Trabajo Final ANOVA

Introducción

El conjunto de datos sleepstudy registra el tiempo de reacción de 18 participantes evaluados durante 10 días consecutivos de privación de sueño. Contiene las variables Reaction (milisegundos), Days (0 a 9) y Subject (identificador). Corresponde a un diseño de medidas repetidas que permite analizar los efectos acumulativos de la privación sobre el rendimiento.

```
data("sleepstudy")
sleepstudy
```

```
    Reaction Days Subject
1   249.5600    0     308
2   258.7047    1     308
3   250.8006    2     308
4   321.4398    3     308
5   356.8519    4     308
6   414.6901    5     308
7   382.2038    6     308
8   290.1486    7     308
9   430.5853    8     308
10  466.3535    9     308
11  222.7339    0     309
12  205.2658    1     309
13  202.9778    2     309
14  204.7070    3     309
15  207.7161    4     309
16  215.9618    5     309
17  213.6303    6     309
18  217.7272    7     309
19  224.2957    8     309
20  237.3142    9     309
```

21	199.0539	0	310
22	194.3322	1	310
23	234.3200	2	310
24	232.8416	3	310
25	229.3074	4	310
26	220.4579	5	310
27	235.4208	6	310
28	255.7511	7	310
29	261.0125	8	310
30	247.5153	9	310
31	321.5426	0	330
32	300.4002	1	330
33	283.8565	2	330
34	285.1330	3	330
35	285.7973	4	330
36	297.5855	5	330
37	280.2396	6	330
38	318.2613	7	330
39	305.3495	8	330
40	354.0487	9	330
41	287.6079	0	331
42	285.0000	1	331
43	301.8206	2	331
44	320.1153	3	331
45	316.2773	4	331
46	293.3187	5	331
47	290.0750	6	331
48	334.8177	7	331
49	293.7469	8	331
50	371.5811	9	331
51	234.8606	0	332
52	242.8118	1	332
53	272.9613	2	332
54	309.7688	3	332
55	317.4629	4	332
56	309.9976	5	332
57	454.1619	6	332
58	346.8311	7	332
59	330.3003	8	332
60	253.8644	9	332
61	283.8424	0	333
62	289.5550	1	333
63	276.7693	2	333

64	299.8097	3	333
65	297.1710	4	333
66	338.1665	5	333
67	332.0265	6	333
68	348.8399	7	333
69	333.3600	8	333
70	362.0428	9	333
71	265.4731	0	334
72	276.2012	1	334
73	243.3647	2	334
74	254.6723	3	334
75	279.0244	4	334
76	284.1912	5	334
77	305.5248	6	334
78	331.5229	7	334
79	335.7469	8	334
80	377.2990	9	334
81	241.6083	0	335
82	273.9472	1	335
83	254.4907	2	335
84	270.8021	3	335
85	251.4519	4	335
86	254.6362	5	335
87	245.4523	6	335
88	235.3110	7	335
89	235.7541	8	335
90	237.2466	9	335
91	312.3666	0	337
92	313.8058	1	337
93	291.6112	2	337
94	346.1222	3	337
95	365.7324	4	337
96	391.8385	5	337
97	404.2601	6	337
98	416.6923	7	337
99	455.8643	8	337
100	458.9167	9	337
101	236.1032	0	349
102	230.3167	1	349
103	238.9256	2	349
104	254.9220	3	349
105	250.7103	4	349
106	269.7744	5	349

```
107 281.5648    6     349
108 308.1020    7     349
109 336.2806    8     349
110 351.6451    9     349
111 256.2968    0     350
112 243.4543    1     350
113 256.2046    2     350
114 255.5271    3     350
115 268.9165    4     350
116 329.7247    5     350
117 379.4445    6     350
118 362.9184    7     350
119 394.4872    8     350
120 389.0527    9     350
121 250.5265    0     351
122 300.0576    1     351
123 269.8939    2     351
124 280.5891    3     351
125 271.8274    4     351
126 304.6336    5     351
127 287.7466    6     351
128 266.5955    7     351
129 321.5418    8     351
130 347.5655    9     351
131 221.6771    0     352
132 298.1939    1     352
133 326.8785    2     352
134 346.8555    3     352
135 348.7402    4     352
136 352.8287    5     352
137 354.4266    6     352
138 360.4326    7     352
139 375.6406    8     352
140 388.5417    9     352
141 271.9235    0     369
142 268.4369    1     369
143 257.2424    2     369
144 277.6566    3     369
145 314.8222    4     369
146 317.2135    5     369
147 298.1353    6     369
148 348.1229    7     369
149 340.2800    8     369
```

```
150 366.5131    9     369
151 225.2640    0     370
152 234.5235    1     370
153 238.9008    2     370
154 240.4730    3     370
155 267.5373    4     370
156 344.1937    5     370
157 281.1481    6     370
158 347.5855    7     370
159 365.1630    8     370
160 372.2288    9     370
161 269.8804    0     371
162 272.4428    1     371
163 277.8989    2     371
164 281.7895    3     371
165 279.1705    4     371
166 284.5120    5     371
167 259.2658    6     371
168 304.6306    7     371
169 350.7807    8     371
170 369.4692    9     371
171 269.4117    0     372
172 273.4740    1     372
173 297.5968    2     372
174 310.6316    3     372
175 287.1726    4     372
176 329.6076    5     372
177 334.4818    6     372
178 343.2199    7     372
179 369.1417    8     372
180 364.1236    9     372
```

```
df <- sleepstudy
```

Exploratory Data analysis

```
glimpse(df)
```

```
Rows: 180
Columns: 3
```

```
$ Reaction <dbl> 249.5600, 258.7047, 250.8006, 321.4398, 356.8519, 414.6901, 3~
$ Days     <dbl> 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 0~
$ Subject  <fct> 308, 308, 308, 308, 308, 308, 308, 308, 308, 308, 309, 309, 3~
```

```r
summary(df)
```

```
    Reaction          Days        Subject
 Min.   :194.3   Min.   :0.0   308    : 10
 1st Qu.:255.4   1st Qu.:2.0   309    : 10
 Median :288.7   Median :4.5   310    : 10
 Mean   :298.5   Mean   :4.5   330    : 10
 3rd Qu.:336.8   3rd Qu.:7.0   331    : 10
 Max.   :466.4   Max.   :9.0   332    : 10
                               (Other):120
```

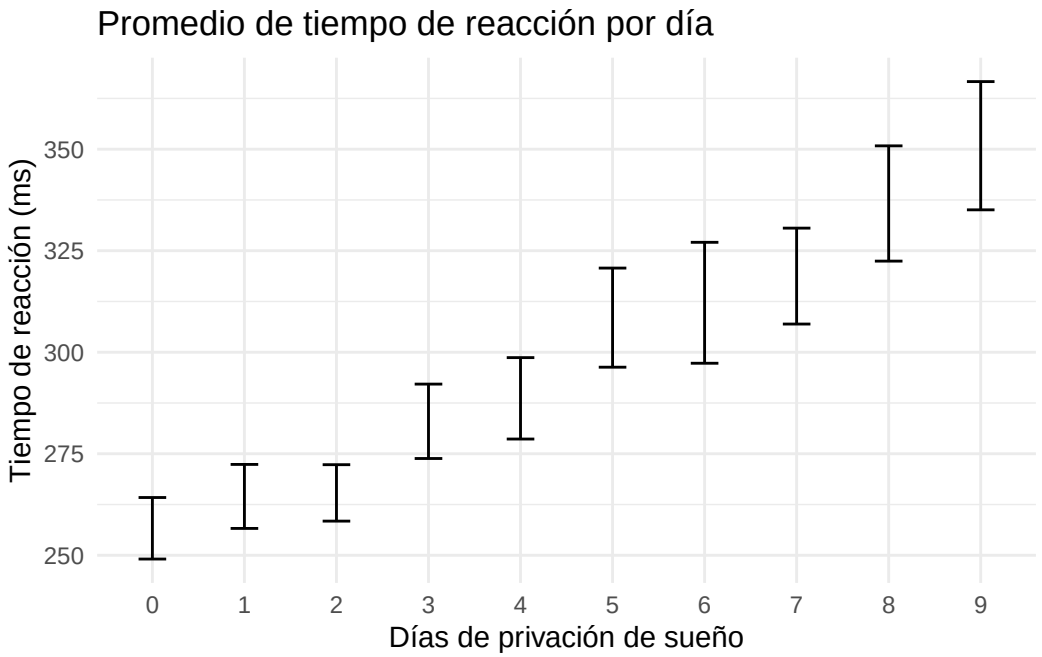
```r
df$Days <- as.factor(df$Days)
```

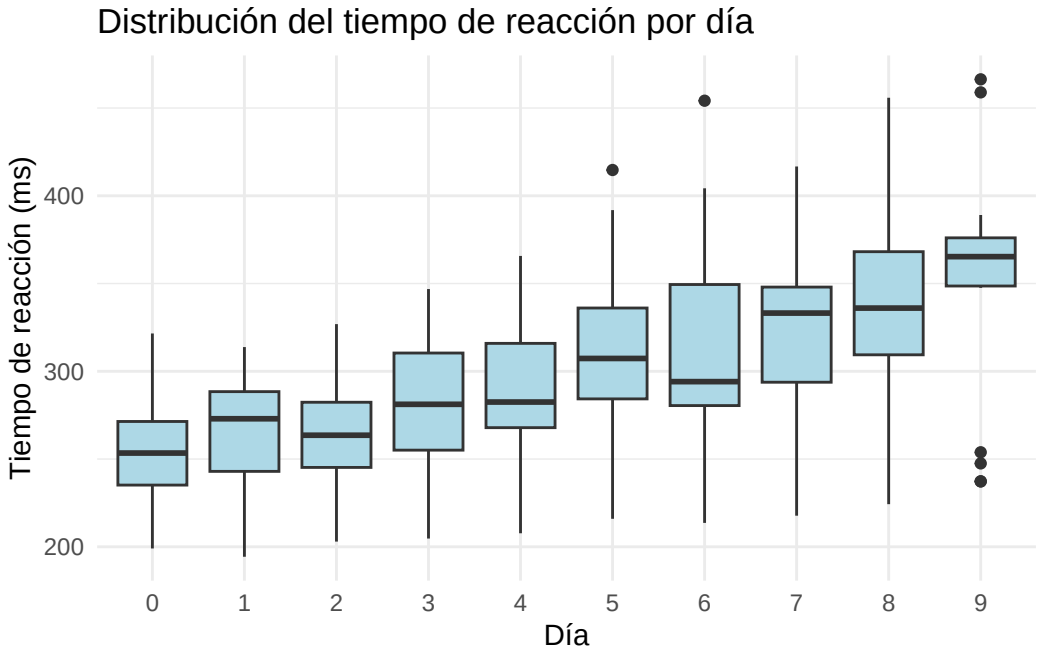
```r
describeBy(sleepstudy, group = sleepstudy$Days)
```

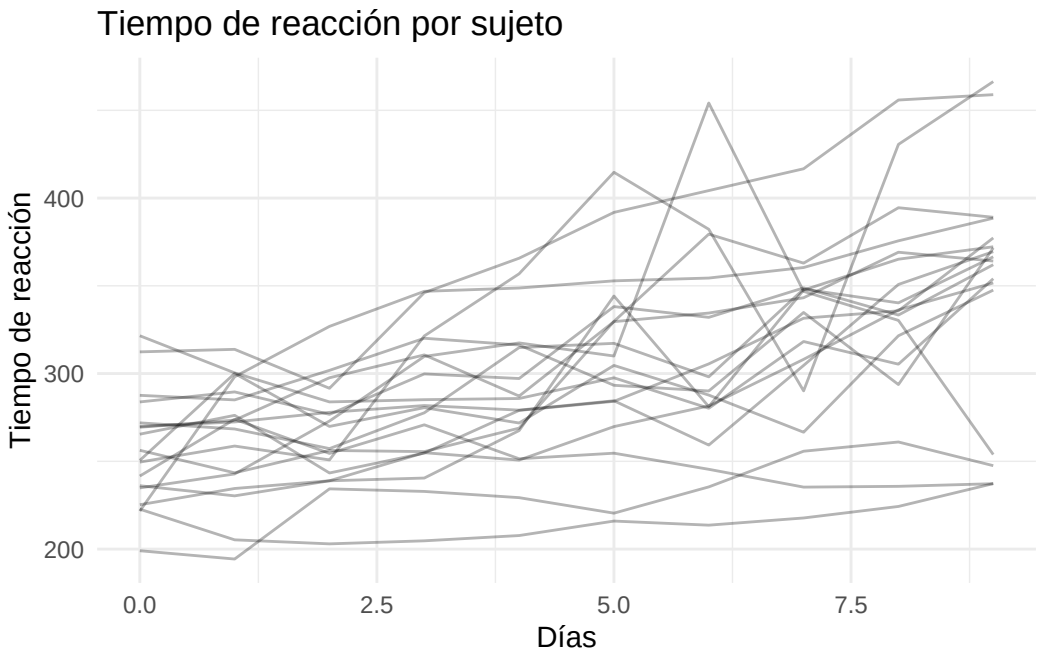
```
 Descriptive statistics by group
group: 0
         vars  n   mean    sd median trimmed   mad    min    max  range skew
Reaction    1 18 256.65 32.13 253.41   256.2 27.47 199.05 321.54 122.49  0.3
Days        2 18   0.00  0.00   0.00     0.0  0.00   0.00   0.00   0.00  NaN
Subject     3 18   9.50  5.34   9.50     9.5  6.67   1.00  18.00  17.00  0.0
         kurtosis   se
Reaction     -0.7 7.57
Days          NaN 0.00
Subject      -1.4 1.26
------------------------------------------------------------
group: 1
         vars  n  mean    sd median trimmed   mad    min    max  range  skew
Reaction    1 18 264.5 33.43 272.96   265.8 38.80 194.33 313.81 119.47 -0.54
Days        2 18   1.0  0.00   1.00     1.0  0.00   1.00   1.00   0.00   NaN
Subject     3 18   9.5  5.34   9.50     9.5  6.67   1.00  18.00  17.00  0.00
         kurtosis   se
Reaction    -0.77 7.88
Days          NaN 0.00
Subject     -1.40 1.26
------------------------------------------------------------
```

```
group: 2
         vars  n   mean    sd median trimmed   mad    min    max range skew
Reaction    1 18 265.36 29.47 263.57  265.42 30.02 202.98 326.88 123.9 0.04
Days        2 18   2.00  0.00   2.00    2.00  0.00   2.00   2.00   0.0  NaN
Subject     3 18   9.50  5.34   9.50    9.50  6.67   1.00  18.00  17.0 0.00
         kurtosis   se
Reaction    -0.41 6.95
Days          NaN 0.00
Subject     -1.40 1.26
------------------------------------------------------------
group: 3
         vars  n   mean    sd median trimmed   mad    min    max  range  skew
Reaction    1 18 282.99 38.86 281.19  283.89 40.84 204.71 346.86 142.15 -0.08
Days        2 18   3.00  0.00   3.00    3.00  0.00   3.00   3.00   0.00   NaN
Subject     3 18   9.50  5.34   9.50    9.50  6.67   1.00  18.00  17.00  0.00
         kurtosis   se
Reaction    -0.89 9.16
Days          NaN 0.00
Subject     -1.40 1.26
------------------------------------------------------------
group: 4
         vars  n   mean    sd median trimmed   mad    min    max  range skew
Reaction    1 18 288.65 42.54 282.48  288.89 46.56 207.72 365.73 158.02 0.13
Days        2 18   4.00  0.00   4.00    4.00  0.00   4.00   4.00   0.00  NaN
Subject     3 18   9.50  5.34   9.50    9.50  6.67   1.00  18.00  17.00 0.00
         kurtosis    se
Reaction    -0.77 10.03
Days          NaN  0.00
Subject     -1.40  1.26
------------------------------------------------------------
group: 5
         vars  n   mean    sd median trimmed   mad    min    max  range skew
Reaction    1 18 308.52 51.77 307.32  307.67 40.01 215.96 414.69 198.73 0.09
Days        2 18   5.00  0.00   5.00    5.00  0.00   5.00   5.00   0.00  NaN
Subject     3 18   9.50  5.34   9.50    9.50  6.67   1.00  18.00  17.00 0.00
         kurtosis    se
Reaction    -0.47 12.20
Days          NaN  0.00
Subject     -1.40  1.26
------------------------------------------------------------
group: 6
         vars  n   mean    sd median trimmed   mad    min    max  range skew
Reaction    1 18 312.18 63.17 294.11  309.46 58.04 213.63 454.16 240.53 0.53
```

```
Days        2 18   6.00  0.00   6.00    6.00  0.00   6.00   6.00   0.00  NaN
Subject     3 18   9.50  5.34   9.50    9.50  6.67   1.00  18.00  17.00 0.00
         kurtosis    se
Reaction    -0.61 14.89
Days          NaN  0.00
Subject     -1.40  1.26
------------------------------------------------------------
group: 7
         vars  n   mean    sd median trimmed   mad    min    max  range  skew
Reaction    1 18 318.75 50.10 333.17  318.94 38.79 217.73 416.69 198.97 -0.36
Days        2 18   7.00  0.00   7.00    7.00  0.00   7.00   7.00   0.00   NaN
Subject     3 18   9.50  5.34   9.50    9.50  6.67   1.00  18.00  17.00  0.00
         kurtosis    se
Reaction    -0.54 11.81
Days          NaN  0.00
Subject     -1.40  1.26
------------------------------------------------------------
group: 8
         vars  n   mean    sd median trimmed   mad   min    max  range  skew
Reaction    1 18 336.63 60.20 336.01   336.2 47.29 224.3 455.86 231.57 -0.04
Days        2 18   8.00  0.00   8.00     8.0  0.00   8.0   8.00   0.00   NaN
Subject     3 18   9.50  5.34   9.50     9.5  6.67   1.0  18.00  17.00  0.00
         kurtosis    se
Reaction    -0.48 14.19
Days          NaN  0.00
Subject     -1.40  1.26
------------------------------------------------------------
group: 9
         vars  n   mean    sd median trimmed   mad    min    max  range  skew
Reaction    1 18 350.85 66.99 365.32  350.73 23.30 237.25 466.35 229.11 -0.37
Days        2 18   9.00  0.00   9.00    9.00  0.00   9.00   9.00   0.00   NaN
Subject     3 18   9.50  5.34   9.50    9.50  6.67   1.00  18.00  17.00  0.00
         kurtosis    se
Reaction    -0.64 15.79
Days          NaN  0.00
Subject     -1.40  1.26
```


Promedio de tiempo de reacción por día
Tiempo de reacción (ms)
350
325
300
275
250
0
1
2
3
4
5
6
7
8
9
Días de privación de sueño


Distribución del tiempo de reacción por día
Tiempo de reacción (ms)
400
300
200
0
1
2
3
4
5
6
7
8
9
Día



Objetivo

Evaluar el efecto de la privación de sueño progresiva sobre el rendimiento cognitivo, medido a través del tiempo de reacción, en participantes sometidos a restricción del sueño durante un período de 10 días consecutivos.

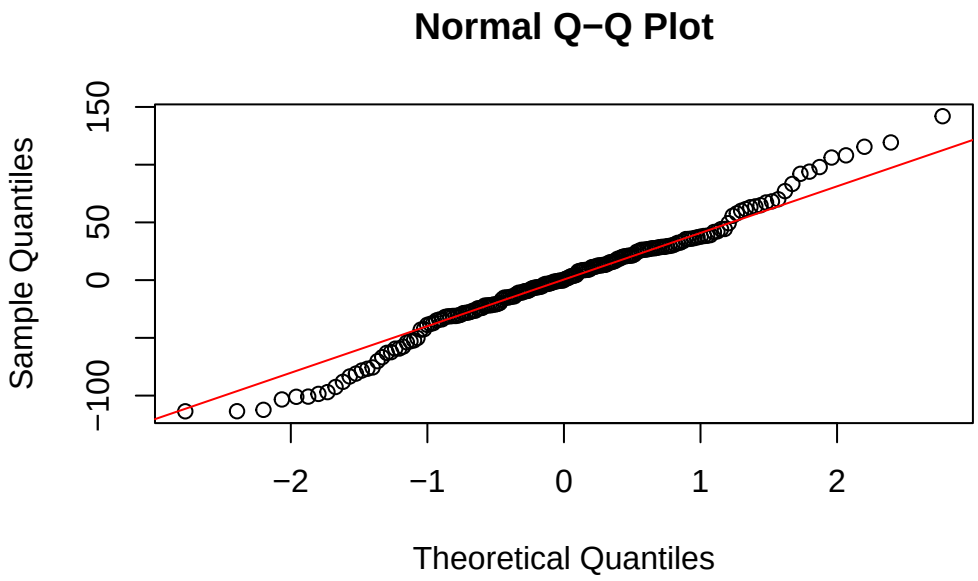
Hipotesis

El tiempo de reacción de los participantes aumenta progresivamente a medida que se acumulan los días de privación de sueño, reflejando un deterioro en el rendimiento cognitivo.

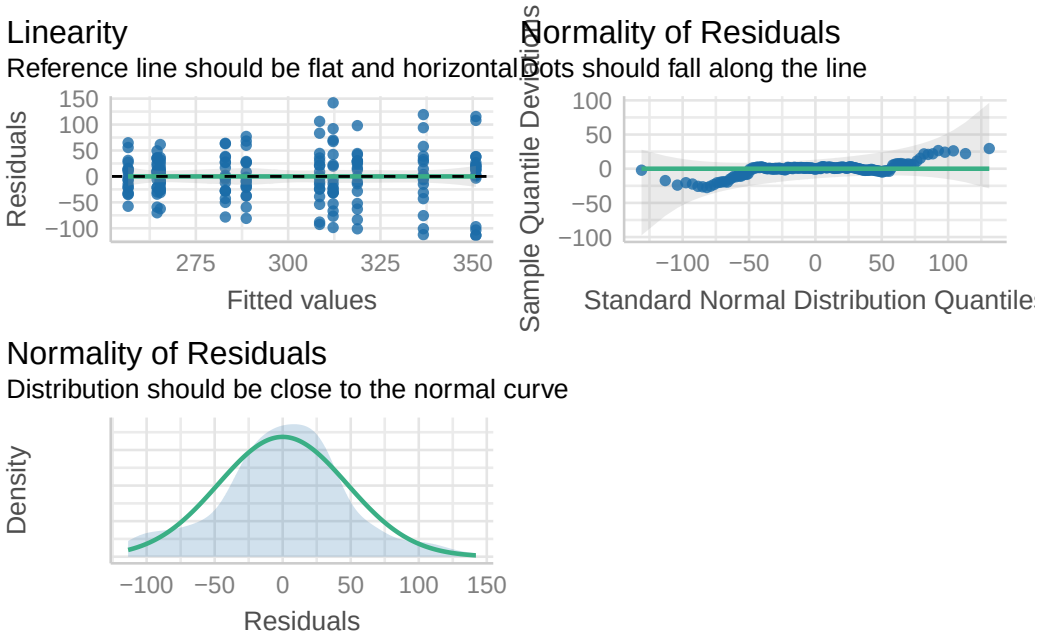
Supuestos y modelo

```r
model <- aov_ez(id = "Subject",
                    dv = "Reaction",
                    within = "Days",
                    data = sleepstudy)
```

```r
qqnorm(residuals(model))
qqline(residuals(model), col = "red")
```




```r
check_model(model)
```




```
shapiro_test <- shapiro.test(residuals(model))
print(shapiro_test)
```

```
    Shapiro-Wilk normality test

data:  residuals(model)
W = 0.98378, p-value = 0.03495
```

La prueba de Shapiro-Wilk fue significativa ($W = 0.98$, $p = 0.035$), lo que indica una **desviación de la normalidad** en los residuos

```
summary(model)
```

```
Univariate Type III Repeated-Measures ANOVA Assuming Sphericity

              Sum Sq num Df Error SS den Df  F value    Pr(>F)
(Intercept) 16039253      1   250618     17 1087.979 < 2.2e-16 ***
Days          166235      9   151101    153   18.703 < 2.2e-16 ***
---
```

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


Mauchly Tests for Sphericity

     Test statistic    p-value
Days     0.00021902 5.1549e-08


Greenhouse-Geisser and Huynh-Feldt Corrections
 for Departure from Sphericity

      GG eps Pr(>F[GG])
Days 0.36903  5.463e-09 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

        HF eps   Pr(>F[HF])
Days 0.4693648 7.076552e-11
```

```r
eta_squared(model, partial = TRUE)
```

```
# Effect Size for ANOVA (Type III)

Parameter | Eta2 (partial) |       95% CI
-----------------------------------------
Days      |           0.52 | [0.42, 1.00]

- One-sided CIs: upper bound fixed at [1.00].
```

```r
emmeans(model, pairwise ~ Days, adjust = "fdr")
```

```
$emmeans
 Days emmean    SE df lower.CL upper.CL
 X0      257  7.57 17      241      273
 X1      264  7.88 17      248      281
 X2      265  6.95 17      251      280
 X3      283  9.16 17      264      302
 X4      289 10.00 17      267      310
 X5      309 12.20 17      283      334
 X6      312 14.90 17      281      344
```

```
 X7      319 11.80 17      294      344
 X8      337 14.20 17      307      367
 X9      351 15.80 17      318      384

Confidence level used: 0.95

$contrasts
 contrast estimate    SE df t.ratio p.value
 X0 - X1    -7.844  5.61 17  -1.397  0.2058
 X0 - X2    -8.710  7.50 17  -1.162  0.2867
 X0 - X3   -26.340  8.77 17  -3.003  0.0120
 X0 - X4   -31.998  9.47 17  -3.378  0.0067
 X0 - X5   -51.867 11.70 17  -4.423  0.0010
 X0 - X6   -55.526 15.10 17  -3.669  0.0041
 X0 - X7   -62.099 10.40 17  -5.957  0.0002
 X0 - X8   -79.978 13.70 17  -5.834  0.0002
 X0 - X9   -94.199 13.50 17  -6.958  0.0001
 X1 - X2    -0.866  5.10 17  -0.170  0.8671
 X1 - X3   -18.496  6.24 17  -2.964  0.0126
 X1 - X4   -24.154  7.73 17  -3.125  0.0099
 X1 - X5   -44.023 10.50 17  -4.212  0.0016
 X1 - X6   -47.682 14.50 17  -3.291  0.0078
 X1 - X7   -54.255 10.60 17  -5.106  0.0004
 X1 - X8   -72.134 13.20 17  -5.452  0.0002
 X1 - X9   -86.355 13.20 17  -6.520  0.0001
 X2 - X3   -17.630  4.56 17  -3.867  0.0029
 X2 - X4   -23.288  7.22 17  -3.226  0.0086
 X2 - X5   -43.157 10.70 17  -4.047  0.0021
 X2 - X6   -46.816 13.30 17  -3.529  0.0053
 X2 - X7   -53.389  9.53 17  -5.601  0.0002
 X2 - X8   -71.268 13.00 17  -5.474  0.0002
 X2 - X9   -85.489 14.30 17  -5.975  0.0002
 X3 - X4    -5.657  4.07 17  -1.388  0.2058
 X3 - X5   -25.526  8.45 17  -3.021  0.0119
 X3 - X6   -29.186 11.00 17  -2.647  0.0231
 X3 - X7   -35.759  9.68 17  -3.695  0.0040
 X3 - X8   -53.637 11.40 17  -4.698  0.0007
 X3 - X9   -67.859 13.00 17  -5.211  0.0003
 X4 - X5   -19.869  6.36 17  -3.125  0.0099
 X4 - X6   -23.529  9.93 17  -2.371  0.0384
 X4 - X7   -30.101  8.69 17  -3.466  0.0058
 X4 - X8   -47.980  9.49 17  -5.057  0.0004
 X4 - X9   -62.202 11.10 17  -5.603  0.0002
```

```
 X5 - X6    -3.660 10.00 17  -0.365  0.7360
 X5 - X7   -10.232  9.46 17  -1.082  0.3153
 X5 - X8   -28.111  6.18 17  -4.546  0.0009
 X5 - X9   -42.333  8.68 17  -4.875  0.0005
 X6 - X7    -6.572 10.70 17  -0.616  0.5714
 X6 - X8   -24.451 10.70 17  -2.279  0.0448
 X6 - X9   -38.673 16.00 17  -2.423  0.0355
 X7 - X8   -17.879  9.25 17  -1.933  0.0852
 X7 - X9   -32.101 12.00 17  -2.683  0.0221
 X8 - X9   -14.222  7.46 17  -1.906  0.0874

P value adjustment: fdr method for 45 tests
```

Se realizó un ANOVA de medidas repetidas para evaluar el efecto de la privación de sueño (Days) sobre el tiempo de reacción. El análisis reveló un efecto significativo del factor Days, $F(9, 153) = 18.70$, $p < .001$, lo que indica que el rendimiento cognitivo varió significativamente a lo largo del tiempo. La prueba de esfericidad de Mauchly fue significativa ($p < .001$), evidenciando una violación de este supuesto; en consecuencia, se aplicaron las correcciones de Greenhouse–Geisser y Huynh–Feldt, que confirmaron la significancia del efecto ($p < .001$). El tamaño del efecto fue grande, ^{2} parcial $= 0.52$, IC 95% [0.42, 1.00], lo que sugiere que más de la mitad de la varianza en el rendimiento se explica por el efecto de los días de privación.

Las comparaciones post hoc, corregidas por FDR, indicaron que los tiempos de reacción aumentan significativamente a partir del día 3 en adelante ($p < .05$), con diferencias particularmente marcadas entre los días iniciales (X0–X2) y los días finales (X7–X9). Estos resultados respaldan la hipótesis de un deterioro progresivo del rendimiento cognitivo con el aumento de los días de privación de sueño.

```r
sleepstudy$Days <- as.numeric(sleepstudy$Days)

reg_model <- lmer(Reaction ~ Days + (1 | Subject), data = sleepstudy)
summary(reg_model)
```

```
Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]
Formula: Reaction ~ Days + (1 | Subject)
   Data: sleepstudy

REML criterion at convergence: 1786.5

Scaled residuals:
```

```
    Min      1Q  Median      3Q     Max
-3.2257 -0.5529  0.0109  0.5188  4.2506

Random effects:
 Groups   Name        Variance Std.Dev.
 Subject  (Intercept) 1378.2   37.12
 Residual              960.5   30.99
Number of obs: 180, groups:  Subject, 18

Fixed effects:
            Estimate Std. Error       df t value Pr(>|t|)
(Intercept) 251.4051     9.7467  22.8102   25.79   <2e-16 ***
Days         10.4673     0.8042 161.0000   13.02   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
     (Intr)
Days -0.371
```

```
standardize_parameters(reg_model)
```

```
# Standardization method: refit

Parameter   | Std. Coef. |        95% CI
-----------------------------------------
(Intercept) |  -6.92e-16 | [-0.32, 0.32]
Days        |       0.54 | [ 0.45, 0.62]
```

```
r2(reg_model)
```

```
# R2 for Mixed Models

  Conditional R2: 0.704
     Marginal R2: 0.280
```

Se ajustó un modelo lineal mixto para predecir el tiempo de reacción a partir del número de días de privación de sueño, incluyendo un intercepto aleatorio por sujeto. Los resultados mostraron que el tiempo de reacción aumentó significativamente con el paso de los días, $= 10.47$, SE $= 0.80$, t(161) $= 13.02$, p $< .001$, lo que indica un deterioro progresivo del rendimiento cognitivo asociado a la restricción del sueño. El coeficiente estandarizado fue $=$

0.54, IC 95% [0.45, 0.62], lo que representa un efecto moderado-alto. El modelo explicó el 28% de la varianza mediante efectos fijos (R^2 marginal = 0.28) y el 70% al considerar también los efectos aleatorios (R^2 condicional = 0.70).