Water Beads Experiment

2025-12-16

1. Random Assignment

```
set.seed(123)
Temperature = factor(c("Room", "Cold", "Hot"))
Type = factor(c("Tap", "Distilled"))
Solution = factor(c("None", "Salt", "Soap"))
design = expand.grid(Temperature = Temperature, Type = Type, Solution = Solution)
design = design[sample(1:18),]
design
```

```
##    Temperature      Type Solution
## 15         Hot       Tap     Soap
## 14        Cold       Tap     Soap
## 3          Hot       Tap     None
## 10        Room Distilled     Salt
## 2         Cold       Tap     None
## 6          Hot Distilled     None
## 11        Cold Distilled     Salt
## 5         Cold Distilled     None
## 4         Room Distilled     None
## 13        Room       Tap     Soap
## 1         Room       Tap     None
## 17        Cold Distilled     Soap
## 16        Room Distilled     Soap
## 12         Hot Distilled     Salt
## 9          Hot       Tap     Salt
## 18         Hot Distilled     Soap
## 8         Cold       Tap     Salt
## 7         Room       Tap     Salt
```

2. Data Table

```
Pre = c(2.2, 2.2, 2.2, 2.1, 2.1, 2.0, 2.1, 2.1, 2.1,
        2.2, 2.2, 2.2, 2.2, 2.2, 2.2, 2.2, 2.2, 2.2)
Post = c(9.6, 8.3, 10.0, 8.1, 9.0, 9.0, 6.6, 9.0, 9.0,
         9.1, 9.2, 8.5, 8.7, 7.5, 7.9, 9.7, 6.8, 7.5)
Growth = c(436.36, 377.27, 454.55, 385.71, 428.57, 450.00, 314.29, 428.57, 428.57,
           413.64, 418.18, 386.36, 395.45, 340.91, 359.10, 440.91, 309.10, 340.91)
design$Pre = Pre
design$Post = Post
design$Growth = Growth
design
```

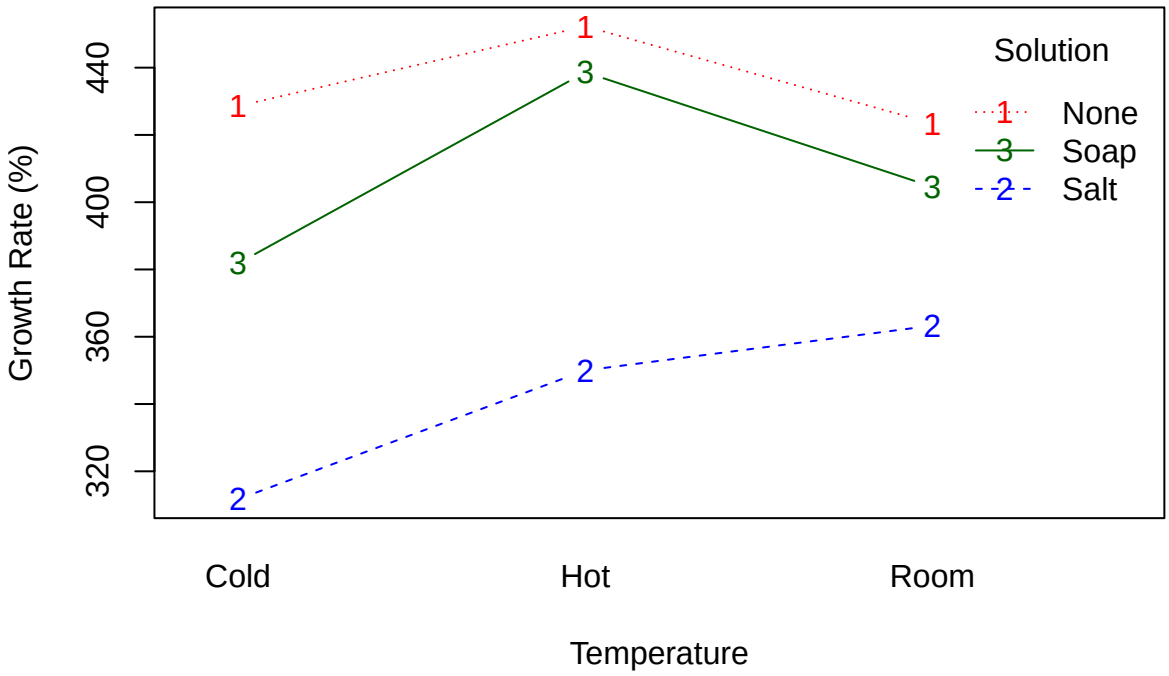
```
##    Temperature      Type Solution Pre Post Growth
## 15         Hot       Tap     Soap 2.2  9.6 436.36
## 14        Cold       Tap     Soap 2.2  8.3 377.27
## 3          Hot       Tap     None 2.2 10.0 454.55
## 10        Room Distilled     Salt 2.1  8.1 385.71
## 2         Cold       Tap     None 2.1  9.0 428.57
## 6          Hot Distilled     None 2.0  9.0 450.00
## 11        Cold Distilled     Salt 2.1  6.6 314.29
## 5         Cold Distilled     None 2.1  9.0 428.57
## 4         Room Distilled     None 2.1  9.0 428.57
## 13        Room       Tap     Soap 2.2  9.1 413.64
## 1         Room       Tap     None 2.2  9.2 418.18
## 17        Cold Distilled     Soap 2.2  8.5 386.36
## 16        Room Distilled     Soap 2.2  8.7 395.45
## 12         Hot Distilled     Salt 2.2  7.5 340.91
## 9          Hot       Tap     Salt 2.2  7.9 359.10
## 18         Hot Distilled     Soap 2.2  9.7 440.91
## 8         Cold       Tap     Salt 2.2  6.8 309.10
## 7         Room       Tap     Salt 2.2  7.5 340.91
```

3. Fit Model

```r
fit = aov(Growth ~ Temperature * Type * Solution, design)
summary(fit)
```

```
##                           Df Sum Sq Mean Sq
## Temperature                2   4749    2375
## Type                       1     61      61
## Solution                   2  27606   13803
## Temperature:Type           2    256     128
## Temperature:Solution       4   2344     586
## Type:Solution              2    117      58
## Temperature:Type:Solution  4   1030     257
```

```r
interaction.plot(design$Temperature, design$Solution, Growth, type = "b",
                 trace.label = "Solution", xlab = "Temperature", ylab = "Growth Rate (%)",
                 col = c("red", "blue", "darkgreen"))
```




```
fit_reduced = aov(Growth ~ Temperature * Solution, design)
summary(fit_reduced)
```

```
##                      Df Sum Sq Mean Sq F value   Pr(>F)
## Temperature           2   4749    2375  14.600   0.0015 **
## Solution              2  27606   13803  84.864 1.44e-06 ***
## Temperature:Solution  4   2344     586   3.603   0.0510 .
## Residuals             9   1464     163
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
TukeyHSD(fit_reduced)
```

```
##   Tukey multiple comparisons of means
##     95% family-wise confidence level
##
## Fit: aov(formula = Growth ~ Temperature * Solution, data = design)
##
## $Temperature
##                diff        lwr       upr     p adj
## Hot-Cold   39.61167  19.053533 60.169801 0.0011571
## Room-Cold  23.05000   2.491866 43.608134 0.0295071
## Room-Hot  -16.56167 -37.119801  3.996467 0.1156400
##
## $Solution
```

```
##                diff        lwr        upr     p adj
## Salt-None -93.07000 -113.62813 -72.511866 0.0000013
## Soap-None -26.40833  -46.96647  -5.850199 0.0146205
## Soap-Salt  66.66167   46.10353  87.219801 0.0000217
##
## $`Temperature:Solution`
##                           diff         lwr        upr     p adj
## Hot:None-Cold:None     23.705  -26.748441  74.158441 0.6517216
## Room:None-Cold:None    -5.195  -55.648441  45.258441 0.9999464
## Cold:Salt-Cold:None  -116.875 -167.328441 -66.421559 0.0001464
## Hot:Salt-Cold:None    -78.565 -129.018441 -28.111559 0.0030515
## Room:Salt-Cold:None   -65.260 -115.713441 -14.806559 0.0108240
## Cold:Soap-Cold:None   -46.755  -97.208441   3.698441 0.0741354
## Hot:Soap-Cold:None     10.065  -40.388441  60.518441 0.9943168
## Room:Soap-Cold:None   -24.025  -74.478441  26.428441 0.6382571
## Room:None-Hot:None    -28.900  -79.353441  21.553441 0.4412563
## Cold:Salt-Hot:None   -140.580 -191.033441 -90.126559 0.0000321
## Hot:Salt-Hot:None    -102.270 -152.723441 -51.816559 0.0004227
## Room:Salt-Hot:None    -88.965 -139.418441 -38.511559 0.0012289
## Cold:Soap-Hot:None    -70.460 -120.913441 -20.006559 0.0065092
## Hot:Soap-Hot:None     -13.640  -64.093441  36.813441 0.9655402
## Room:Soap-Hot:None    -47.730  -98.183441   2.723441 0.0668180
## Cold:Salt-Room:None  -111.680 -162.133441 -61.226559 0.0002108
## Hot:Salt-Room:None    -73.370 -123.823441 -22.916559 0.0049345
## Room:Salt-Room:None   -60.065 -110.518441  -9.611559 0.0182900
## Cold:Soap-Room:None   -41.560  -92.013441   8.893441 0.1286246
## Hot:Soap-Room:None     15.260  -35.193441  65.713441 0.9383650
## Room:Soap-Room:None   -18.830  -69.283441  31.623441 0.8418838
## Hot:Salt-Cold:Salt     38.310  -12.143441  88.763441 0.1803384
## Room:Salt-Cold:Salt    51.615    1.161559 102.068441 0.0442005
## Cold:Soap-Cold:Salt    70.120   19.666559 120.573441 0.0067258
## Hot:Soap-Cold:Salt    126.940   76.486559 177.393441 0.0000747
## Room:Soap-Cold:Salt    92.850   42.396559 143.303441 0.0008902
## Room:Salt-Hot:Salt     13.305  -37.148441  63.758441 0.9699089
## Cold:Soap-Hot:Salt     31.810  -18.643441  82.263441 0.3411494
## Hot:Soap-Hot:Salt      88.630   38.176559 139.083441 0.0012641
## Room:Soap-Hot:Salt     54.540    4.086559 104.993441 0.0324592
## Cold:Soap-Room:Salt    18.505  -31.948441  68.958441 0.8526108
## Hot:Soap-Room:Salt     75.325   24.871559 125.778441 0.0041095
## Room:Soap-Room:Salt    41.235   -9.218441  91.688441 0.1330905
## Hot:Soap-Cold:Soap     56.820    6.366559 107.273441 0.0255730
## Room:Soap-Cold:Soap    22.730  -27.723441  73.183441 0.6925050
## Room:Soap-Hot:Soap    -34.090  -84.543441  16.363441 0.2749848
```

```
model.tables(fit, "means", se = TRUE)
```

```
## Tables of means
## Grand mean
##
## 394.9139
##
##  Temperature
## Temperature
##  Cold   Hot  Room
```

```
## 374.0 413.6 397.1
##
##  Type
## Type
## Distilled       Tap
##     396.8     393.1
##
##  Solution
## Solution
##  None  Salt  Soap
## 434.7 341.7 408.3
##
##  Temperature:Type
##             Type
## Temperature Distilled Tap
##        Cold 376.4     371.6
##        Hot  410.6     416.7
##        Room 403.2     390.9
##
##  Temperature:Solution
##             Solution
## Temperature None  Salt  Soap
##        Cold 428.6 311.7 381.8
##        Hot  452.3 350.0 438.6
##        Room 423.4 363.3 404.5
##
##  Type:Solution
##             Solution
## Type         None  Salt  Soap
##   Distilled 435.7 347.0 407.6
##   Tap       433.8 336.4 409.1
##
##  Temperature:Type:Solution
## , , Solution = None
##
##             Type
## Temperature Distilled Tap
##        Cold 428.6     428.6
##        Hot  450.0     454.6
##        Room 428.6     418.2
##
## , , Solution = Salt
##
##             Type
## Temperature Distilled Tap
##        Cold 314.3     309.1
##        Hot  340.9     359.1
##        Room 385.7     340.9
##
## , , Solution = Soap
##
##             Type
## Temperature Distilled Tap
##        Cold 386.4     377.3
```

```
##        Hot  440.9     436.4
##        Room 395.5     413.6
##
##
## Standard errors for differences of means
##         Temperature Type Solution Temperature:Type Temperature:Solution
##                 NaN  NaN      NaN              NaN                   NaN
## replic.           6    9        6                3                     2
##         Type:Solution Temperature:Type:Solution
##                   NaN                      NaN
## replic.             3                        1
```