Effect of β-blockade on reproducibility of heart rate, oxygen uptake and work rate across repeated bouts of short-duration perceptually regulated exercise

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Contents

1 Data preparation

```r
library(dplyr)
library(tidyr)
library(lme4)       # v1.1.35.5
library(lmerTest)   # v3.1.3
library(emmeans)    # v1.10.5
library(irr)        # v0.84.1
```

```r
# Function to calculate METs using ACSM metabolic equation for treadmill running
calculate_mets <- function(speed, grade) {
  (3.5 + (0.2 * (speed * (1000 / 60))) +
     (0.9 * (speed * (1000 / 60)) * (grade / 100))) / 3.5
}
```

```r
# Load intervals data
intervals <- read.csv("../../Data/RPE_Intervals.csv")

# Load GXT outcomes data
gxt <- read.csv("../../Data/GXT_outcomes.csv") |>
  mutate(mets_peak = calculate_mets(speed_peak, grade_peak)) |>
  select(pid, condition, vo2kg_vt, hr_vt, vo2kg_peak, hr_peak, mets_peak) |>
  filter(pid %in% unique(intervals$pid))

# Load resting CV measures data
rest_cv <- read.csv("../../Data/RestingCV_final.csv") |>
  select(pid, condition, hr_60, sbp_60, dbp_60, spo2_60) |>
  filter(pid %in% unique(intervals$pid))
```

```r
# Prepare intervals data
intervals <- intervals |>
  left_join(gxt, by = c("pid", "condition")) |>
  # Define condition & intensity as factors
  mutate(
    condition = factor(condition, c(0, 1), c("control", "bblock")),
    intensity = factor(intensity, c(13, 15), c("rpe13", "rpe15"))
  ) |>
  # Calculate secondary variables
  mutate(
    mets = calculate_mets(speed, grade),
    pct_vo2kg_vt = (vo2kg / vo2kg_vt) * 100,
    pct_vo2kg_peak = (vo2kg / vo2kg_peak) * 100,
    pct_hr_vt = (hr / hr_vt) * 100,
    pct_hr_peak = (hr / hr_peak) * 100,
    pct_mets_peak = (mets / mets_peak) * 100,
  )
```

2 Preliminary analyses

```r
# Transform resting CV measures to wide format
rest_cv_wide <- rest_cv |>
```

```
  mutate(condition = factor(condition, c(0, 1), c("control", "bblock"))) |>
  pivot_wider(names_from = condition, values_from = c(hr_60:spo2_60))
```

```
# Transform GXT outcomes to wide format
gxt_wide <- gxt |>
  mutate(condition = factor(condition, c(0, 1), c("control", "bblock"))) |>
  pivot_wider(names_from = condition, values_from = c(vo2kg_vt:mets_peak))
```

2.1 Difference in resting cardiovascular measures between conditions

```
# Difference in resting HR, B-blockade vs. Control
t.test(rest_cv_wide$hr_60_bblock, rest_cv_wide$hr_60_control, paired = TRUE)
```

```
    Paired t-test

data:  rest_cv_wide$hr_60_bblock and rest_cv_wide$hr_60_control
t = -5.4198, df = 12, p-value = 0.000155
alternative hypothesis: true mean difference is not equal to 0
95 percent confidence interval:
 -13.08613  -5.58156
sample estimates:
mean difference
      -9.333846
```

```
# Difference in resting systolic BP, B-blockade vs. Control
t.test(rest_cv_wide$sbp_60_bblock, rest_cv_wide$sbp_60_control, paired = TRUE)
```

```
    Paired t-test

data:  rest_cv_wide$sbp_60_bblock and rest_cv_wide$sbp_60_control
t = -4.2315, df = 12, p-value = 0.001165
alternative hypothesis: true mean difference is not equal to 0
95 percent confidence interval:
 -9.261881 -2.965811
sample estimates:
mean difference
      -6.113846
```

```
# Difference in resting diastolic BP, B-blockade vs. Control
t.test(rest_cv_wide$dbp_60_bblock, rest_cv_wide$dbp_60_control, paired = TRUE)
```

```
    Paired t-test

data:  rest_cv_wide$dbp_60_bblock and rest_cv_wide$dbp_60_control
t = -2.0166, df = 12, p-value = 0.06668
alternative hypothesis: true mean difference is not equal to 0
```

```
95 percent confidence interval:
 -5.268338  0.203723
sample estimates:
mean difference
      -2.532308
```

```r
# Difference in resting SpO2, B-blockade vs. Control
t.test(rest_cv_wide$spo2_60_bblock, rest_cv_wide$spo2_60_control, paired = TRUE)
```

```
    Paired t-test

data:  rest_cv_wide$spo2_60_bblock and rest_cv_wide$spo2_60_control
t = -0.15694, df = 12, p-value = 0.8779
alternative hypothesis: true mean difference is not equal to 0
95 percent confidence interval:
 -0.2175211  0.1882903
sample estimates:
mean difference
    -0.01461538
```

2.2 Difference in exercise responses between conditions

```r
# Difference in VO2kg @ VT, B-blockade vs. Control
t.test(gxt_wide$vo2kg_vt_bblock, gxt_wide$vo2kg_vt_control, paired = TRUE)
```

```
    Paired t-test

data:  gxt_wide$vo2kg_vt_bblock and gxt_wide$vo2kg_vt_control
t = -2.5167, df = 12, p-value = 0.02707
alternative hypothesis: true mean difference is not equal to 0
95 percent confidence interval:
 -2.7986182 -0.2013818
sample estimates:
mean difference
           -1.5
```

```r
# Difference in peak VO2kg, B-blockade vs. Control
t.test(gxt_wide$vo2kg_peak_bblock, gxt_wide$vo2kg_peak_control, paired = TRUE)
```

```
    Paired t-test

data:  gxt_wide$vo2kg_peak_bblock and gxt_wide$vo2kg_peak_control
t = -3.1832, df = 12, p-value = 0.007875
alternative hypothesis: true mean difference is not equal to 0
95 percent confidence interval:
 -5.587288 -1.046558
sample estimates:
mean difference
      -3.316923
```

```r
# Difference in HR @ VT, B-blockade vs. Control
t.test(gxt_wide$hr_vt_bblock, gxt_wide$hr_vt_control, paired = TRUE)
```

```
    Paired t-test

data:  gxt_wide$hr_vt_bblock and gxt_wide$hr_vt_control
t = -7.8674, df = 12, p-value = 4.46e-06
alternative hypothesis: true mean difference is not equal to 0
95 percent confidence interval:
 -33.66116 -19.06038
sample estimates:
mean difference
      -26.36077
```

```r
# Difference in peak HR, B-blockade vs. Control
t.test(gxt_wide$hr_peak_bblock, gxt_wide$hr_peak_control, paired = TRUE)
```

```
    Paired t-test

data:  gxt_wide$hr_peak_bblock and gxt_wide$hr_peak_control
t = -7.3809, df = 12, p-value = 8.491e-06
alternative hypothesis: true mean difference is not equal to 0
95 percent confidence interval:
 -48.24108 -26.25123
sample estimates:
mean difference
      -37.24615
```

```r
# Difference in peak work rate (METs), B-blockade vs. Control
t.test(gxt_wide$mets_peak_bblock, gxt_wide$mets_peak_control, paired = TRUE)
```

```
    Paired t-test

data:  gxt_wide$mets_peak_bblock and gxt_wide$mets_peak_control
t = -2.9845, df = 12, p-value = 0.01139
alternative hypothesis: true mean difference is not equal to 0
95 percent confidence interval:
 -1.5893589 -0.2480037
sample estimates:
mean difference
     -0.9186813
```

3 Linear mixed-effects models

3.1 Heart rate

```r
# Fit fully specified model for heart rate
lmm_hr_full <- lmer(
  hr ~ condition * intensity * bout_rpe + (1 | pid),
  data = intervals
)
```

```r
# Fit reduced model for heart rate without second-order interaction
lmm_hr_reduced <- lmer(
  hr ~ condition + intensity + bout_rpe + condition:intensity +
    condition:bout_rpe + intensity:bout_rpe + (1 | pid),
  data = intervals
)
```

```r
# Compare models via likelihood ratio test
anova(lmm_hr_full, lmm_hr_reduced)
```

```
Data: intervals
Models:
lmm_hr_reduced: hr ~ condition + intensity + bout_rpe + condition:intensity + condition:bout_rpe + inter
lmm_hr_full: hr ~ condition * intensity * bout_rpe + (1 | pid)
               npar    AIC    BIC  logLik deviance  Chisq Df Pr(>Chisq)
lmm_hr_reduced    9 1155.1 1182.5 -568.54   1137.1
lmm_hr_full      10 1156.0 1186.5 -567.98   1136.0 1.1245  1     0.2889
```

```r
summary(lmm_hr_reduced)
```

```
Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]
Formula: hr ~ condition + intensity + bout_rpe + condition:intensity +
    condition:bout_rpe + intensity:bout_rpe + (1 | pid)
   Data: intervals

REML criterion at convergence: 1117.4

Scaled residuals:
     Min       1Q   Median       3Q      Max
-1.98001 -0.62936 -0.04739  0.58758  2.40672

Random effects:
 Groups   Name        Variance Std.Dev.
 pid      (Intercept) 117.93   10.860
 Residual              69.55    8.339
Number of obs: 156, groups:  pid, 13

Fixed effects:
                              Estimate Std. Error      df t value Pr(>|t|)
(Intercept)                    132.897      4.345  43.530  30.586  < 2e-16 ***
conditionbblock                -36.494      3.777 137.000  -9.662  < 2e-16 ***
intensityrpe15                  19.935      3.777 137.000   5.278 4.99e-07 ***
bout_rpe                         6.538      1.416 137.000   4.616 8.92e-06 ***
conditionbblock:intensityrpe15  -5.521      2.671 137.000  -2.067   0.0406 *
conditionbblock:bout_rpe        -1.763      1.636 137.000  -1.078   0.2828
```

```
intensityrpe15:bout_rpe          -2.437      1.636 137.000  -1.490   0.1386
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) cndtnb intn15 bot_rp cnd:15 cndt:_
condtnbblck -0.435
intnstyrp15 -0.435  0.125
bout_rpe    -0.652  0.500  0.500
cndtnbbl:15  0.154 -0.354 -0.354  0.000
cndtnbblc:_  0.376 -0.866  0.000 -0.577  0.000
intnsty15:_  0.376  0.000 -0.866 -0.577  0.000  0.000
```

```
confint(lmm_hr_reduced)
```

```
                                    2.5 %      97.5 %
.sig01                           7.224191  16.4358637
.sigma                           7.300799   9.2084335
(Intercept)                    124.457854 141.3357358
conditionbblock                -43.788417 -29.1987621
intensityrpe15                  12.639788  27.2294430
bout_rpe                         3.801940   9.2730604
conditionbblock:intensityrpe15 -10.678735  -0.3622907
conditionbblock:bout_rpe        -4.922215   1.3952915
intensityrpe15:bout_rpe         -5.595291   0.7222146
```

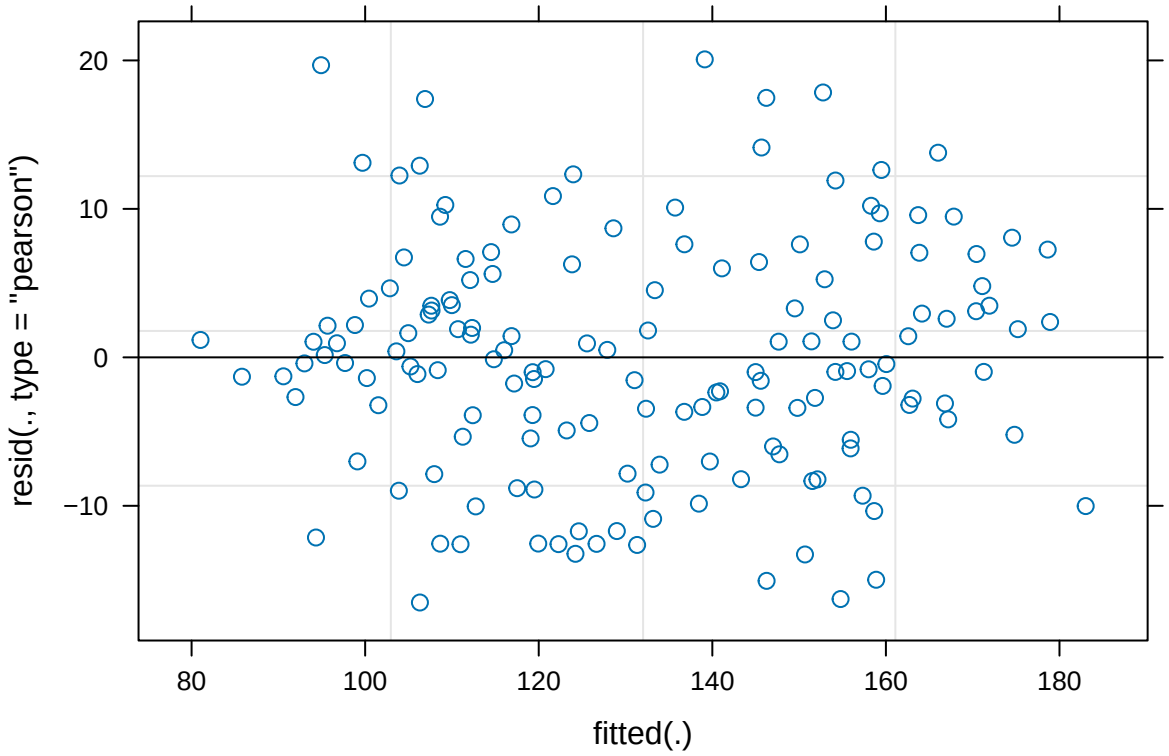
```
# Pairwise comparisons for condition * intensity
emmeans(lmm_hr_reduced, pairwise ~ condition * intensity)
```

```
$emmeans
 condition intensity emmean   SE   df lower.CL upper.CL
 control   rpe13        146 3.29 15.6      139      153
 bblock    rpe13        106 3.29 15.6       99      113
 control   rpe15        161 3.29 15.6      154      168
 bblock    rpe15        115 3.29 15.6      108      122

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95

$contrasts
 contrast                      estimate   SE  df t.ratio p.value
 control rpe13 - bblock rpe13     40.02 1.89 137  21.191  <.0001
 control rpe13 - control rpe15   -15.06 1.89 137  -7.975  <.0001
 control rpe13 - bblock rpe15     30.48 1.89 137  16.139  <.0001
 bblock rpe13 - control rpe15    -55.08 1.89 137 -29.167  <.0001
 bblock rpe13 - bblock rpe15      -9.54 1.89 137  -5.052  <.0001
 control rpe15 - bblock rpe15     45.54 1.89 137  24.115  <.0001

Degrees-of-freedom method: kenward-roger
P value adjustment: tukey method for comparing a family of 4 estimates
```

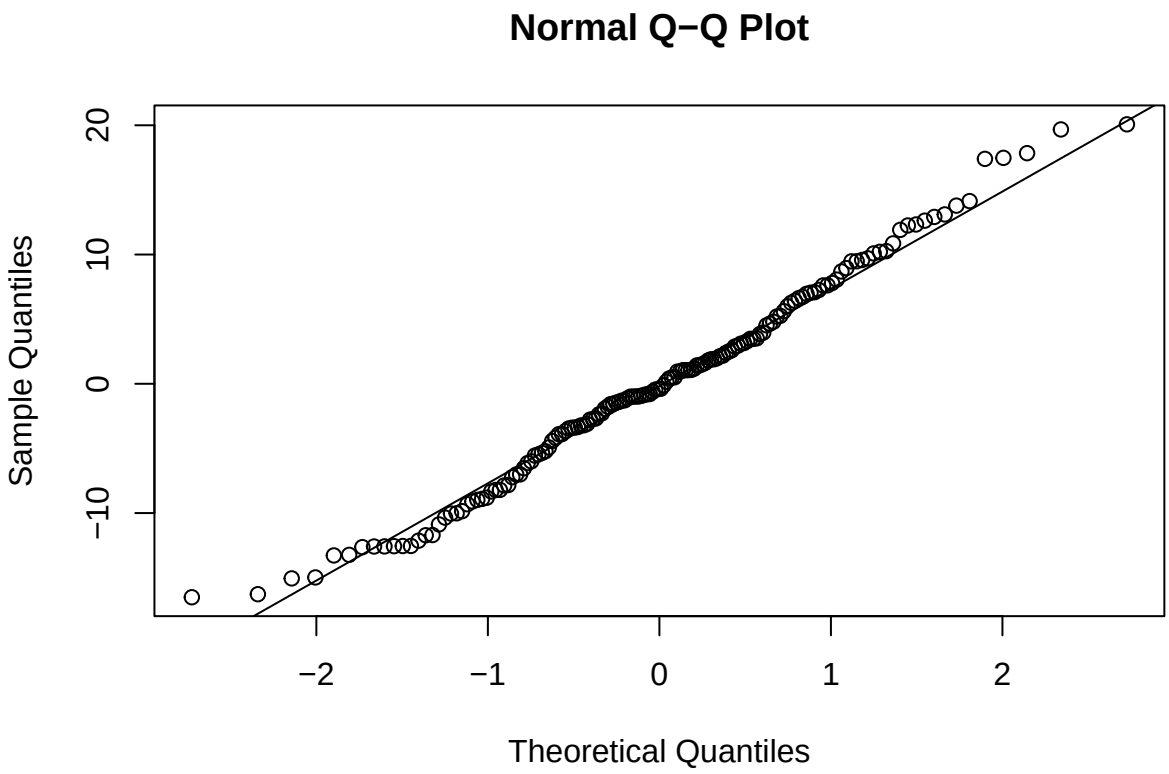
```r
# Planned contrasts between conditions within intensity
summary(
  emmeans(lmm_hr_reduced, pairwise ~ condition | intensity),
  infer = TRUE
)
```

```
$emmeans
intensity = rpe13:
 condition emmean   SE   df lower.CL upper.CL t.ratio p.value
 control      146 3.29 15.6      139      153  44.305  <.0001
 bblock       106 3.29 15.6       99      113  32.158  <.0001

intensity = rpe15:
 condition emmean   SE   df lower.CL upper.CL t.ratio p.value
 control      161 3.29 15.6      154      168  48.877  <.0001
 bblock       115 3.29 15.6      108      122  35.054  <.0001

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95

$contrasts
intensity = rpe13:
 contrast         estimate   SE  df lower.CL upper.CL t.ratio p.value
 control - bblock     40.0 1.89 137     36.3     43.8  21.191  <.0001

intensity = rpe15:
 contrast         estimate   SE  df lower.CL upper.CL t.ratio p.value
 control - bblock     45.5 1.89 137     41.8     49.3  24.115  <.0001

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95
```

```r
plot(lmm_hr_reduced)
```




```
qqnorm(residuals(lmm_hr_reduced))
qqline(residuals(lmm_hr_reduced))
```



3.2 %HRpeak

```
# Fit fully specified model for %HRpeak
lmm_pcthrpeak_full <- lmer(
  pct_hr_peak ~ condition * intensity * bout_rpe + (1 | pid),
  data = intervals
)
```

```
# Fit reduced model for %HRpeak without second-order interaction
lmm_pcthrpeak_reduced <- lmer(
  pct_hr_peak ~ condition + intensity + bout_rpe + condition:intensity +
    condition:bout_rpe + intensity:bout_rpe + (1 | pid),
  data = intervals
)
```

```
# Compare models via likelihood ratio test
anova(lmm_pcthrpeak_full, lmm_pcthrpeak_reduced)
```

```
Data: intervals
Models:
lmm_pcthrpeak_reduced: pct_hr_peak ~ condition + intensity + bout_rpe + condition:intensity + condition
lmm_pcthrpeak_full: pct_hr_peak ~ condition * intensity * bout_rpe + (1 | pid)
                      npar    AIC    BIC  logLik deviance  Chisq Df Pr(>Chisq)
```

```
lmm_pcthrpeak_reduced    9 977.92 1005.4 -479.96   959.92
lmm_pcthrpeak_full      10 978.93 1009.4 -479.46   958.93 0.9953  1     0.3185
```

```
summary(lmm_pcthrpeak_reduced)
```

```
Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]
Formula:
pct_hr_peak ~ condition + intensity + bout_rpe + condition:intensity +
    condition:bout_rpe + intensity:bout_rpe + (1 | pid)
   Data: intervals

REML criterion at convergence: 947.9

Scaled residuals:
    Min      1Q  Median      3Q     Max
-1.8747 -0.7818 -0.1272  0.6251  2.8144

Random effects:
 Groups   Name        Variance Std.Dev.
 pid      (Intercept) 86.92    9.323
 Residual             20.77    4.557
Number of obs: 156, groups:  pid, 13

Fixed effects:
                             Estimate Std. Error       df t value Pr(>|t|)
(Intercept)                   69.7848     3.1008  23.5109  22.506  < 2e-16
conditionbblock               -5.5488     2.0640 137.0000  -2.688  0.00807
intensityrpe15                10.5296     2.0640 137.0000   5.102 1.10e-06
bout_rpe                       3.4459     0.7740 137.0000   4.452 1.75e-05
conditionbblock:intensityrpe15 -1.7853     1.4595 137.0000  -1.223  0.22334
conditionbblock:bout_rpe       -0.4921     0.8938 137.0000  -0.551  0.58282
intensityrpe15:bout_rpe        -1.2963     0.8938 137.0000  -1.450  0.14924

(Intercept)                   ***
conditionbblock               **
intensityrpe15                ***
bout_rpe                      ***
conditionbblock:intensityrpe15
conditionbblock:bout_rpe
intensityrpe15:bout_rpe
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) cndtnb intn15 bot_rp cnd:15 cndt:_
condtnbblck -0.333
intnstyrp15 -0.333  0.125
bout_rpe    -0.499  0.500  0.500
cndtnbbl:15  0.118 -0.354 -0.354  0.000
cndtnbblc:_  0.288 -0.866  0.000 -0.577  0.000
intnsty15:_  0.288  0.000 -0.866 -0.577  0.000  0.000
```

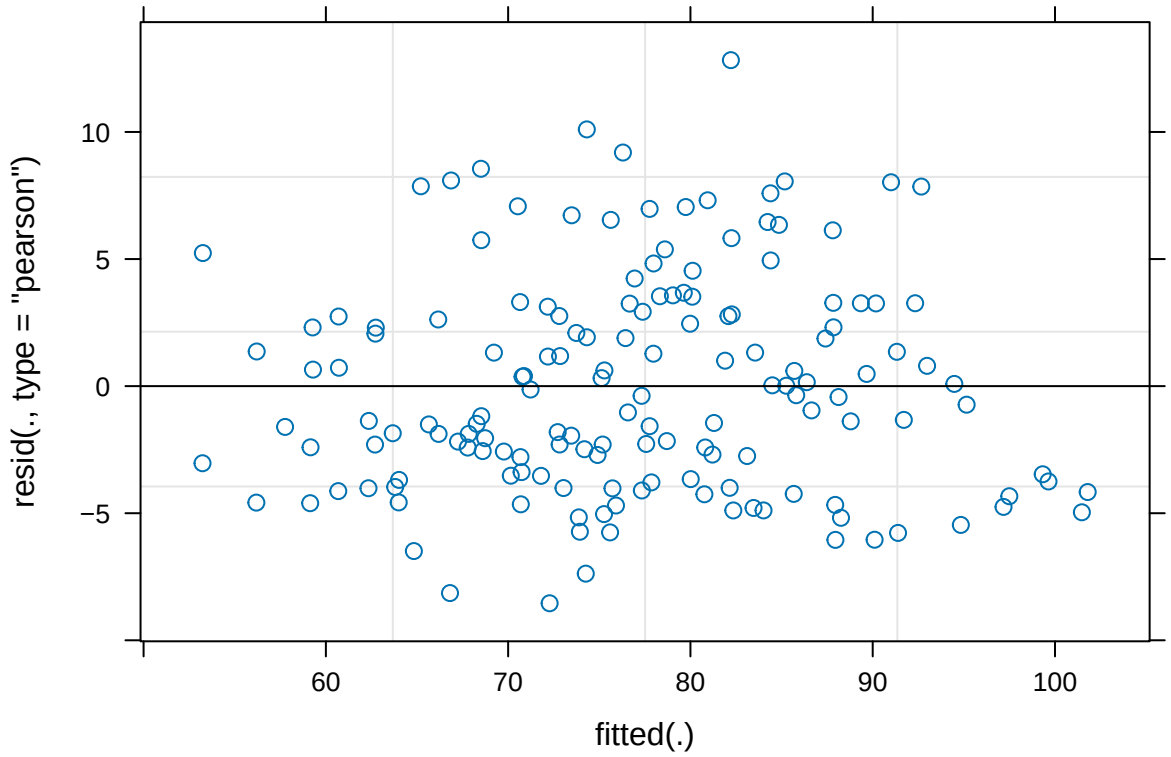
```r
confint(lmm_pcthrpeak_reduced)
```

```
                                   2.5 %     97.5 %
.sig01                          6.302837 13.9950955
.sigma                          3.989645  5.0321038
(Intercept)                    63.671694 75.8979967
conditionbblock                -9.535167 -1.5624039
intensityrpe15                  6.543265 14.5160278
bout_rpe                        1.951041  4.9408267
conditionbblock:intensityrpe15 -4.604103  1.0334917
conditionbblock:bout_rpe       -2.218228  1.2340797
intensityrpe15:bout_rpe        -3.022423  0.4298849
```

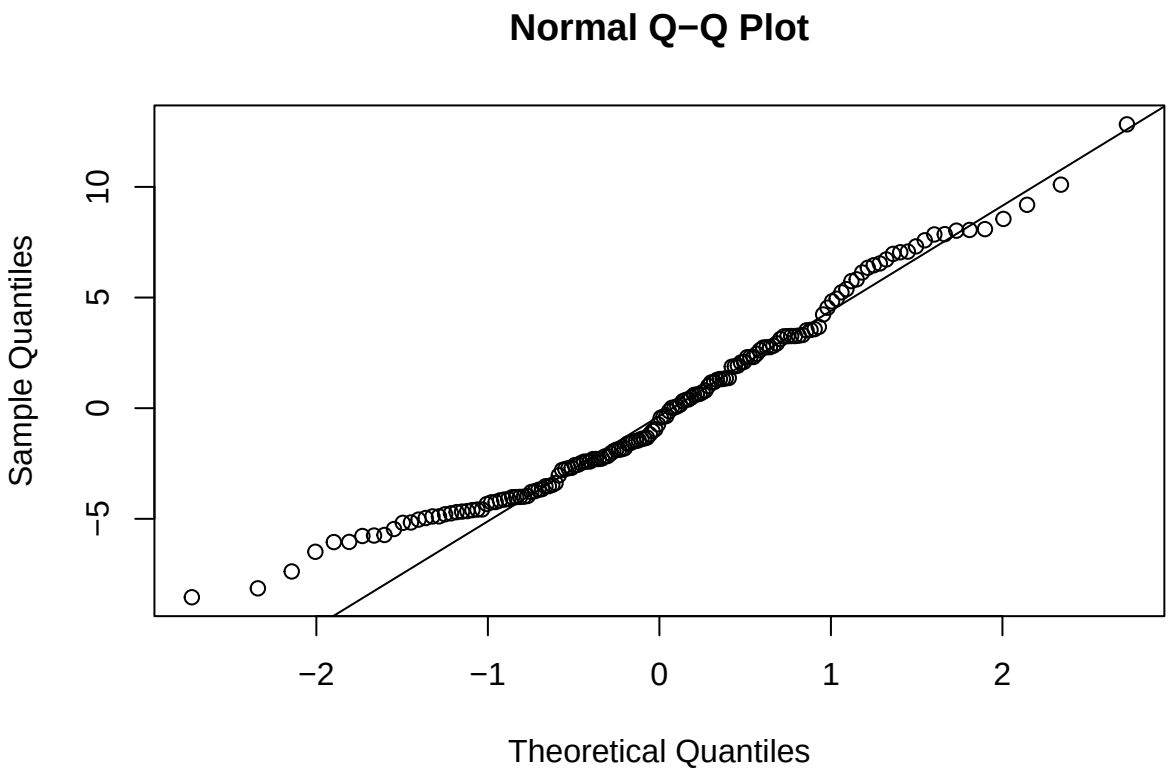
```r
# Planned contrasts between conditions within intensity
summary(
  emmeans(lmm_pcthrpeak_reduced, pairwise ~ condition | intensity),
  infer = TRUE
)
```

```
$emmeans
intensity = rpe13:
 condition emmean   SE   df lower.CL upper.CL t.ratio p.value
 control     76.7 2.69 13.4     70.9     82.5  28.539  <.0001
 bblock      70.1 2.69 13.4     64.4     75.9  26.108  <.0001

intensity = rpe15:
 condition emmean   SE   df lower.CL upper.CL t.ratio p.value
 control     84.6 2.69 13.4     78.8     90.4  31.493  <.0001
 bblock      76.3 2.69 13.4     70.5     82.1  28.397  <.0001

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95

$contrasts
intensity = rpe13:
 contrast         estimate   SE  df lower.CL upper.CL t.ratio p.value
 control - bblock     6.53 1.03 137     4.49     8.57   6.330  <.0001

intensity = rpe15:
 contrast         estimate   SE  df lower.CL upper.CL t.ratio p.value
 control - bblock     8.32 1.03 137     6.28    10.36   8.060  <.0001

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95
```

```
plot(lmm_pcthrpeak_reduced)
```




```
qqnorm(residuals(lmm_pcthrpeak_reduced))
qqline(residuals(lmm_pcthrpeak_reduced))
```



3.3 Oxygen uptake

```
# Fit fully specified model for oxygen uptake
lmm_vo2kg_full <- lmer(
  vo2kg ~ condition * intensity * bout_rpe + (1 | pid),
  data = intervals
)
```

```
# Fit reduced model for VO2kg without second-order interaction
lmm_vo2kg_reduced <- lmer(
  vo2kg ~ condition + intensity + bout_rpe + condition:intensity +
    condition:bout_rpe + intensity:bout_rpe + (1 | pid),
  data = intervals
)
```

```
# Compare models via likelihood ratio test
anova(lmm_vo2kg_full, lmm_vo2kg_reduced)
```

```
Data: intervals
Models:
lmm_vo2kg_reduced: vo2kg ~ condition + intensity + bout_rpe + condition:intensity + condition:bout_rpe +
lmm_vo2kg_full: vo2kg ~ condition * intensity * bout_rpe + (1 | pid)
                  npar    AIC    BIC  logLik deviance  Chisq Df Pr(>Chisq)
```

```
lmm_vo2kg_reduced    9 727.83 755.28 -354.91   709.83
lmm_vo2kg_full      10 729.77 760.27 -354.89   709.77 0.0567  1     0.8118
```

```
summary(lmm_vo2kg_reduced)
```

```
Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]
Formula: vo2kg ~ condition + intensity + bout_rpe + condition:intensity +
    condition:bout_rpe + intensity:bout_rpe + (1 | pid)
   Data: intervals

REML criterion at convergence: 708.9

Scaled residuals:
     Min       1Q   Median       3Q      Max
-2.76528 -0.56346 -0.05623  0.64966  2.16911

Random effects:
 Groups   Name        Variance Std.Dev.
 pid      (Intercept) 22.95    4.79
 Residual              4.08    2.02
Number of obs: 156, groups:  pid, 13

Fixed effects:
                              Estimate Std. Error       df t value Pr(>|t|)
(Intercept)                    29.9179     1.5298  20.3193  19.556 1.19e-14
conditionbblock                -4.2231     0.9148 137.0000  -4.616 8.89e-06
intensityrpe15                  6.5538     0.9148 137.0000   7.164 4.38e-11
bout_rpe                        0.5423     0.3431 137.0000   1.581   0.1162
conditionbblock:intensityrpe15 -0.5282     0.6469 137.0000  -0.817   0.4156
conditionbblock:bout_rpe        0.6654     0.3961 137.0000   1.680   0.0953
intensityrpe15:bout_rpe        -0.5500     0.3961 137.0000  -1.388   0.1673

(Intercept)                    ***
conditionbblock                ***
intensityrpe15                 ***
bout_rpe
conditionbblock:intensityrpe15
conditionbblock:bout_rpe       .
intensityrpe15:bout_rpe
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) cndtnb intn15 bot_rp cnd:15 cndt:_
condtnbblck -0.299
intnstyrp15 -0.299  0.125
bout_rpe    -0.448  0.500  0.500
cndtnbbl:15  0.106 -0.354 -0.354  0.000
cndtnbblc:_  0.259 -0.866  0.000 -0.577  0.000
intnsty15:_  0.259  0.000 -0.866 -0.577  0.000  0.000
```

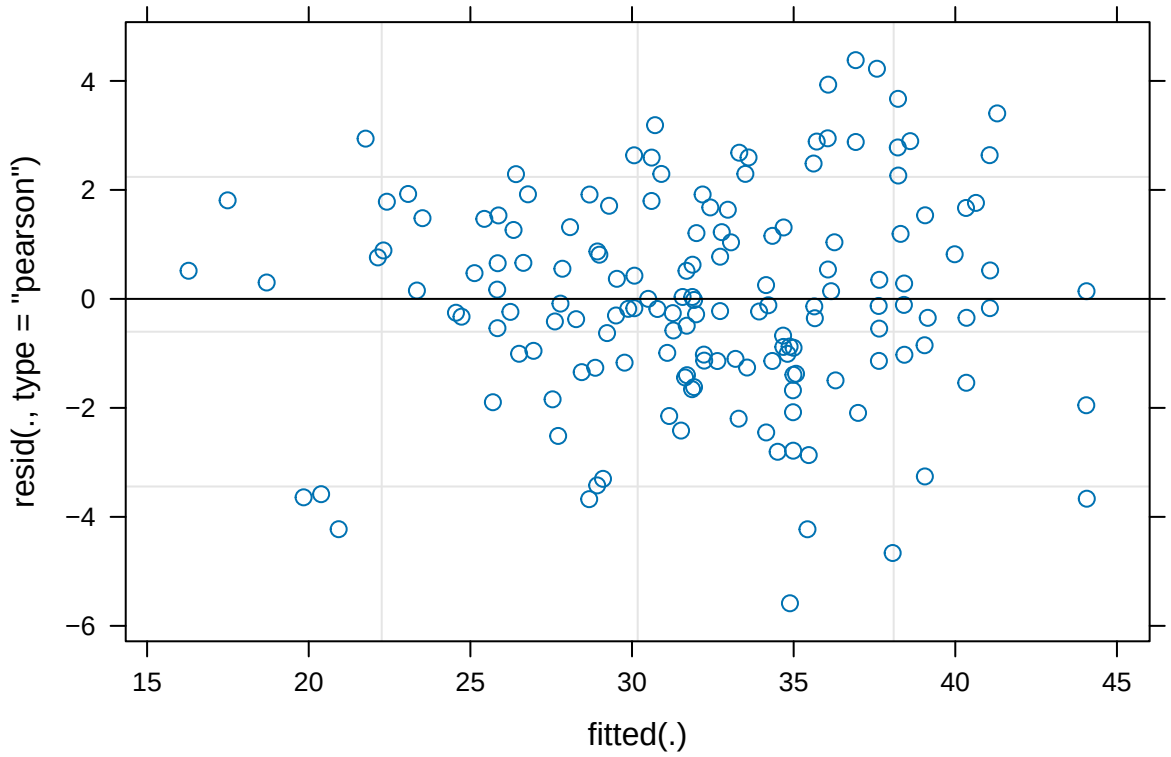
```r
confint(lmm_vo2kg_reduced)
```

```
                                    2.5 %     97.5 %
.sig01                           3.24735361  7.1804449
.sigma                           1.76826502  2.2302972
(Intercept)                     26.88641374 32.9494836
conditionbblock                 -5.98989571 -2.4562581
intensityrpe15                   4.78702737  8.3206649
bout_rpe                        -0.12024935  1.2048647
conditionbblock:intensityrpe15 -1.77753467  0.7211244
conditionbblock:bout_rpe       -0.09967036  1.4304396
intensityrpe15:bout_rpe        -1.31505498  0.2150550
```

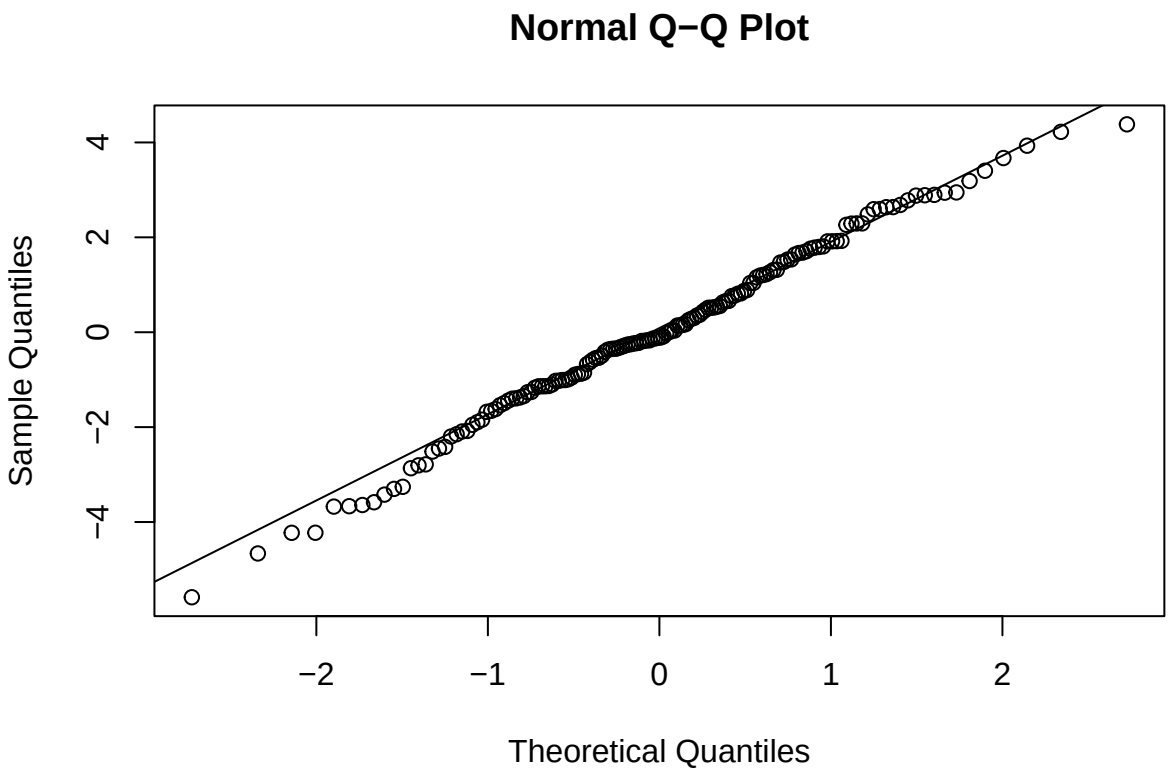
```r
# Planned contrasts between conditions within intensity
summary(
  emmeans(lmm_vo2kg_reduced, pairwise ~ condition | intensity),
  infer = TRUE
)
```

```
$emmeans
intensity = rpe13:
 condition emmean   SE   df lower.CL upper.CL t.ratio p.value
 control     31.0 1.37 13.1     28.1     34.0  22.673  <.0001
 bblock      28.1 1.37 13.1     25.2     31.1  20.558  <.0001

intensity = rpe15:
 condition emmean   SE   df lower.CL upper.CL t.ratio p.value
 control     36.5 1.37 13.1     33.5     39.4  26.662  <.0001
 bblock      33.0 1.37 13.1     30.1     36.0  24.160  <.0001

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95

$contrasts
intensity = rpe13:
 contrast         estimate    SE  df lower.CL upper.CL t.ratio p.value
 control - bblock     2.89 0.457 137     1.99     3.80   6.323  <.0001

intensity = rpe15:
 contrast         estimate    SE  df lower.CL upper.CL t.ratio p.value
 control - bblock     3.42 0.457 137     2.52     4.32   7.478  <.0001

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95
```

```
plot(lmm_vo2kg_reduced)
```




```
qqnorm(residuals(lmm_vo2kg_reduced))
qqline(residuals(lmm_vo2kg_reduced))
```



3.4 %VO2peak

```
# Fit fully specified model for %VO2peak
lmm_pctvo2kgpeak_full <- lmer(
  pct_vo2kg_peak ~ condition * intensity * bout_rpe + (1 | pid),
  data = intervals
)
```

```
# Fit reduced model for %VO2peak without second-order interaction
lmm_pctvo2kgpeak_reduced <- lmer(
  pct_vo2kg_peak ~ condition + intensity + bout_rpe + condition:intensity +
    condition:bout_rpe + intensity:bout_rpe + (1 | pid),
  data = intervals
)
```

```
# Compare models via likelihood ratio test
anova(lmm_pctvo2kgpeak_full, lmm_pctvo2kgpeak_reduced)
```

```
Data: intervals
Models:
lmm_pctvo2kgpeak_reduced: pct_vo2kg_peak ~ condition + intensity + bout_rpe + condition:intensity + cond
lmm_pctvo2kgpeak_full: pct_vo2kg_peak ~ condition * intensity * bout_rpe + (1 | pid)
                         npar    AIC    BIC  logLik deviance  Chisq Df
```

```
lmm_pctvo2kgpeak_reduced    9 958.82 986.26 -470.41   940.82
lmm_pctvo2kgpeak_full      10 960.76 991.26 -470.38   940.76 0.0572  1
                         Pr(>Chisq)
lmm_pctvo2kgpeak_reduced
lmm_pctvo2kgpeak_full         0.811
```

```
summary(lmm_pctvo2kgpeak_reduced)
```

```
Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]
Formula:
pct_vo2kg_peak ~ condition + intensity + bout_rpe + condition:intensity +
    condition:bout_rpe + intensity:bout_rpe + (1 | pid)
   Data: intervals

REML criterion at convergence: 929.7

Scaled residuals:
     Min       1Q   Median       3Q      Max
-2.38874 -0.57723  0.03762  0.61146  2.16649

Random effects:
 Groups   Name        Variance Std.Dev.
 pid      (Intercept) 69.36    8.328
 Residual             18.54    4.306
Number of obs: 156, groups:  pid, 13

Fixed effects:
                              Estimate Std. Error       df t value Pr(>|t|)
(Intercept)                    58.4026     2.8196  25.0389  20.713  < 2e-16
conditionbblock                -4.0697     1.9503 137.0000  -2.087   0.0388
intensityrpe15                 13.2442     1.9503 137.0000   6.791 3.11e-10
bout_rpe                        1.1410     0.7314 137.0000   1.560   0.1211
conditionbblock:intensityrpe15 -0.5441     1.3791 137.0000  -0.395   0.6938
conditionbblock:bout_rpe        1.4076     0.8445 137.0000   1.667   0.0978
intensityrpe15:bout_rpe        -1.1611     0.8445 137.0000  -1.375   0.1714

(Intercept)                    ***
conditionbblock                *
intensityrpe15                 ***
bout_rpe
conditionbblock:intensityrpe15
conditionbblock:bout_rpe       .
intensityrpe15:bout_rpe
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) cndtnb intn15 bot_rp cnd:15 cndt:_
condtnbblck -0.346
intntsyrp15 -0.346  0.125
bout_rpe    -0.519  0.500  0.500
cndtnbbl:15  0.122 -0.354 -0.354  0.000
cndtnbblc:_  0.300 -0.866  0.000 -0.577  0.000
```

```
intnsty15:_  0.300  0.000 -0.866 -0.577  0.000  0.000
```

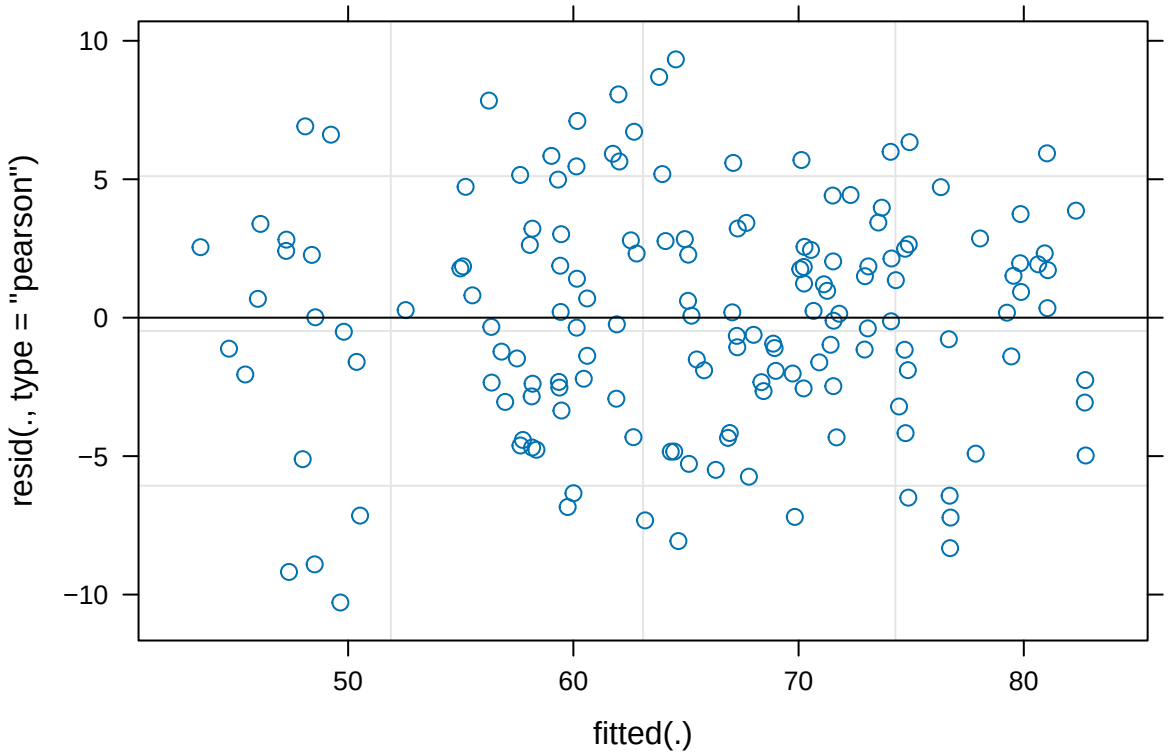
```r
confint(lmm_pctvo2kgpeak_reduced)
```

```
                                    2.5 %     97.5 %
.sig01                          5.6230280 12.5099971
.sigma                          3.7698685  4.7549021
(Intercept)                    52.8548919 63.9503423
conditionbblock                -7.8364556 -0.3028852
intensityrpe15                  9.4774642 17.0110346
bout_rpe                       -0.2715604  2.5535285
conditionbblock:intensityrpe15 -3.2076423  2.1193964
conditionbblock:bout_rpe       -0.2234541  3.0386776
intensityrpe15:bout_rpe        -2.7921618  0.4699698
```

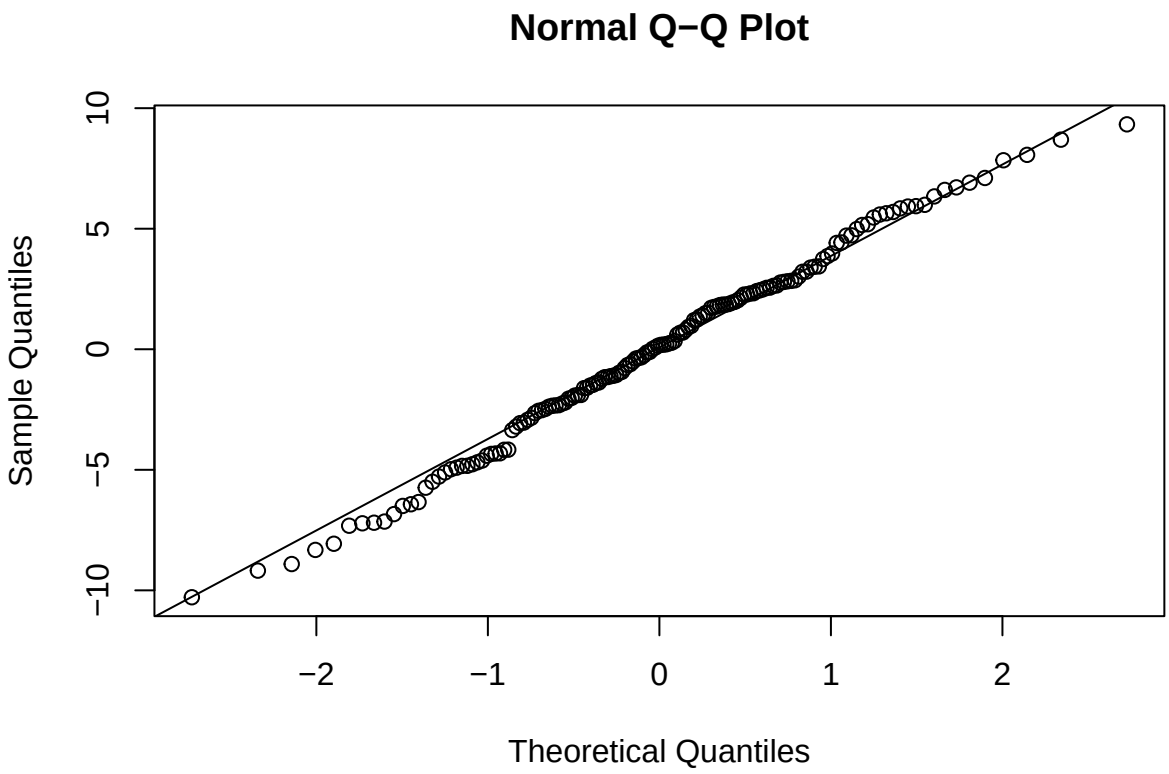
```r
# Planned contrasts between conditions within intensity
summary(
  emmeans(lmm_pctvo2kgpeak_reduced, pairwise ~ condition | intensity),
  infer = TRUE
)
```

```
$emmeans
intensity = rpe13:
 condition emmean   SE   df lower.CL upper.CL t.ratio p.value
 control     60.7 2.41 13.6     55.5     65.9  25.175  <.0001
 bblock      59.4 2.41 13.6     54.2     64.6  24.655  <.0001

intensity = rpe15:
 condition emmean   SE   df lower.CL upper.CL t.ratio p.value
 control     71.6 2.41 13.6     66.4     76.8  29.706  <.0001
 bblock      69.8 2.41 13.6     64.6     75.0  28.960  <.0001

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95

$contrasts
intensity = rpe13:
 contrast         estimate    SE  df lower.CL upper.CL t.ratio p.value
 control - bblock     1.25 0.975 137   -0.674     3.18   1.286  0.2005

intensity = rpe15:
 contrast         estimate    SE  df lower.CL upper.CL t.ratio p.value
 control - bblock     1.80 0.975 137   -0.130     3.73   1.844  0.0673

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95
```

```r
plot(lmm_pctvo2kgpeak_reduced)
```




```
qqnorm(residuals(lmm_pctvo2kgpeak_reduced))
qqline(residuals(lmm_pctvo2kgpeak_reduced))
```



3.5 Work rate (METs)

```
# Fit fully specified model for METs
lmm_mets_full <- lmer(
  mets ~ condition * intensity * bout_rpe + (1 | pid),
  data = intervals
)
```

```
# Fit reduced model for METs without second-order interaction
lmm_mets_reduced <- lmer(
  mets ~ condition + intensity + bout_rpe + condition:intensity +
    condition:bout_rpe + intensity:bout_rpe + (1 | pid),
  data = intervals
)
```

```
# Compare models via likelihood ratio test
anova(lmm_mets_full, lmm_mets_reduced)
```

```
Data: intervals
Models:
lmm_mets_reduced: mets ~ condition + intensity + bout_rpe + condition:intensity + condition:bout_rpe + i
lmm_mets_full: mets ~ condition * intensity * bout_rpe + (1 | pid)
                 npar    AIC    BIC  logLik deviance  Chisq Df Pr(>Chisq)
```

```
lmm_mets_reduced    9 334.50 361.95 -158.25   316.50
lmm_mets_full      10 336.48 366.98 -158.24   316.48 0.0231  1     0.8793
```

```
summary(lmm_mets_reduced)
```

```
Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]
Formula: mets ~ condition + intensity + bout_rpe + condition:intensity +
    condition:bout_rpe + intensity:bout_rpe + (1 | pid)
   Data: intervals

REML criterion at convergence: 333.2

Scaled residuals:
     Min       1Q   Median       3Q      Max
-2.76891 -0.56977 -0.04115  0.58926  2.44065

Random effects:
 Groups   Name        Variance Std.Dev.
 pid      (Intercept) 1.9427   1.3938
 Residual             0.3263   0.5712
Number of obs: 156, groups:  pid, 13

Fixed effects:
                               Estimate Std. Error        df t value Pr(>|t|)
(Intercept)                     9.04816    0.44210  19.81925  20.466 8.47e-15
conditionbblock                -0.60027    0.25871 137.00000  -2.320   0.0218
intensityrpe15                  2.22292    0.25871 137.00000   8.592 1.70e-14
bout_rpe                        0.14666    0.09702 137.00000   1.512   0.1329
conditionbblock:intensityrpe15 -0.21415    0.18294 137.00000  -1.171   0.2438
conditionbblock:bout_rpe        0.06588    0.11203 137.00000   0.588   0.5575
intensityrpe15:bout_rpe        -0.21604    0.11203 137.00000  -1.929   0.0559

(Intercept)                    ***
conditionbblock                *
intensityrpe15                 ***
bout_rpe
conditionbblock:intensityrpe15
conditionbblock:bout_rpe
intensityrpe15:bout_rpe        .
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) cndtnb intn15 bot_rp cnd:15 cndt:_
condtnbblck -0.293
intnstyrp15 -0.293  0.125
bout_rpe    -0.439  0.500  0.500
cndtnbbl:15  0.103 -0.354 -0.354  0.000
cndtnbblc:_  0.253 -0.866  0.000 -0.577  0.000
intnsty15:_  0.253  0.000 -0.866 -0.577  0.000  0.000
```

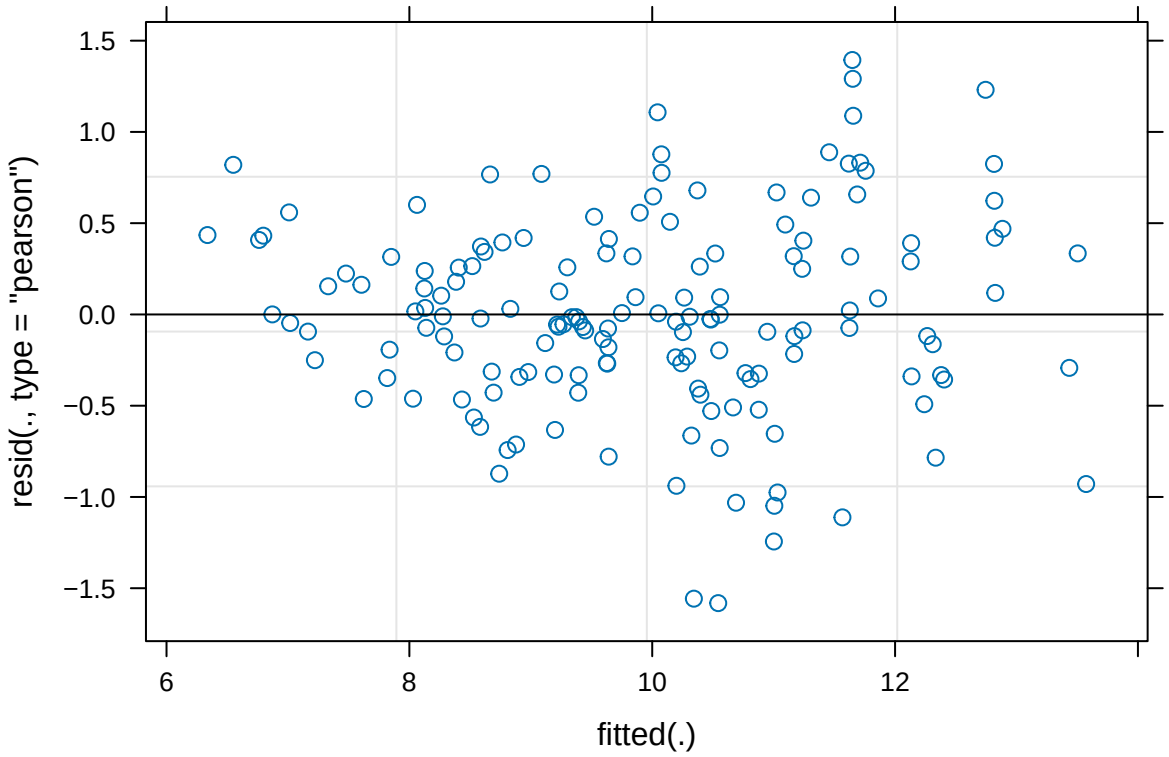
```r
confint(lmm_mets_reduced)
```

```
                                    2.5 %       97.5 %
.sig01                         0.94531057  2.0888359548
.sigma                         0.50007609  0.6307415850
(Intercept)                    8.17126106  9.9250637009
conditionbblock               -1.09993571 -0.1006015339
intensityrpe15                 1.72325111  2.7225852793
bout_rpe                      -0.04071765  0.3340326665
conditionbblock:intensityrpe15 -0.56746939  0.1391665810
conditionbblock:bout_rpe       -0.15048307  0.2822413160
intensityrpe15:bout_rpe        -0.43240615  0.0003182391
```

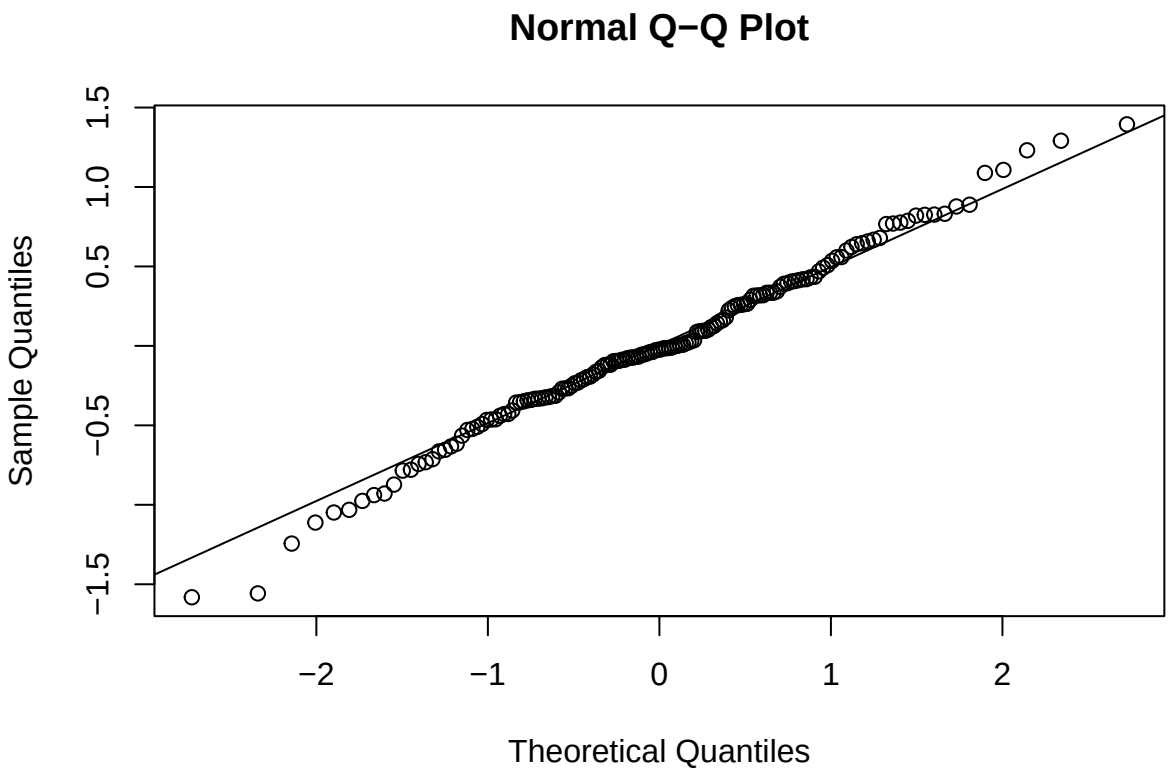
```r
# Planned contrasts between conditions within intensity
summary(
  emmeans(lmm_mets_reduced, pairwise ~ condition | intensity),
  infer = TRUE
)
```

```
$emmeans
intensity = rpe13:
 condition emmean    SE df lower.CL upper.CL t.ratio p.value
 control     9.34 0.397 13     8.48    10.20  23.515  <.0001
 bblock      8.87 0.397 13     8.01     9.73  22.336  <.0001

intensity = rpe15:
 condition emmean    SE df lower.CL upper.CL t.ratio p.value
 control    11.13 0.397 13    10.27    11.99  28.024  <.0001
 bblock     10.45 0.397 13     9.59    11.31  26.305  <.0001

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95

$contrasts
intensity = rpe13:
 contrast         estimate    SE  df lower.CL upper.CL t.ratio p.value
 control - bblock    0.469 0.129 137    0.213    0.724   3.622  0.0004

intensity = rpe15:
 contrast         estimate    SE  df lower.CL upper.CL t.ratio p.value
 control - bblock    0.683 0.129 137    0.427    0.938   5.277  <.0001

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95
```

```
plot(lmm_mets_reduced)
```




```
qqnorm(residuals(lmm_mets_reduced))
qqline(residuals(lmm_mets_reduced))
```



3.6 %WRpeak (%METpeak)

```
# Fit fully specified model for %METpeak
lmm_pctmetspeak_full <- lmer(
  pct_mets_peak ~ condition * intensity * bout_rpe + (1 | pid),
  data = intervals
)
```

```
# Fit reduced model for %METpeak without second-order interaction
lmm_pctmetspeak_reduced <- lmer(
  pct_mets_peak ~ condition + intensity + bout_rpe + condition:intensity +
    condition:bout_rpe + intensity:bout_rpe + (1 | pid),
  data = intervals
)
```

```
# Compare models via likelihood ratio test
anova(lmm_pctmetspeak_full, lmm_pctmetspeak_reduced)
```

```
Data: intervals
Models:
lmm_pctmetspeak_reduced: pct_mets_peak ~ condition + intensity + bout_rpe + condition:intensity + condi
lmm_pctmetspeak_full: pct_mets_peak ~ condition * intensity * bout_rpe + (1 | pid)
                        npar    AIC    BIC  logLik deviance  Chisq Df
```

```
lmm_pctmetspeak_reduced    9 891.40 918.85 -436.70   873.40
lmm_pctmetspeak_full      10 893.37 923.87 -436.68   873.37 0.0321  1
                        Pr(>Chisq)
lmm_pctmetspeak_reduced
lmm_pctmetspeak_full        0.8577
```

```
summary(lmm_pctmetspeak_reduced)
```

```
Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]
Formula:
pct_mets_peak ~ condition + intensity + bout_rpe + condition:intensity +
    condition:bout_rpe + intensity:bout_rpe + (1 | pid)
   Data: intervals

REML criterion at convergence: 865.3

Scaled residuals:
     Min       1Q   Median       3Q      Max
-2.65256 -0.71294 -0.04799  0.74067  2.22726

Random effects:
 Groups   Name        Variance Std.Dev.
 pid      (Intercept) 42.93    6.552
 Residual             12.09    3.477
Number of obs: 156, groups:  pid, 13

Fixed effects:
                              Estimate Std. Error       df t value Pr(>|t|)
(Intercept)                    52.5900     2.2376  25.8138  23.503  < 2e-16
conditionbblock                -0.1507     1.5747 137.0000  -0.096   0.9239
intensityrpe15                 12.8633     1.5747 137.0000   8.169 1.84e-13
bout_rpe                        0.8678     0.5905 137.0000   1.470   0.1439
conditionbblock:intensityrpe15 -0.7151     1.1135 137.0000  -0.642   0.5218
conditionbblock:bout_rpe        0.3932     0.6818 137.0000   0.577   0.5651
intensityrpe15:bout_rpe        -1.2934     0.6818 137.0000  -1.897   0.0599

(Intercept)                    ***
conditionbblock
intensityrpe15                 ***
bout_rpe
conditionbblock:intensityrpe15
conditionbblock:bout_rpe
intensityrpe15:bout_rpe        .
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) cndtnb intn15 bot_rp cnd:15 cndt:_
condtnbblck -0.352
intnstyrp15 -0.352  0.125
bout_rpe    -0.528  0.500  0.500
cndtnbbl:15  0.124 -0.354 -0.354  0.000
cndtnbblc:_  0.305 -0.866  0.000 -0.577  0.000
```

```
intnsty15:_  0.305  0.000 -0.866 -0.577  0.000  0.000
```

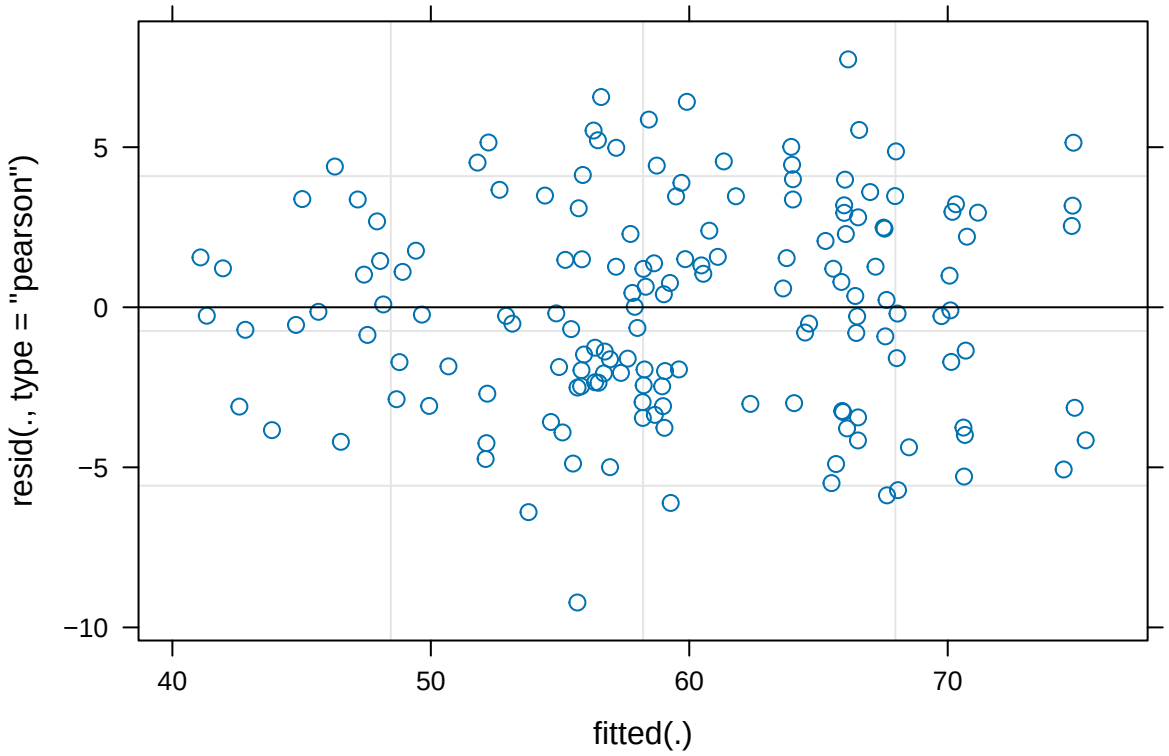
```
confint(lmm_pctmetspeak_reduced)
```

```
                                    2.5 %      97.5 %
.sig01                          4.4208550  9.84505492
.sigma                          3.0437233  3.83902154
(Intercept)                    48.1915495 56.98842227
conditionbblock                -3.1919385  2.89052938
intensityrpe15                  9.8221006 15.90456844
bout_rpe                       -0.2726325  2.00829292
conditionbblock:intensityrpe15 -2.8656000  1.43535427
conditionbblock:bout_rpe       -0.9236957  1.71009015
intensityrpe15:bout_rpe        -2.6103403  0.02344554
```

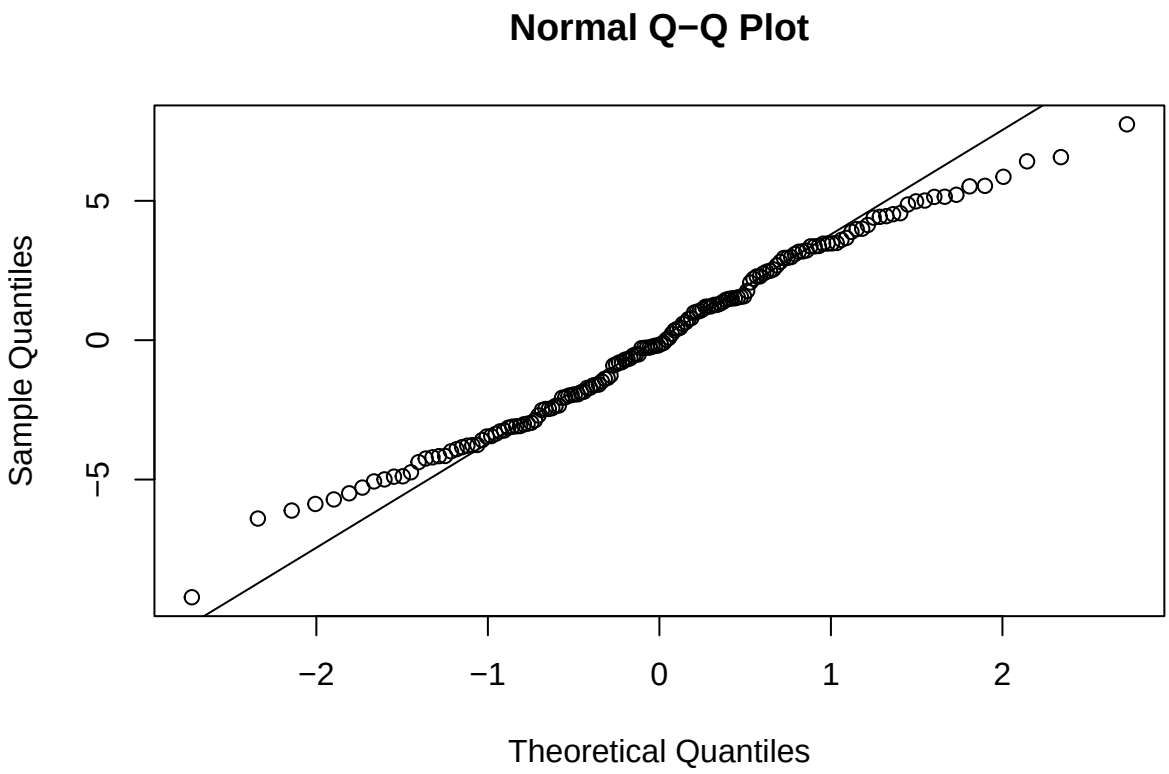
```
# Planned contrasts between conditions within intensity
summary(
  emmeans(lmm_pctmetspeak_reduced, pairwise ~ condition | intensity),
  infer = TRUE
)
```

```
$emmeans
intensity = rpe13:
 condition emmean  SE   df lower.CL upper.CL t.ratio p.value
 control     54.3 1.9 13.7     50.2     58.4  28.585  <.0001
 bblock      55.0 1.9 13.7     50.9     59.0  28.919  <.0001

intensity = rpe15:
 condition emmean  SE   df lower.CL upper.CL t.ratio p.value
 control     64.6 1.9 13.7     60.5     68.7  33.992  <.0001
 bblock      64.5 1.9 13.7     60.4     68.6  33.950  <.0001

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95

$contrasts
intensity = rpe13:
 contrast         estimate    SE  df lower.CL upper.CL t.ratio p.value
 control - bblock  -0.6357 0.787 137    -2.19    0.921  -0.807  0.4208

intensity = rpe15:
 contrast         estimate    SE  df lower.CL upper.CL t.ratio p.value
 control - bblock   0.0794 0.787 137    -1.48    1.636   0.101  0.9198

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95
```

```
plot(lmm_pctmetspeak_reduced)
```




```
qqnorm(residuals(lmm_pctmetspeak_reduced))
qqline(residuals(lmm_pctmetspeak_reduced))
```



4 Intraclass Correlations

```
# Transform intervals data to wide format
intervals_wide <- intervals |>
  select(-c(bout_session, speed:mets_peak)) |>
  pivot_wider(
    names_from = c(condition, intensity, bout_rpe),
    values_from = c(hr, pct_hr_vt, pct_hr_peak, vo2kg, pct_vo2kg_vt,
                    pct_vo2kg_peak, mets, pct_mets_peak),
    names_glue = "{gsub('_', '', .value)}_{condition}_{intensity}_{bout_rpe}"
  )
```

```
fisherz_compare <- function(icc_control, icc_bblock) {
  fisher_z <- function(icc) {
    0.5 * log((1 + icc) / (1 - icc))
  }

  z_control <- fisher_z(icc_control$value)
  z_bblock  <- fisher_z(icc_bblock$value)

  z_diff <- z_control - z_bblock
  se_diff <- sqrt(2 / (icc_control$subjects - 3))
```

```
  z_score  <- z_diff / se_diff
  p_value <- 2 * (1 - pnorm(abs(z_score)))

  return(
    list("z_diff" = z_diff, "z_score" = z_score, "p_value" = p_value)
  )
}
```

4.1 Heart rate

```
# ICC for Control, RPE 13
icc_hr_control_13 <- intervals_wide |>
  select(hr_control_rpe13_1:hr_control_rpe13_3) |>
  icc("twoway", "agreement", "single")

icc_hr_control_13
```

```
 Single Score Intraclass Correlation

   Model: twoway
   Type : agreement

   Subjects = 13
     Raters = 3
   ICC(A,1) = 0.746

 F-Test, H0: r0 = 0 ; H1: r0 > 0
 F(12,4.02) = 30.4 , p = 0.00231

 95%-Confidence Interval for ICC Population Values:
  0.2 < ICC < 0.925
```

```
# ICC for B-blockade, RPE 13
icc_hr_bblock_13 <- intervals_wide |>
  select(hr_bblock_rpe13_1:hr_bblock_rpe13_3) |>
  icc("twoway", "agreement", "single")

icc_hr_bblock_13
```

```
 Single Score Intraclass Correlation

   Model: twoway
   Type : agreement

   Subjects = 13
     Raters = 3
   ICC(A,1) = 0.791

 F-Test, H0: r0 = 0 ; H1: r0 > 0
 F(12,8.22) = 21.6 , p = 7.34e-05
```

```
 95%-Confidence Interval for ICC Population Values:
  0.438 < ICC < 0.932
```

```
# Fisher's z-transformation & z-test
fisherz_compare(icc_hr_control_13, icc_hr_bblock_13)
```

```
$z_diff
[1] -0.1094322

$z_score
[1] -0.2446979

$p_value
[1] 0.8066904
```

```
# ICC for Control, RPE 15
icc_hr_control_15 <- intervals_wide |>
  select(hr_control_rpe15_1:hr_control_rpe15_3) |>
  icc("twoway", "agreement", "single")

icc_hr_control_15
```

```
 Single Score Intraclass Correlation

   Model: twoway
   Type : agreement

   Subjects = 13
     Raters = 3
   ICC(A,1) = 0.883

 F-Test, H0: r0 = 0 ; H1: r0 > 0
 F(12,8.49) = 40.5 , p = 4.49e-06

 95%-Confidence Interval for ICC Population Values:
  0.634 < ICC < 0.964
```

```
# ICC for B-blockade, RPE 15
icc_hr_bblock_15 <- intervals_wide |>
  select(hr_bblock_rpe15_1:hr_bblock_rpe15_3) |>
  icc("twoway", "agreement", "single")

icc_hr_bblock_15
```

```
 Single Score Intraclass Correlation

   Model: twoway
   Type : agreement

   Subjects = 13
     Raters = 3
```

```
   ICC(A,1) = 0.86

 F-Test, H0: r0 = 0 ; H1: r0 > 0
 F(12,8.84) = 32.6 , p = 7.49e-06

 95%-Confidence Interval for ICC Population Values:
  0.587 < ICC < 0.956
```

```
# Fisher's z-transformation & z-test
fisherz_compare(icc_hr_control_15, icc_hr_bblock_15)
```

```
$z_diff
[1] 0.09656875

$z_score
[1] 0.2159343

$p_value
[1] 0.829039
```

4.2 %HRpeak

```
# ICC for Control, RPE 13
icc_pcthrpeak_control_13 <- intervals_wide |>
  select(pcthrpeak_control_rpe13_1:pcthrpeak_control_rpe13_3) |>
  icc("twoway", "agreement", "single")

icc_pcthrpeak_control_13
```

```
 Single Score Intraclass Correlation

   Model: twoway
   Type : agreement

   Subjects = 13
     Raters = 3
   ICC(A,1) = 0.782

 F-Test, H0: r0 = 0 ; H1: r0 > 0
    F(12,4) = 36.6 , p = 0.00167

 95%-Confidence Interval for ICC Population Values:
  0.242 < ICC < 0.938
```

```
# ICC for B-blockade, RPE 13
icc_pcthrpeak_bblock_13 <- intervals_wide |>
  select(pcthrpeak_bblock_rpe13_1:pcthrpeak_bblock_rpe13_3) |>
  icc("twoway", "agreement", "single")

icc_pcthrpeak_bblock_13
```

```
 Single Score Intraclass Correlation

   Model: twoway
   Type : agreement

   Subjects = 13
     Raters = 3
   ICC(A,1) = 0.905

 F-Test, H0: r0 = 0 ; H1: r0 > 0
 F(12,7.91) = 52.5 , p = 3.32e-06

 95%-Confidence Interval for ICC Population Values:
  0.678 < ICC < 0.971
```

```
# Fisher's z-transformation & z-test
fisherz_compare(icc_pcthrpeak_control_13, icc_pcthrpeak_bblock_13)
```

```
$z_diff
[1] -0.4487036

$z_score
[1] -1.003332

$p_value
[1] 0.3157008
```

```
# ICC for Control, RPE 15
icc_pcthrpeak_control_15 <- intervals_wide |>
  select(pcthrpeak_control_rpe15_1:pcthrpeak_control_rpe15_3) |>
  icc("twoway", "agreement", "single")

icc_pcthrpeak_control_15
```

```
 Single Score Intraclass Correlation

   Model: twoway
   Type : agreement

   Subjects = 13
     Raters = 3
   ICC(A,1) = 0.916

 F-Test, H0: r0 = 0 ; H1: r0 > 0
 F(12,8.31) = 58.5 , p = 1.26e-06

 95%-Confidence Interval for ICC Population Values:
  0.717 < ICC < 0.975
```

```
# ICC for B-blockade, RPE 15
icc_pcthrpeak_bblock_15 <- intervals_wide |>
  select(pcthrpeak_bblock_rpe15_1:pcthrpeak_bblock_rpe15_3) |>
```

```
  icc("twoway", "agreement", "single")

icc_pcthrpeak_bblock_15
```

```
 Single Score Intraclass Correlation

   Model: twoway
   Type : agreement

   Subjects = 13
     Raters = 3
   ICC(A,1) = 0.931

 F-Test, H0: r0 = 0 ; H1: r0 > 0
 F(12,7.47) = 75.7 , p = 1.57e-06

 95%-Confidence Interval for ICC Population Values:
  0.743 < ICC < 0.98
```

```
# Fisher's z-transformation & z-test
fisherz_compare(icc_pcthrpeak_control_15, icc_pcthrpeak_bblock_15)
```

```
$z_diff
[1] -0.09796802

$z_score
[1] -0.2190631

$p_value
[1] 0.8266009
```

4.3 Oxygen uptake

```
# ICC for Control, RPE 13
icc_vo2kg_control_13 <- intervals_wide |>
  select(vo2kg_control_rpe13_1:vo2kg_control_rpe13_3) |>
  icc("twoway", "agreement", "single")

icc_vo2kg_control_13
```

```
 Single Score Intraclass Correlation

   Model: twoway
   Type : agreement

   Subjects = 13
     Raters = 3
   ICC(A,1) = 0.863

 F-Test, H0: r0 = 0 ; H1: r0 > 0
```

```
 F(12,25.6) = 20.8 , p = 3.23e-10

 95%-Confidence Interval for ICC Population Values:
  0.7 < ICC < 0.951
```

```r
# ICC for B-blockade, RPE 13
icc_vo2kg_bblock_13 <- intervals_wide |>
  select(vo2kg_bblock_rpe13_1:vo2kg_bblock_rpe13_3) |>
  icc("twoway", "agreement", "single")

icc_vo2kg_bblock_13
```

```
 Single Score Intraclass Correlation

   Model: twoway
   Type : agreement

   Subjects = 13
     Raters = 3
   ICC(A,1) = 0.851

 F-Test, H0: r0 = 0 ; H1: r0 > 0
 F(12,6.11) = 38.1 , p = 0.000101

 95%-Confidence Interval for ICC Population Values:
  0.49 < ICC < 0.956
```

```r
# Fisher's z-transformation & z-test
fisherz_compare(icc_vo2kg_control_13, icc_vo2kg_bblock_13)
```

```
$z_diff
[1] 0.04572165

$z_score
[1] 0.1022367

$p_value
[1] 0.9185688
```

```r
# ICC for Control, RPE 15
icc_vo2kg_control_15 <- intervals_wide |>
  select(vo2kg_control_rpe15_1:vo2kg_control_rpe15_3) |>
  icc("twoway", "agreement", "single")

icc_vo2kg_control_15
```

```
 Single Score Intraclass Correlation

   Model: twoway
   Type : agreement

   Subjects = 13
```

```
     Raters = 3
   ICC(A,1) = 0.93

 F-Test, H0: r0 = 0 ; H1: r0 > 0
 F(12,25.9) = 41.5 , p = 8.06e-14

 95%-Confidence Interval for ICC Population Values:
  0.836 < ICC < 0.976
```

```
# ICC for B-blockade, RPE 15
icc_vo2kg_bblock_15 <- intervals_wide |>
  select(vo2kg_bblock_rpe15_1:vo2kg_bblock_rpe15_3) |>
  icc("twoway", "agreement", "single")

icc_vo2kg_bblock_15
```

```
 Single Score Intraclass Correlation

   Model: twoway
   Type : agreement

   Subjects = 13
     Raters = 3
   ICC(A,1) = 0.926

 F-Test, H0: r0 = 0 ; H1: r0 > 0
 F(12,21.1) = 44.7 , p = 2.96e-12

 95%-Confidence Interval for ICC Population Values:
  0.82 < ICC < 0.975
```

```
# Fisher's z-transformation & z-test
fisherz_compare(icc_vo2kg_control_15, icc_vo2kg_bblock_15)
```

```
$z_diff
[1] 0.02833481

$z_score
[1] 0.06335856

$p_value
[1] 0.949481
```

4.4 %VO2peak

```
# ICC for Control, RPE 13
icc_pctvo2kgpeak_control_13 <- intervals_wide |>
  select(pctvo2kgpeak_control_rpe13_1:pctvo2kgpeak_control_rpe13_3) |>
  icc("twoway", "agreement", "single")

icc_pctvo2kgpeak_control_13
```

```
 Single Score Intraclass Correlation

   Model: twoway
   Type : agreement

   Subjects = 13
     Raters = 3
   ICC(A,1) = 0.825

 F-Test, H0: r0 = 0 ; H1: r0 > 0
 F(12,25.5) = 15.9 , p = 6.4e-09

 95%-Confidence Interval for ICC Population Values:
  0.629 < ICC < 0.937
```

```
# ICC for B-blockade, RPE 13
icc_pctvo2kgpeak_bblock_13 <- intervals_wide |>
  select(pctvo2kgpeak_bblock_rpe13_1:pctvo2kgpeak_bblock_rpe13_3) |>
  icc("twoway", "agreement", "single")

icc_pctvo2kgpeak_bblock_13
```

```
 Single Score Intraclass Correlation

   Model: twoway
   Type : agreement

   Subjects = 13
     Raters = 3
   ICC(A,1) = 0.847

 F-Test, H0: r0 = 0 ; H1: r0 > 0
 F(12,5.32) = 41 , p = 0.000225

 95%-Confidence Interval for ICC Population Values:
  0.443 < ICC < 0.956
```

```
# Fisher's z-transformation & z-test
fisherz_compare(icc_pctvo2kgpeak_control_13, icc_pctvo2kgpeak_bblock_13)
```

```
$z_diff
[1] -0.0710036

$z_score
[1] -0.1587689

$p_value
[1] 0.873851
```

```
# ICC for Control, RPE 15
icc_pctvo2kgpeak_control_15 <- intervals_wide |>
  select(pctvo2kgpeak_control_rpe15_1:pctvo2kgpeak_control_rpe15_3) |>
```

```
  icc("twoway", "agreement", "single")

icc_pctvo2kgpeak_control_15
```

```
 Single Score Intraclass Correlation

   Model: twoway
   Type : agreement

   Subjects = 13
     Raters = 3
   ICC(A,1) = 0.909

 F-Test, H0: r0 = 0 ; H1: r0 > 0
   F(12,26) = 31.5 , p = 2.12e-12

 95%-Confidence Interval for ICC Population Values:
  0.793 < ICC < 0.968
```

```
# ICC for B-blockade, RPE 15
icc_pctvo2kgpeak_bblock_15 <- intervals_wide |>
  select(pctvo2kgpeak_bblock_rpe15_1:pctvo2kgpeak_bblock_rpe15_3) |>
  icc("twoway", "agreement", "single")

icc_pctvo2kgpeak_bblock_15
```

```
 Single Score Intraclass Correlation

   Model: twoway
   Type : agreement

   Subjects = 13
     Raters = 3
   ICC(A,1) = 0.91

 F-Test, H0: r0 = 0 ; H1: r0 > 0
 F(12,20.4) = 37 , p = 3.59e-11

 95%-Confidence Interval for ICC Population Values:
  0.784 < ICC < 0.969
```

```
# Fisher's z-transformation & z-test
fisherz_compare(icc_pctvo2kgpeak_control_15, icc_pctvo2kgpeak_bblock_15)
```

```
$z_diff
[1] -0.005714326

$z_score
[1] -0.01277762

$p_value
[1] 0.9898052
```

4.5 Work rate (METs)

```
# ICC for Control, RPE 13
icc_mets_control_13 <- intervals_wide |>
  select(mets_control_rpe13_1:mets_control_rpe13_3) |>
  icc("twoway", "agreement", "single")

icc_mets_control_13
```

```
 Single Score Intraclass Correlation

   Model: twoway
   Type : agreement

   Subjects = 13
     Raters = 3
   ICC(A,1) = 0.875

 F-Test, H0: r0 = 0 ; H1: r0 > 0
 F(12,25.6) = 23 , p = 1.04e-10

 95%-Confidence Interval for ICC Population Values:
  0.724 < ICC < 0.956
```

```
# ICC for B-blockade, RPE 13
icc_mets_bblock_13 <- intervals_wide |>
  select(mets_bblock_rpe13_1:mets_bblock_rpe13_3) |>
  icc("twoway", "agreement", "single")

icc_mets_bblock_13
```

```
 Single Score Intraclass Correlation

   Model: twoway
   Type : agreement

   Subjects = 13
     Raters = 3
   ICC(A,1) = 0.866

 F-Test, H0: r0 = 0 ; H1: r0 > 0
 F(12,19.7) = 24.4 , p = 3.23e-09

 95%-Confidence Interval for ICC Population Values:
  0.69 < ICC < 0.953
```

```
# Fisher's z-transformation & z-test
fisherz_compare(icc_mets_control_13, icc_mets_bblock_13)
```

```
$z_diff
[1] 0.04013578
```

```
$z_score
[1] 0.08974634

$p_value
[1] 0.9284888
```

```
# ICC for Control, RPE 15
icc_mets_control_15 <- intervals_wide |>
  select(mets_control_rpe15_1:mets_control_rpe15_3) |>
  icc("twoway", "agreement", "single")

icc_mets_control_15
```

```
 Single Score Intraclass Correlation

   Model: twoway
   Type : agreement

   Subjects = 13
     Raters = 3
   ICC(A,1) = 0.958

 F-Test, H0: r0 = 0 ; H1: r0 > 0
 F(12,25.8) = 67.9 , p = 2.12e-16

 95%-Confidence Interval for ICC Population Values:
  0.899 < ICC < 0.986
```

```
# ICC for B-blockade, RPE 15
icc_mets_bblock_15 <- intervals_wide |>
  select(mets_bblock_rpe15_1:mets_bblock_rpe15_3) |>
  icc("twoway", "agreement", "single")

icc_mets_bblock_15
```

```
 Single Score Intraclass Correlation

   Model: twoway
   Type : agreement

   Subjects = 13
     Raters = 3
   ICC(A,1) = 0.964

 F-Test, H0: r0 = 0 ; H1: r0 > 0
 F(12,24.4) = 76.1 , p = 2.64e-16

 95%-Confidence Interval for ICC Population Values:
  0.912 < ICC < 0.988
```

```r
# Fisher's z-transformation & z-test
fisherz_compare(icc_mets_control_15, icc_mets_bblock_15)
```

```
$z_diff
[1] -0.0795566

$z_score
[1] -0.177894

$p_value
[1] 0.8588063
```

4.6 %WRpeak (%METpeak)

```r
# ICC for Control, RPE 13
icc_pctmetspeak_control_13 <- intervals_wide |>
  select(pctmetspeak_control_rpe13_1:pctmetspeak_control_rpe13_3) |>
  icc("twoway", "agreement", "single")

icc_pctmetspeak_control_13
```

```
 Single Score Intraclass Correlation

   Model: twoway
   Type : agreement

   Subjects = 13
     Raters = 3
   ICC(A,1) = 0.829

 F-Test, H0: r0 = 0 ; H1: r0 > 0
 F(12,25.5) = 16.3 , p = 5.03e-09

 95%-Confidence Interval for ICC Population Values:
  0.636 < ICC < 0.938
```

```r
# ICC for B-blockade, RPE 13
icc_pctmetspeak_bblock_13 <- intervals_wide |>
  select(pctmetspeak_bblock_rpe13_1:pctmetspeak_bblock_rpe13_3) |>
  icc("twoway", "agreement", "single")

icc_pctmetspeak_bblock_13
```

```
 Single Score Intraclass Correlation

   Model: twoway
   Type : agreement

   Subjects = 13
     Raters = 3
```

```
   ICC(A,1) = 0.882

 F-Test, H0: r0 = 0 ; H1: r0 > 0
 F(12,17.7) = 29.4 , p = 3.01e-09

 95%-Confidence Interval for ICC Population Values:
  0.717 < ICC < 0.96
```

```
# Fisher's z-transformation & z-test
fisherz_compare(icc_pctmetspeak_control_13, icc_pctmetspeak_bblock_13)
```

```
$z_diff
[1] -0.202165

$z_score
[1] -0.4520547

$p_value
[1] 0.6512296
```

```
# ICC for Control, RPE 15
icc_pctmetspeak_control_15 <- intervals_wide |>
  select(pctmetspeak_control_rpe15_1:pctmetspeak_control_rpe15_3) |>
  icc("twoway", "agreement", "single")

icc_pctmetspeak_control_15
```

```
 Single Score Intraclass Correlation

   Model: twoway
   Type : agreement

   Subjects = 13
     Raters = 3
   ICC(A,1) = 0.917

 F-Test, H0: r0 = 0 ; H1: r0 > 0
   F(12,26) = 33.7 , p = 9.51e-13

 95%-Confidence Interval for ICC Population Values:
  0.808 < ICC < 0.971
```

```
# ICC for B-blockade, RPE 15
icc_pctmetspeak_bblock_15 <- intervals_wide |>
  select(pctmetspeak_bblock_rpe15_1:pctmetspeak_bblock_rpe15_3) |>
  icc("twoway", "agreement", "single")

icc_pctmetspeak_bblock_15
```

```
 Single Score Intraclass Correlation

   Model: twoway
```

```
   Type : agreement

   Subjects = 13
     Raters = 3
   ICC(A,1) = 0.942

 F-Test, H0: r0 = 0 ; H1: r0 > 0
 F(12,24.5) = 46.2 , p = 8.29e-14

 95%-Confidence Interval for ICC Population Values:
  0.861 < ICC < 0.98
```

```
# Fisher's z-transformation & z-test
fisherz_compare(icc_pctmetspeak_control_15, icc_pctmetspeak_bblock_15)
```

```
$z_diff
[1] -0.1860927

$z_score
[1] -0.4161159

$p_value
[1] 0.6773252
```

5 Coefficients of variation

```
calculate_cv <- function(x) {
  (sd(x, na.rm = TRUE) / mean(x, na.rm = TRUE)) * 100
}
```

```
intervals_cv <- intervals |>
  group_by(pid, condition, intensity) |>
  summarise(
    hr = calculate_cv(hr),
    vo2kg = calculate_cv(vo2kg),
    mets = calculate_cv(mets),
    .groups = "drop"
  )
```

```
intervals_cv |>
  pivot_wider(
    names_from = c(condition, intensity),
    values_from = c(hr, vo2kg, mets)
  ) |>
  pivot_longer(
    cols = !pid,
    names_to = "outcome",
    values_to = "cv"
  ) |>
  group_by(outcome) |>
```

```
  summarise(
    mean_cv = round(mean(cv, na.rm = TRUE), 1),
    sd_cv = round(sd(cv, na.rm = TRUE), 1),
    min_cv = round(min(cv, na.rm = TRUE), 1),
    max_cv = round(max(cv, na.rm = TRUE), 1)
  )
```

```
# A tibble: 12 x 5
   outcome             mean_cv sd_cv min_cv max_cv
   <chr>                 <dbl> <dbl>  <dbl>  <dbl>
 1 hr_bblock_rpe13         4.9   2.2    1.5    9.6
 2 hr_bblock_rpe15         3.5   1.8    1.3    7.4
 3 hr_control_rpe13        5.5   2.8    1.7   10.5
 4 hr_control_rpe15        2.8   1.1    1.1    5.3
 5 mets_bblock_rpe13       4.2   2.6    1.5   10.3
 6 mets_bblock_rpe15       2.8   1.4    1.2    5.9
 7 mets_control_rpe13      4.5   2.5    1.1    9.2
 8 mets_control_rpe15      2.6   1.6    0.5    4.9
 9 vo2kg_bblock_rpe13      5.5   3.2    0.7   11.9
10 vo2kg_bblock_rpe15      3.7   1.5    1      6.3
11 vo2kg_control_rpe13     5.8   3.1    1.3   10.9
12 vo2kg_control_rpe15     3.3   1.4    1.4    6.3
```

```
# ANOVA
anova_hr_cv <- aov(
  hr ~ intensity * condition + Error(pid / (intensity * condition)),
  data = intervals_cv
)

summary(anova_hr_cv)
```

```
Error: pid
          Df Sum Sq Mean Sq F value Pr(>F)
Residuals 12  111.4   9.283

Error: pid:intensity
          Df Sum Sq Mean Sq F value  Pr(>F)
intensity  1  53.61   53.61   13.68 0.00304 **
Residuals 12  47.01    3.92
---
Signif. codes:  0 ’***’ 0.001 ’**’ 0.01 ’*’ 0.05 ’.’ 0.1 ’ ’ 1

Error: pid:condition
          Df Sum Sq Mean Sq F value Pr(>F)
condition  1   0.03  0.0323    0.01  0.921
Residuals 12  37.48  3.1234

Error: pid:intensity:condition
                   Df Sum Sq Mean Sq F value Pr(>F)
intensity:condition  1  5.675   5.675   5.164 0.0423 *
Residuals           12 13.188   1.099
---
```

```
Signif. codes:  0 ’***’ 0.001 ’**’ 0.01 ’*’ 0.05 ’.’ 0.1 ’ ’ 1
```

```r
# ANOVA
anova_vo2kg_cv <- aov(
  vo2kg ~ intensity * condition + Error(pid / (intensity * condition)),
  data = intervals_cv
)

summary(anova_vo2kg_cv)
```

```
Error: pid
          Df Sum Sq Mean Sq F value Pr(>F)
Residuals 12  115.6   9.631

Error: pid:intensity
          Df Sum Sq Mean Sq F value  Pr(>F)
intensity  1  59.96   59.96   12.74 0.00385 **
Residuals 12  56.45    4.70
---
Signif. codes:  0 ’***’ 0.001 ’**’ 0.01 ’*’ 0.05 ’.’ 0.1 ’ ’ 1

Error: pid:condition
          Df Sum Sq Mean Sq F value Pr(>F)
condition  1   0.04   0.038   0.008  0.931
Residuals 12  58.18   4.849

Error: pid:intensity:condition
                   Df Sum Sq Mean Sq F value Pr(>F)
intensity:condition  1   1.72   1.716   0.329  0.577
Residuals           12  62.61   5.218
```

```r
# ANOVA
anova_mets_cv <- aov(
  mets ~ intensity * condition + Error(pid / (intensity * condition)),
  data = intervals_cv
)

summary(anova_mets_cv)
```

```
Error: pid
          Df Sum Sq Mean Sq F value Pr(>F)
Residuals 12  85.41   7.117

Error: pid:intensity
          Df Sum Sq Mean Sq F value Pr(>F)
intensity  1  36.13   36.13   5.919 0.0316 *
Residuals 12  73.24    6.10
---
Signif. codes:  0 ’***’ 0.001 ’**’ 0.01 ’*’ 0.05 ’.’ 0.1 ’ ’ 1

Error: pid:condition
```

```
          Df Sum Sq Mean Sq F value Pr(>F)
condition  1  0.002  0.0017   0.002  0.969
Residuals 12 13.024  1.0854

Error: pid:intensity:condition
                   Df Sum Sq Mean Sq F value Pr(>F)
intensity:condition  1   0.63  0.6265   0.202  0.661
Residuals           12  37.28  3.1070
```