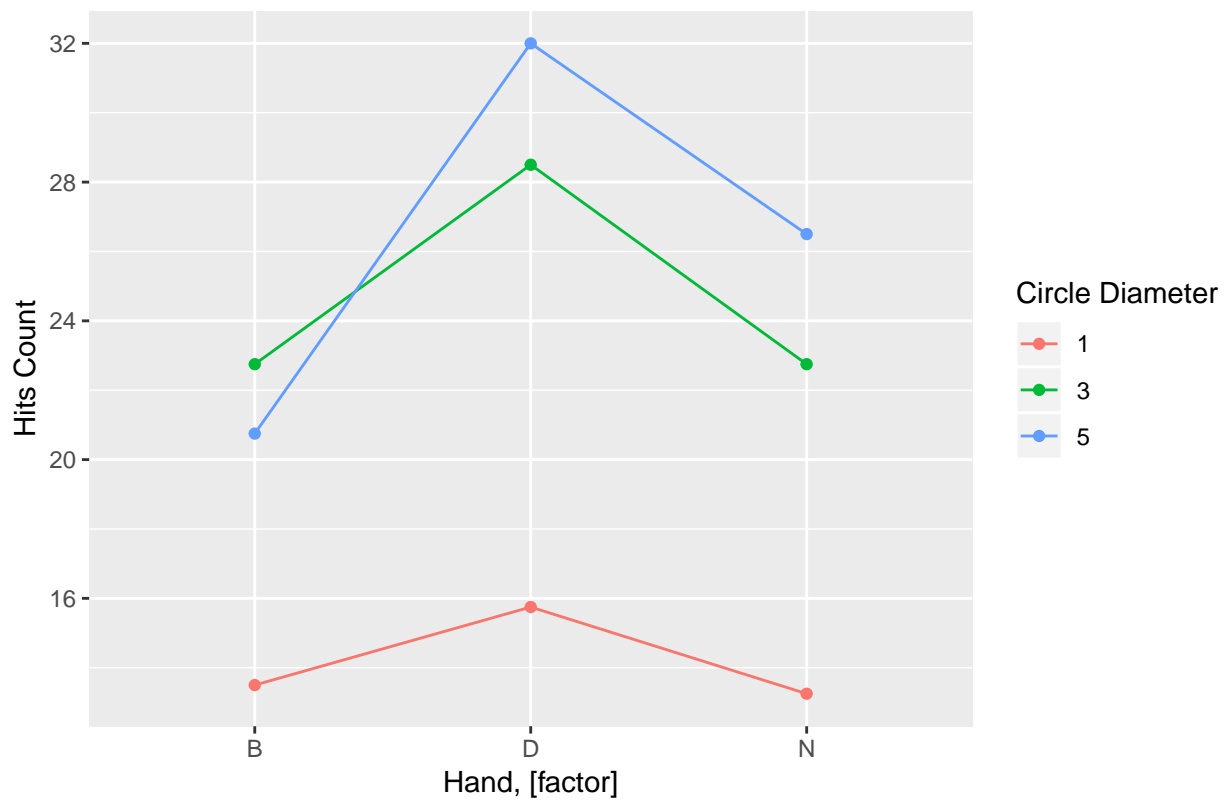


According to the boxplot visualization we can speculate, that mean values are significantly different for the “DIAMETER” variable.

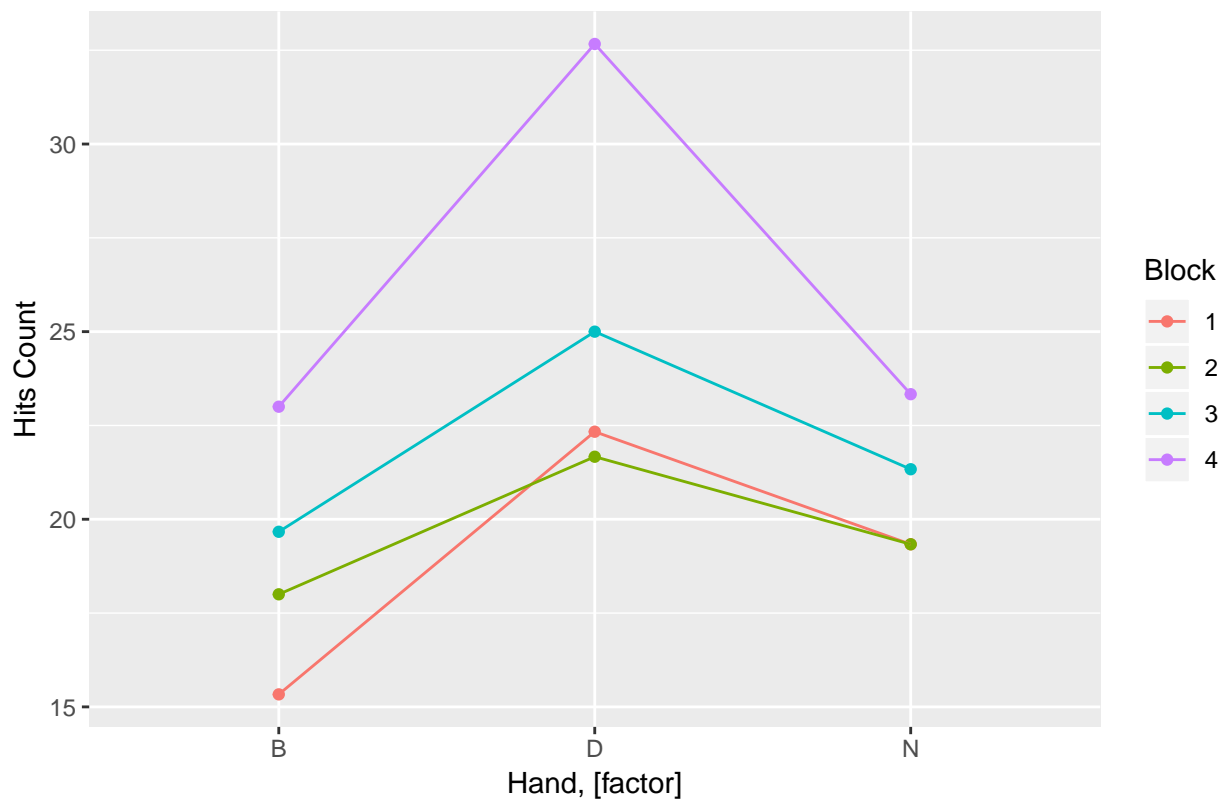
## Interaction plots



Interaction Plot of Hits with Respect to Hand and Circle Diameter



Interaction Plot of Hits with Respect to Hand and Blocks



Interaction plots 1 and 3 display, that the 4th block (operator) is different from the rest. Others show similar ring hits count. This can possibly be caused by the effect of noise. Interaction plot 2 displays the dependence of the ring hits count on the “HAND” and “DIAMETER” variables, e.g. hits count to the ring of diameter 5 cm for the dominant hand is the largest.

## ANOVA without interactions

```
##          Df Sum Sq Mean Sq F value    Pr(>F)
## BLOCK      3  296.8    98.9    8.925 0.000261 ***
## HAND       2  262.2   131.1   11.827 0.000189 ***
## DIAMETER    2 1053.5   526.7   47.526 9.98e-10 ***
## Residuals  28  310.3    11.1
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

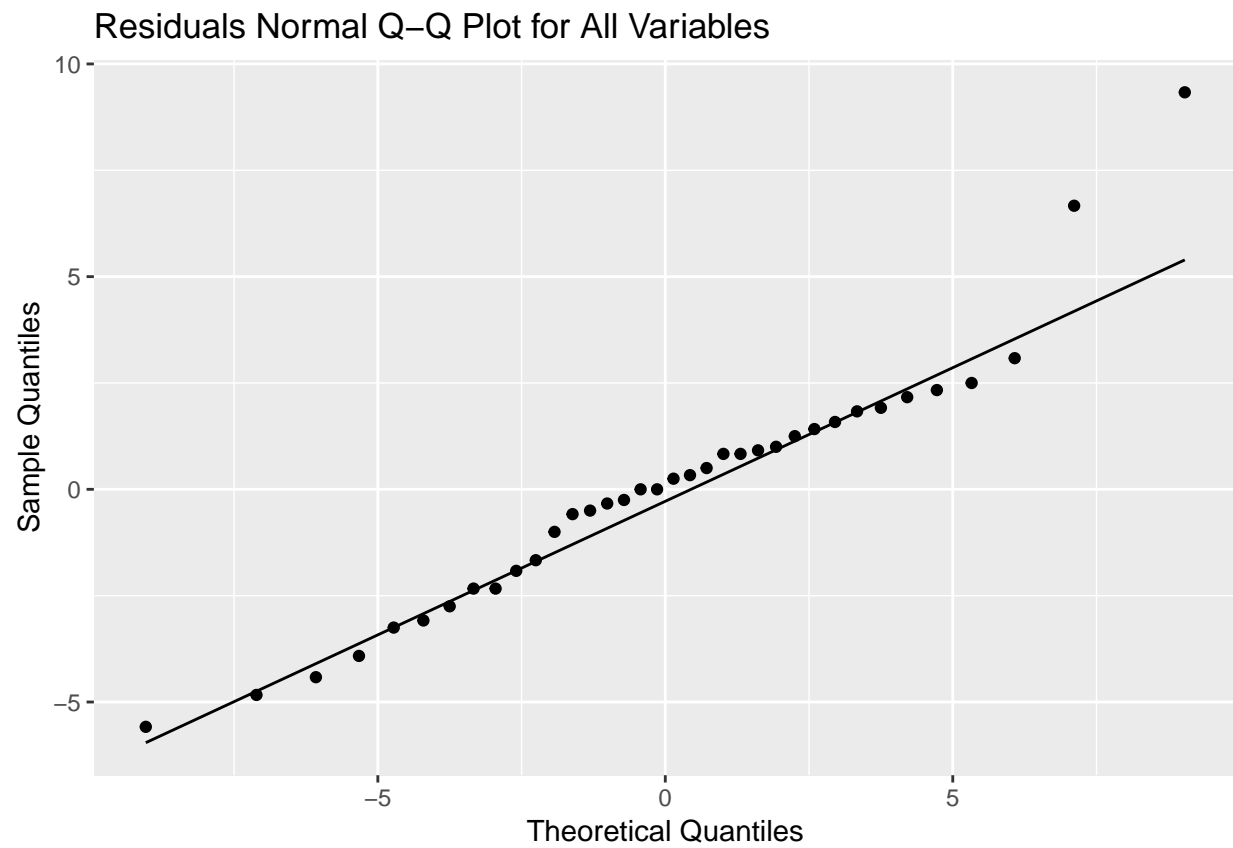
ANOVA has shown, that all variables are significant on the 95% significance level.

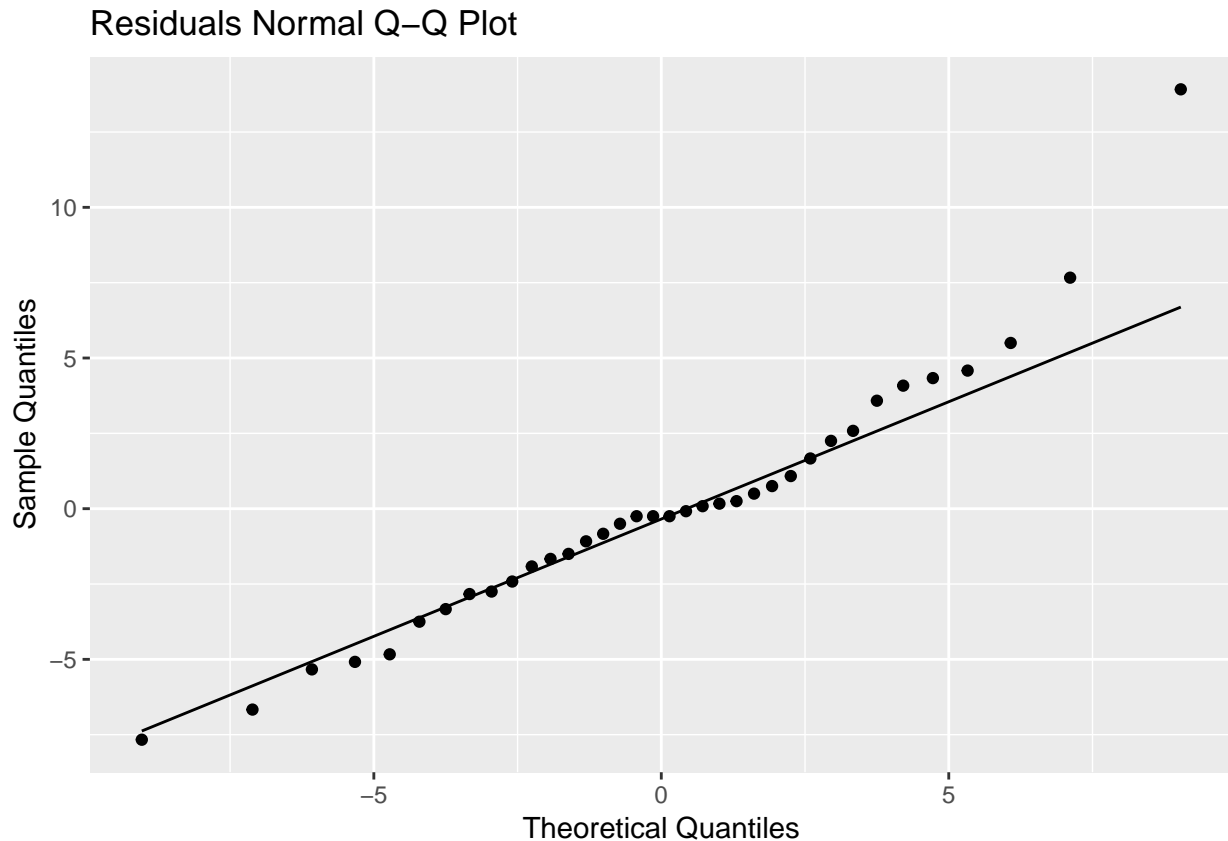
```
##          Df Sum Sq Mean Sq F value    Pr(>F)
## HAND      2  262.2   131.1    6.694 0.00383 **
## DIAMETER   2 1053.5   526.8   26.898 1.68e-07 ***
## Residuals  31  607.1    19.6
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Variables “HAND” and “DIAMETER” are still significant even without dependence of the ring hits on the blocks (operators). That enables us to reject the hypothesis about the equality of mean values.

## Residuals

### Q-Q plot for residuals





Q-Q plots lines fit the data in an acceptable way. However, a few values display outlying behavior. Normality tests must be carried out. We perform Shapiro-Wilk test. The following is the result of the test.

```
##
##  Shapiro-Wilk normality test
##
## data:  residuals_aov_all
## W = 0.94306, p-value = 0.06331

##
##  Shapiro-Wilk normality test
##
## data:  residuals_aov
## W = 0.94531, p-value = 0.07444
```

As p-values from the Shapiro-Wilk test are close to the set significance level (5%), we will also perform the Lilliefors test of normality.

```
##
##  Lilliefors (Kolmogorov-Smirnov) normality test
##
## data:  residuals_aov_all
## D = 0.11724, p-value = 0.2403

##
##  Lilliefors (Kolmogorov-Smirnov) normality test
##
## data:  residuals_aov
## D = 0.12299, p-value = 0.1828
```



As a result of the test, we cannot reject the residuals normality hypothesis for both models.

### Fisher's LSD-test.

```
## $statistics
##      MSerror Df  Mean      CV  t.value      LSD
##      11.1 28 21.75 15.31801 2.048407 2.786135
##
## $parameters
##      test p.adjusted      name.t ntr alpha
##  Fisher-LSD      none hit_data$HAND   3  0.05
##
## $means
##  hit_data$HITS_SUM      std r      LCL      UCL Min Max  Q25  Q50  Q75
## B      19.00000 5.460603 12 17.02991 20.97009   9 28 15.75 18.5 22.25
## D      25.41667 9.080031 12 23.44657 27.38676  13 44 17.75 25.0 30.00
## N      20.83333 6.220689 12 18.86324 22.80343  13 31 13.75 22.5 25.25
##
## $comparison
## NULL
##
## $groups
##  hit_data$HITS_SUM groups
## D      25.41667      a
## N      20.83333      b
## B      19.00000      b
##
## attr("class")
## [1] "group"

## $statistics
##      MSerror Df  Mean      CV  t.value      LSD
##      11.1 28 21.75 15.31801 2.048407 3.217152
##
## $parameters
##      test p.adjusted      name.t ntr alpha
##  Fisher-LSD      none hit_data$BLOCK   4  0.05
##
## $means
##  hit_data$HITS_SUM      std r      LCL      UCL Min Max  Q25  Q50  Q75
## 1      19.00000 5.545268 9 16.72513 21.27487   9 25 17 20 24
## 2      19.66667 5.567764 9 17.39180 21.94154  13 29 16 20 23
## 3      22.00000 6.383573 9 19.72513 24.27487  14 30 15 23 26
## 4      26.33333 10.037430 9 24.05846 28.60820  13 44 18 26 31
##
## $comparison
## NULL
##
## $groups
##  hit_data$HITS_SUM groups
## 4      26.33333      a
## 3      22.00000      b
## 2      19.66667      b
## 1      19.00000      b
```

```
##
## attr("class")
## [1] "group"

## $statistics
##      MSerror Df  Mean      CV  t.value      LSD
##      11.1 28 21.75 15.31801 2.048407 2.786135
##
## $parameters
##      test p.adjusted      name.t ntr alpha
## Fisher-LSD      none hit_data$DIAMETER 3 0.05
##
## $means
##      hit_data$HITS_SUM      std  r      LCL      UCL Min Max  Q25  Q50  Q75
## 1      14.16667 2.329000 12 12.19657 16.13676 9 18 13.00 14.0 15.25
## 3      24.66667 4.579268 12 22.69657 26.63676 20 36 21.75 23.5 26.00
## 5      26.41667 7.254570 12 24.44657 28.38676 16 44 23.50 25.5 29.25
##
## $comparison
## NULL
##
## $groups
##      hit_data$HITS_SUM groups
## 5      26.41667      a
## 3      24.66667      a
## 1      14.16667      b
##
## attr("class")
## [1] "group"
```

## Tukey's HSD-test.

```
##      Tukey multiple comparisons of means
##      95% family-wise confidence level
##
## Fit: aov(formula = HITS_SUM ~ BLOCK + HAND + DIAMETER, data = hit_data)
##
## $BLOCK
##      diff      lwr      upr      p adj
## 2-1 0.6666667 -3.61823787 4.951571 0.9737563
## 3-1 3.0000000 -1.28490454 7.284905 0.2462305
## 4-1 7.3333333 3.04842879 11.618238 0.0003754
## 3-2 2.3333333 -1.95157121 6.618238 0.4585614
## 4-2 6.6666667 2.38176213 10.951571 0.0011687
## 4-3 4.3333333 0.04842879 8.618238 0.0467076
##
## $HAND
##      diff      lwr      upr      p adj
## D-B 6.416667 3.053714 9.779619 0.0001711
## N-B 1.833333 -1.529619 5.196286 0.3808515
## N-D -4.583333 -7.946286 -1.220381 0.0060219
##
## $DIAMETER
##      diff      lwr      upr      p adj
```

```
## 3-1 10.50 7.137047 13.862953 0.0000001
## 5-1 12.25 8.887047 15.612953 0.0000000
## 5-3 1.75 -1.612953 5.112953 0.4137523
```

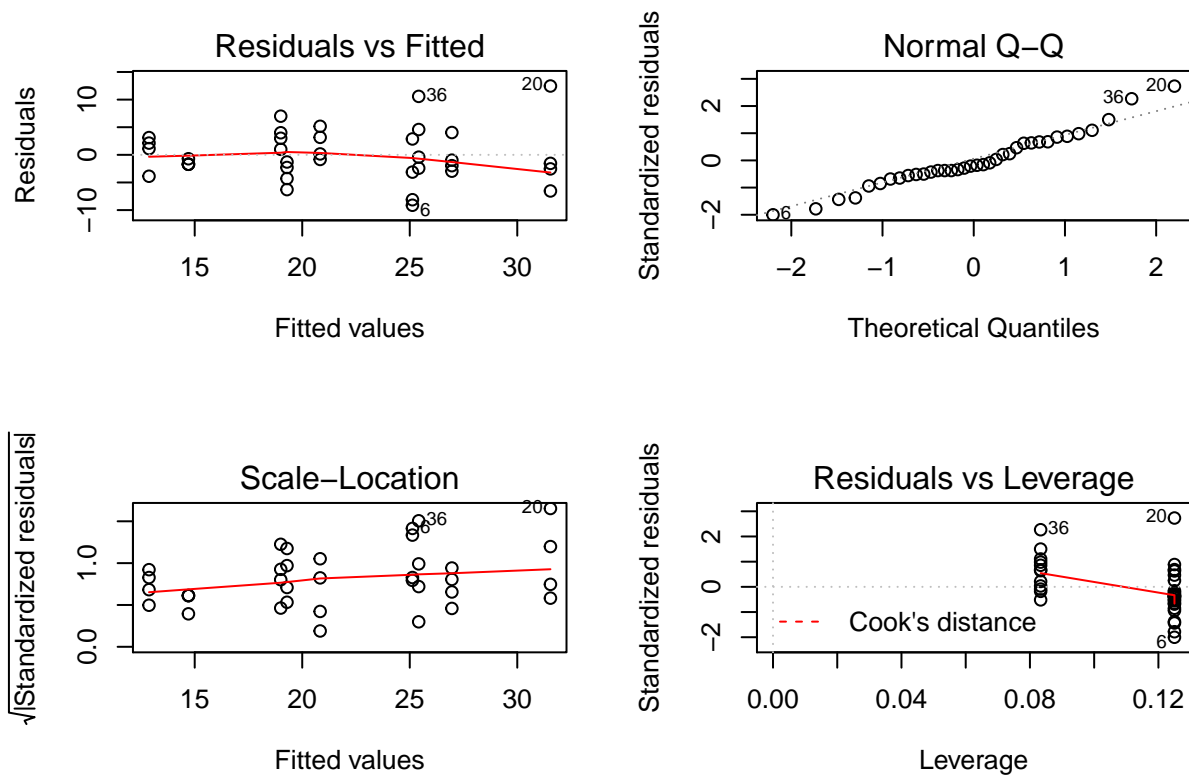
Once again, we observe significant difference between the 4th block (operator) and 3 other blocks. An interesting observation is that the 3rd block is on the edge of being significantly similar to the 4th one.

Both tests have confirmed, that the performance of the dominant hand is significantly different from other variants.

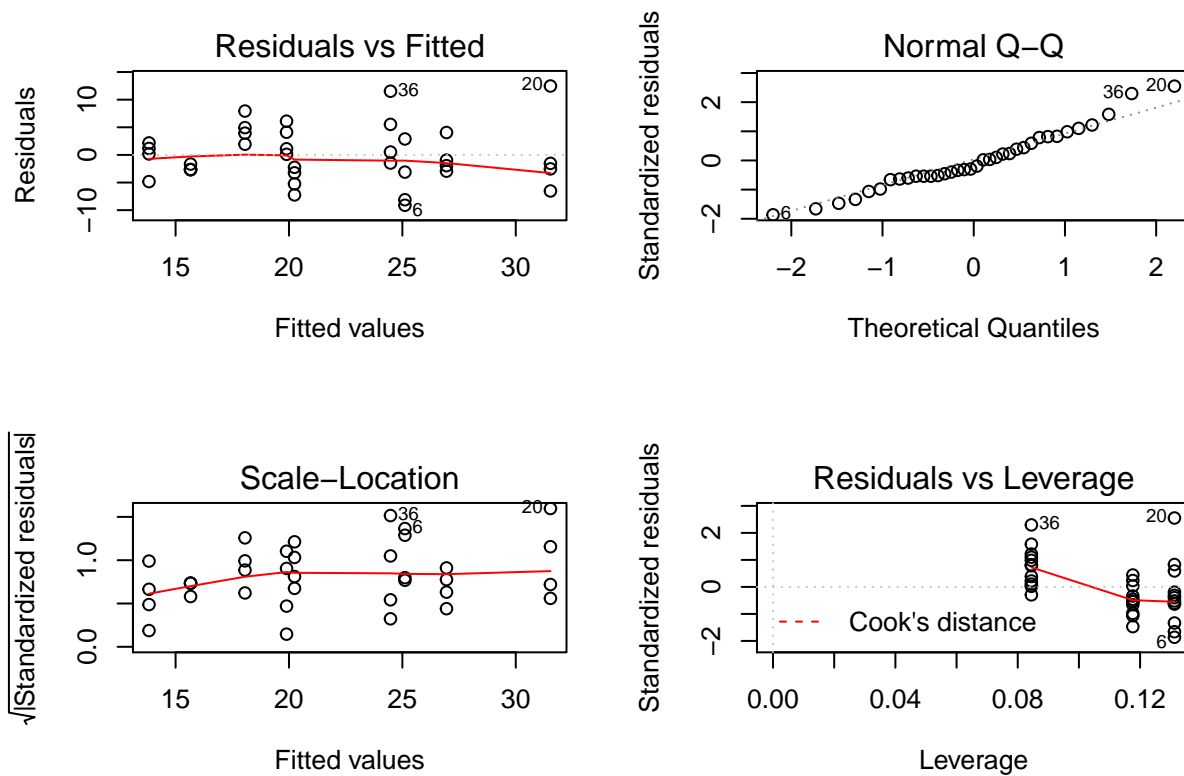
Tukey's HSD test and Fisher's LSD test indicate, that rings with diameters 3 cm and 5 cm are significantly similar. On the other hand, the ring with diameter of 1 cm is significantly different from two other ones.

## Linear Regression

```
##
## Call:
## lm(formula = HITS_SUM ~ -1 + DIAMETER + HAND, data = lm_data)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -9.1250 -2.4479 -0.8958  3.0312 12.4583
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## DIAMETER      6.1250     0.9949   6.156 6.91e-07 ***
## HANDB         6.7500     2.4370   2.770 0.00926 **
## HANDD        13.1667     2.4370   5.403 6.15e-06 ***
## HANDN         8.5833     2.4370   3.522 0.00131 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 4.874 on 32 degrees of freedom
## Multiple R-squared:  0.9599, Adjusted R-squared:  0.9549
## F-statistic: 191.5 on 4 and 32 DF,  p-value: < 2.2e-16
```



```
##
## Call:
## lm(formula = HITS_SUM ~ -1 + I(DIAMETER^2) + HAND, data = lm_data)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -9.113 -2.732 -1.211  3.150 12.470
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## I(DIAMETER^2)   1.4107     0.2649   5.325 7.72e-06 ***
## HANDB           12.4167     1.9548   6.352 3.94e-07 ***
## HANDD           18.8333     1.9548   9.634 5.60e-11 ***
## HANDN           14.2500     1.9548   7.290 2.76e-08 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 5.245 on 32 degrees of freedom
## Multiple R-squared:  0.9535, Adjusted R-squared:  0.9477
## F-statistic: 164.2 on 4 and 32 DF,  p-value: < 2.2e-16
```



## Normality of residuals

```
##
## Shapiro-Wilk normality test
##
## data:  lm_circle_1$residuals
## W = 0.96522, p-value = 0.3096
##
## Shapiro-Wilk normality test
##
## data:  lm_circle_2$residuals
## W = 0.96775, p-value = 0.3674
```

As Q-Q plots and Shapiro-Wilk test indicate, general assumptions for performing the linear regression task are met. According to the R-squared statistic, the model with the ring diameter set to the power of 2 explains the hit data slightly worse. However, the difference is negligible. As a result, we choose the first model.