Bilingualism

R Markdown

We load the data and remove the cases with NA values.

```
str(D1)
```

```
## 'data.frame':    104 obs. of  16 variables:
##  $ Name  : Factor w/ 104 levels "Albert Denk",..: 1 2 3 4 5 6 7 8 9 10 ...
##  $ CoR   : Factor w/ 2 levels "0","1": 1 2 2 2 2 2 2 1 1 2 ...
##  $ Hand  : Factor w/ 2 levels "0","1": 2 2 2 1 2 2 2 2 2 2 ...
##  $ EO    : Factor w/ 2 levels "0","1": 1 1 2 2 2 2 2 1 1 2 ...
##  $ List  : Factor w/ 2 levels "0","1": 1 1 2 1 1 2 2 2 2 2 ...
##  $ CEF   : Ord.factor w/ 3 levels "3"<"4"<"5": 2 3 2 3 2 3 1 3 3 3 ...
##  $ SRRC  : num  3.8 4 4 4 4 5 3 5 3.5 5 ...
##  $ PRE   : num  0.33 0.5 1 1 0.78 1 0.83 1 0.88 1 ...
##  $ POST1 : num  0.94 1 1 1 0.94 1 1 1 1 1 ...
##  $ POST2 : num  1 0.88 1 1 0.88 1 1 0.88 0.88 1 ...
##  $ STAY  : Factor w/ 2 levels "0","1": 1 1 2 2 1 2 1 2 2 2 ...
##  $ LEAYRS: num  4.2 5 4 3.08 5 5 1.5 7 15 10 ...
##  $ HRSD  : num  0.25 0.75 0.5 0.125 0 1.5 0 4 1 0.125 ...
##  $ RPV   : num  5 5 3.5 5 5 2.5 3 2.5 4 2.5 ...
##  $ AMGE  : num  3.5 4 4.5 4 4.5 5 4.5 5 5 4.5 ...
##  $ AMSP  : num  4.1 3.67 4.17 4.33 3.33 ...
```

```
L0 <- read.csv2("size.csv",na.strings="#NUM!",sep=";",dec=",",header=TRUE)
LM<-L0 %>% select(Name,MEDIAN.2)
names(LM)[2]<-"time"
L0$Median <- apply(L0[c(3:10,15:21)],1,median,na.rm = TRUE)
LMM<-L0 %>% select(Name, Median)#MISMATCH.RTdominantanswerMedian)
names(LMM)[2]<-"time"

SM<-left_join(D1,LM,by="Name")
```

```
## Warning in left_join_impl(x, y, by$x, by$y): joining factors with
## different levels, coercing to character vector
```

```
SMM<-left_join(D1,LMM,by="Name")
```

```
## Warning in left_join_impl(x, y, by$x, by$y): joining factors with
## different levels, coercing to character vector
```

```
S<-rbind(data.frame(SM,type="MATCH"),data.frame(SMM,type="MISMATCH"))
S<-na.omit(S)
```

In total we have 225 data points.

Multiple Linear Regression

We try first a first order multiple linear regression model

```
S<-S%>%select(-Name)
m<-lm(data=S,time~.)
print(anova(m),signif.stars=TRUE)
```

```
## Analysis of Variance Table
##
## Response: time
##            Df   Sum Sq Mean Sq F value  Pr(>F)
## CoR         1   187158  187158    0.98 0.32435
## Hand        1   504558  504558    2.63 0.10650
## EO          1    18687   18687    0.10 0.75516
## List        1   961957  961957    5.02 0.02637 *
## CEF         2   100327   50163    0.26 0.76989
## SRRC        1    51294   51294    0.27 0.60549
## PRE         1    30891   30891    0.16 0.68849
## POST1       1      363     363    0.00 0.96533
## POST2       1   111787  111787    0.58 0.44598
## STAY        1    87515   87515    0.46 0.50001
## LEAYRS      1    38984   38984    0.20 0.65247
## HRSD        1   428788  428788    2.24 0.13652
## RPV         1   250644  250644    1.31 0.25431
## AMGE        1    92346   92346    0.48 0.48843
## AMSP        1  1063263 1063263    5.55 0.01966 *
## type        1  2860579 2860579   14.94 0.00016 ***
## Residuals 162 31025123  191513
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

and then we include all second order terms:

```
library(MASS)
m2<-lm(data=S,time~.^2)
print(anova(m2),signif.stars=TRUE)
```

```
## Analysis of Variance Table
##
## Response: time
##             Df  Sum Sq Mean Sq F value  Pr(>F)
## CoR          1  187158  187158    1.89 0.17343
## Hand         1  504558  504558    5.09 0.02699 *
## EO           1   18687   18687    0.19 0.66529
## List         1  961957  961957    9.71 0.00262 **
## CEF          2  100327   50163    0.51 0.60469
## SRRC         1   51294   51294    0.52 0.47402
## PRE          1   30891   30891    0.31 0.57821
## POST1        1     363     363    0.00 0.95190
## POST2        1  111787  111787    1.13 0.29154
## STAY         1   87515   87515    0.88 0.35030
## LEAYRS       1   38984   38984    0.39 0.53235
```

```
## HRSD          1  428788  428788    4.33 0.04096 *
## RPV           1  250644  250644    2.53 0.11596
## AMGE          1   92346   92346    0.93 0.33741
## AMSP          1 1063263 1063263   10.74 0.00161 **
## type          1 2860579 2860579   28.88 8.8e-07 ***
## CoR:Hand      1   39114   39114    0.39 0.53167
## CoR:List      1  258390  258390    2.61 0.11057
## CoR:CEF       2  840832  420416    4.25 0.01803 *
## CoR:SRRC      1  954499  954499    9.64 0.00271 **
## CoR:PRE       1   68843   68843    0.70 0.40714
## CoR:POST1     1   19297   19297    0.19 0.66021
## CoR:POST2     1 1120250 1120250   11.31 0.00123 **
## CoR:STAY      1    1917    1917    0.02 0.88972
## CoR:LEAYRS    1  357884  357884    3.61 0.06125 .
## CoR:HRSD      1  424964  424964    4.29 0.04185 *
## CoR:RPV       1   82391   82391    0.83 0.36471
## CoR:AMGE      1  276766  276766    2.79 0.09886 .
## CoR:AMSP      1      92      92    0.00 0.97574
## CoR:type      1   19079   19079    0.19 0.66202
## Hand:EO       1   32430   32430    0.33 0.56892
## Hand:List     1   49928   49928    0.50 0.47995
## Hand:CEF      2  220655  110327    1.11 0.33375
## Hand:SRRC     1   40721   40721    0.41 0.52338
## Hand:PRE      1    2678    2678    0.03 0.86984
## Hand:POST1    1  650665  650665    6.57 0.01243 *
## Hand:POST2    1  164145  164145    1.66 0.20202
## Hand:STAY     1    6050    6050    0.06 0.80547
## Hand:type     1  160583  160583    1.62 0.20693
## EO:List       1  114980  114980    1.16 0.28481
## EO:CEF        2  167981   83990    0.85 0.43241
## EO:SRRC       1     604     604    0.01 0.93798
## EO:PRE        1 1416002 1416002   14.30 0.00032 ***
## EO:POST1      1  433396  433396    4.38 0.03992 *
## EO:POST2      1    1261    1261    0.01 0.91048
## EO:STAY       1  168278  168278    1.70 0.19649
## EO:LEAYRS     1  136477  136477    1.38 0.24425
## EO:HRSD       1   15799   15799    0.16 0.69075
## EO:RPV        1  170443  170443    1.72 0.19367
## EO:AMGE       1  210794  210794    2.13 0.14887
## EO:AMSP       1 2390757 2390757   24.14 5.3e-06 ***
## EO:type       1   23154   23154    0.23 0.63017
## List:CEF      2  920762  460381    4.65 0.01258 *
## List:SRRC     1  408102  408102    4.12 0.04600 *
## List:PRE      1  595038  595038    6.01 0.01663 *
## List:POST1    1     375     375    0.00 0.95109
## List:POST2    1 1299350 1299350   13.12 0.00054 ***
## List:STAY     1    8792    8792    0.09 0.76659
## List:LEAYRS   1  152419  152419    1.54 0.21873
## List:HRSD     1  258073  258073    2.61 0.11078
## List:RPV      1  143893  143893    1.45 0.23195
## List:AMGE     1  601297  601297    6.07 0.01609 *
## List:AMSP     1  680615  680615    6.87 0.01065 *
## List:type     1  434754  434754    4.39 0.03962 *
## CEF:SRRC      2 2021163 1010581   10.20 0.00012 ***
```

```
## CEF:PRE      2  293438  146719    1.48 0.23405
## CEF:POST1    2  331946  165973    1.68 0.19426
## CEF:POST2    2  796412  398206    4.02 0.02205 *
## CEF:STAY     2  184269   92134    0.93 0.39905
## CEF:LEAYRS   2  511021  255510    2.58 0.08267 .
## CEF:HRSD     2   22017   11008    0.11 0.89495
## CEF:RPV      1    6616    6616    0.07 0.79678
## CEF:AMGE     1  377189  377189    3.81 0.05483 .
## CEF:AMSP     1   15234   15234    0.15 0.69605
## CEF:type     2   76620   38310    0.39 0.68059
## SRRC:PRE     1  704627  704627    7.11 0.00941 **
## SRRC:POST1   1    8401    8401    0.08 0.77168
## SRRC:POST2   1  472639  472639    4.77 0.03213 *
## SRRC:STAY    1   26848   26848    0.27 0.60417
## SRRC:LEAYRS  1  201358  201358    2.03 0.15816
## SRRC:HRSD    1     722     722    0.01 0.93217
## SRRC:RPV     1   36127   36127    0.36 0.54773
## SRRC:AMGE    1  212073  212073    2.14 0.14766
## SRRC:type    1     396     396    0.00 0.94974
## PRE:type     1   51409   51409    0.52 0.47353
## POST1:type   1  167275  167275    1.69 0.19781
## POST2:type   1  182566  182566    1.84 0.17873
## STAY:type    1     160     160    0.00 0.96800
## LEAYRS:type  1   67512   67512    0.68 0.41169
## HRSD:type    1  149946  149946    1.51 0.22247
## RPV:type     1   69162   69162    0.70 0.40606
## AMGE:type    1   66233   66233    0.67 0.41614
## AMSP:type    1  196616  196616    1.99 0.16308
## Residuals   73 7229557   99035
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

We apply stepwise model search procedure:

```
model.stp<-stepAIC(aov(data=S,time~.^2),scope=list(upper=~.^2,lower=~1),
                   direction="backward",trace=FALSE)
print(model.stp$anova,signif.stars=TRUE)
```

```
## Stepwise Model Path
## Analysis of Deviance Table
##
## Initial Model:
## time ~ (CoR + Hand + EO + List + CEF + SRRC + PRE + POST1 + POST2 +
##     STAY + LEAYRS + HRSD + RPV + AMGE + AMSP + type)^2
##
## Final Model:
## time ~ CoR + Hand + EO + List + CEF + SRRC + PRE + POST1 + POST2 +
##     STAY + LEAYRS + HRSD + RPV + AMGE + AMSP + type + CoR:List +
##     CoR:CEF + CoR:SRRC + CoR:POST1 + CoR:STAY + CoR:LEAYRS +
##     CoR:HRSD + CoR:RPV + CoR:AMSP + CoR:type + Hand:EO + Hand:List +
##     Hand:CEF + Hand:SRRC + Hand:PRE + Hand:POST1 + EO:List +
##     EO:CEF + EO:SRRC + EO:PRE + EO:POST1 + EO:POST2 + EO:STAY +
##     EO:LEAYRS + EO:HRSD + EO:RPV + List:SRRC + List:PRE + List:POST1 +
```

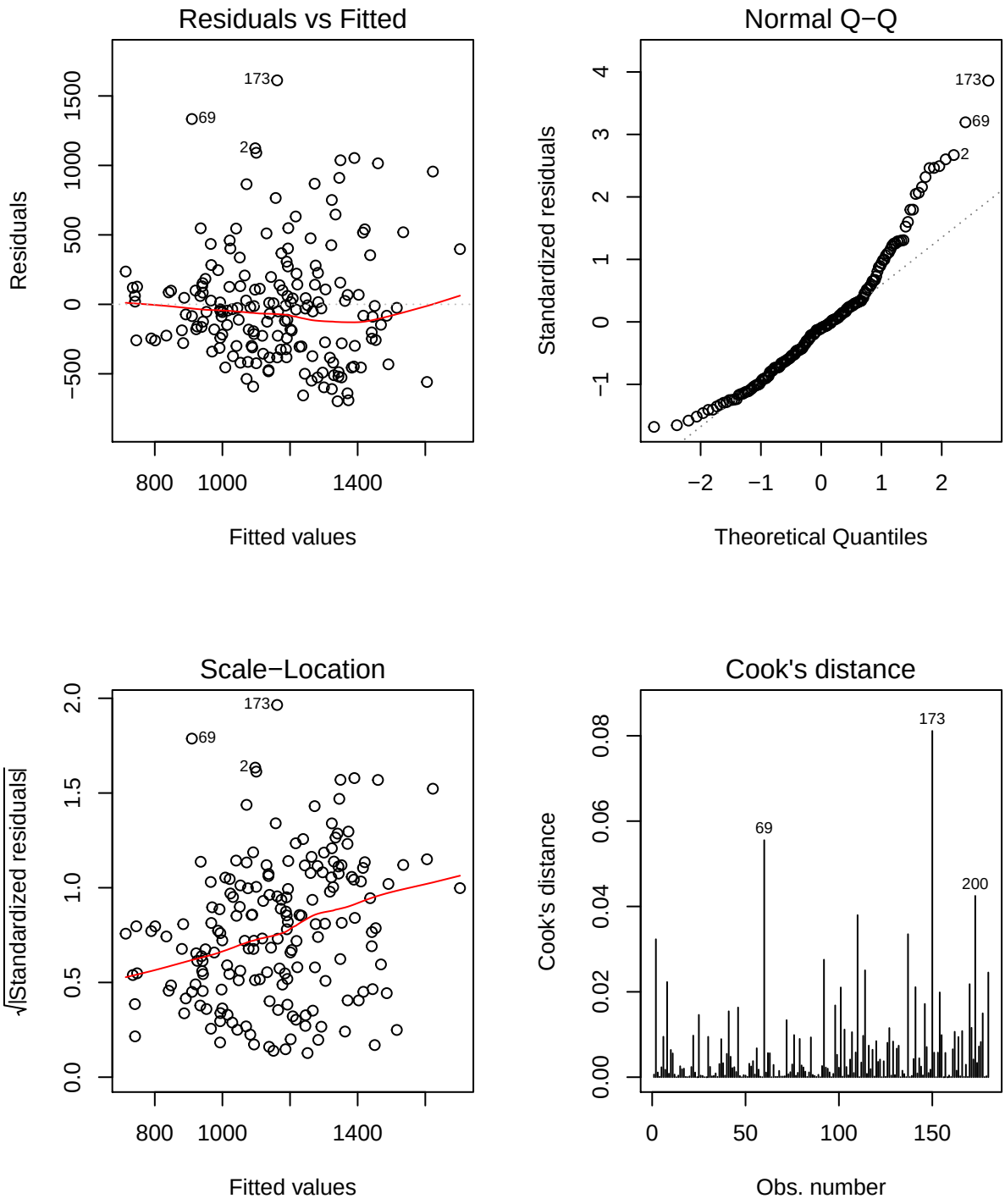
```
##     List:POST2 + List:STAY + List:LEAYRS + List:HRSD + List:RPV +
##     List:AMGE + List:AMSP + List:type + CEF:POST1 + CEF:POST2 +
##     CEF:STAY + CEF:HRSD + CEF:RPV + CEF:AMGE + CEF:AMSP + SRRC:POST1 +
##     SRRC:STAY + SRRC:LEAYRS + SRRC:HRSD + SRRC:RPV + SRRC:AMGE +
##     SRRC:type + POST2:type + STAY:type + HRSD:type + AMGE:type +
##     AMSP:type
##
##
##              Step Df   Deviance Resid. Df Resid. Dev    AIC
## 1                                      73    7229557 2122.1
## 2     - AMGE:AMSP  0 0.0000e+00        73    7229557 2122.1
## 3      - RPV:AMSP  0 0.0000e+00        73    7229557 2122.1
## 4      - RPV:AMGE  0 0.0000e+00        73    7229557 2122.1
## 5     - HRSD:AMSP  0 0.0000e+00        73    7229557 2122.1
## 6     - HRSD:AMGE  0 0.0000e+00        73    7229557 2122.1
## 7      - HRSD:RPV  0 0.0000e+00        73    7229557 2122.1
## 8   - LEAYRS:AMSP  0 0.0000e+00        73    7229557 2122.1
## 9   - LEAYRS:AMGE  0 0.0000e+00        73    7229557 2122.1
## 10   - LEAYRS:RPV  0 0.0000e+00        73    7229557 2122.1
## 11  - LEAYRS:HRSD  0 0.0000e+00        73    7229557 2122.1
## 12    - STAY:AMSP  0 0.0000e+00        73    7229557 2122.1
## 13    - STAY:AMGE  0 0.0000e+00        73    7229557 2122.1
## 14     - STAY:RPV  0 0.0000e+00        73    7229557 2122.1
## 15    - STAY:HRSD  0 0.0000e+00        73    7229557 2122.1
## 16  - STAY:LEAYRS  0 0.0000e+00        73    7229557 2122.1
## 17   - POST2:AMSP  0 0.0000e+00        73    7229557 2122.1
## 18   - POST2:AMGE  0 0.0000e+00        73    7229557 2122.1
## 19    - POST2:RPV  0 0.0000e+00        73    7229557 2122.1
## 20   - POST2:HRSD  0 0.0000e+00        73    7229557 2122.1
## 21 - POST2:LEAYRS  0 0.0000e+00        73    7229557 2122.1
## 22   - POST2:STAY  0 0.0000e+00        73    7229557 2122.1
## 23   - POST1:AMSP  0 0.0000e+00        73    7229557 2122.1
## 24   - POST1:AMGE  0 0.0000e+00        73    7229557 2122.1
## 25    - POST1:RPV  0 0.0000e+00        73    7229557 2122.1
## 26   - POST1:HRSD  0 0.0000e+00        73    7229557 2122.1
## 27 - POST1:LEAYRS  0 0.0000e+00        73    7229557 2122.1
## 28   - POST1:STAY  0 0.0000e+00        73    7229557 2122.1
## 29  - POST1:POST2  0 0.0000e+00        73    7229557 2122.1
## 30     - PRE:AMSP  0 0.0000e+00        73    7229557 2122.1
## 31     - PRE:AMGE  0 0.0000e+00        73    7229557 2122.1
## 32      - PRE:RPV  0 0.0000e+00        73    7229557 2122.1
## 33     - PRE:HRSD  0 0.0000e+00        73    7229557 2122.1
## 34   - PRE:LEAYRS  0 0.0000e+00        73    7229557 2122.1
## 35     - PRE:STAY  0 0.0000e+00        73    7229557 2122.1
## 36    - PRE:POST2  0 0.0000e+00        73    7229557 2122.1
## 37    - PRE:POST1  0 0.0000e+00        73    7229557 2122.1
## 38    - SRRC:AMSP  0 0.0000e+00        73    7229557 2122.1
## 39      - EO:AMSP  0 8.1025e-08        73    7229557 2122.1
## 40      - EO:AMGE  0 8.4285e-07        73    7229557 2122.1
## 41    - Hand:AMSP  0 0.0000e+00        73    7229557 2122.1
## 42    - Hand:AMGE  0 0.0000e+00        73    7229557 2122.1
## 43     - Hand:RPV  0 0.0000e+00        73    7229557 2122.1
## 44    - Hand:HRSD  0 0.0000e+00        73    7229557 2122.1
## 45  - Hand:LEAYRS  0 0.0000e+00        73    7229557 2122.1
```

```
## 46    - Hand:STAY  0 3.5204e-07        73    7229557 2122.1
## 47       - CoR:EO  0 0.0000e+00        73    7229557 2122.1
## 48      - CEF:PRE  2 1.5538e+04        75    7245095 2118.5
## 49     - CEF:SRRC  2 4.5441e+04        77    7290536 2115.6
## 50     - List:CEF  2 1.1093e+04        79    7301629 2111.9
## 51   - CEF:LEAYRS  2 7.2191e+04        81    7373820 2109.7
## 52     - PRE:type  1 3.7804e+03        82    7377601 2107.8
## 53    - CoR:POST2  1 4.1539e+03        83    7381755 2105.9
## 54     - SRRC:PRE  1 8.4906e+03        84    7390245 2104.1
## 55   - Hand:POST2  1 1.3421e+04        85    7403666 2102.4
## 56      - EO:type  1 1.6417e+04        86    7420083 2100.8
## 57     - CoR:Hand  1 2.0564e+04        87    7440647 2099.3
## 58     - CEF:type  2 1.3177e+05        89    7572413 2098.5
## 59    - Hand:type  1 2.9859e+04        90    7602271 2097.2
## 60   - POST1:type  1 5.7693e+04        91    7659965 2096.5
## 61     - CoR:AMGE  1 6.3252e+04        92    7723217 2096.0
## 62      - CoR:PRE  1 6.7213e+04        93    7790429 2095.6
## 63     - RPV:type  1 8.1964e+04        94    7872393 2095.5
## 64  - LEAYRS:type  1 7.1529e+04        95    7943922 2095.1
## 65   - SRRC:POST2  1 8.4278e+04        96    8028200 2095.0
```

```
#m2b<-lm(data=D1,)
#print(anova(m2b),signif.stars = TRUE)
#anova(m2b,m2)
```

Diagnostic plots

```
par(mfrow=c(2,2))
plot(m,which=1:4)
```



From the qplot we see that the point 1071 is an outlier: With hindsight we already remove it above. Afterwards the qqplot looks perfectly normal.

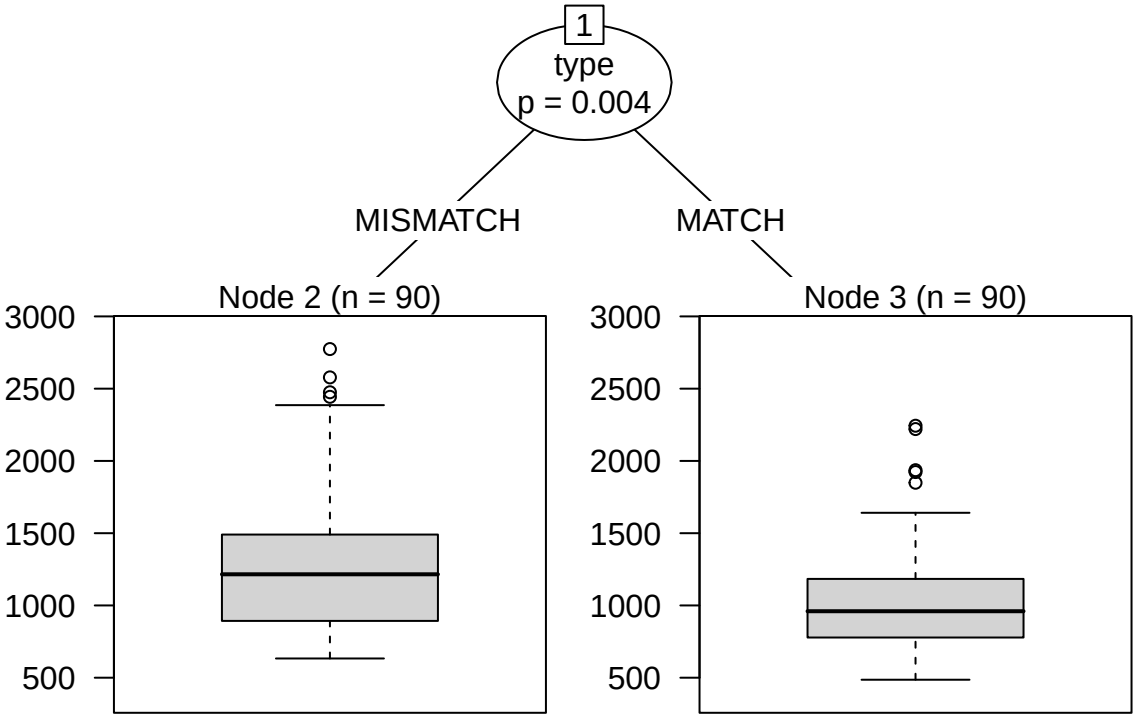
Regression tree

Another type of analysis by means of regression tree:

```
ct <- ctree(data=S,time~.^2)
ct
```

```
##
##   Conditional inference tree with 2 terminal nodes
##
## Response:  time
## Inputs:  CoR, Hand, EO, List, CEF, SRRC, PRE, POST1, POST2, STAY, LEAYRS, HRSD, RPV, AMGE, AMSP, type
## Number of observations:  180
##
## 1) type == {MISMATCH}; criterion = 0.996, statistic = 13.541
##   2)*  weights = 90
## 1) type == {MATCH}
##   3)*  weights = 90
```

```
plot(ct)
```



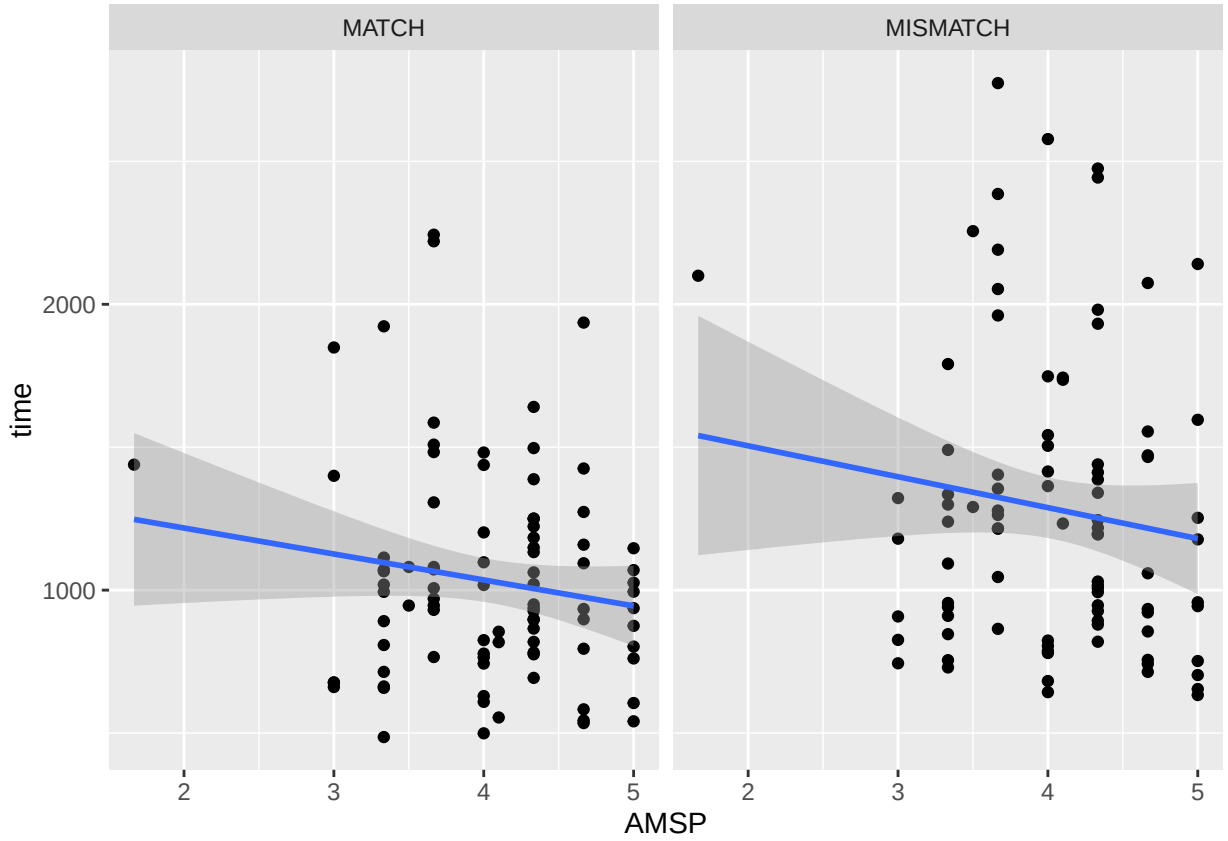
From the plot we understand that regression trees find only two factors POST1 and Hand and their interaction as relevant expalin differences in the response time.

Data visualization

We visualize the influence of the two factors that have been found explaning the most the reponse time. We separate the plots in match and mismatch cases, although this factor was found not to be important.

```
q<-ggplot(data=S,aes(y=time,x=AMSP))
q<-q+facet_grid(.~type)
q<-q+geom_point()
q<-q+geom_smooth(method=lm)
```

```
q<-q+theme(legend.position="top")
print(q)
```



We shall conclude that the response time depends on the hand and on the general proficency in the verbs as assessed by the POST1 test. Right handed subjects with good performance in the POST1 test respond faster.