Chapter 5. Exploring assumptions

Daehyeog Lee

2023-09-12

Table of contents

5.0. Importing libraries

```r
library(car); library(ggplot2); library(pastecs); library(psych)
```

```
Loading required package: carData

Attaching package: 'psych'

The following objects are masked from 'package:ggplot2':

    %+%, alpha

The following object is masked from 'package:car':

    logit
```

5.1. What will this chapter tell me?

How can we turn the ugly data into a beautiful swan?

5.2. What are assumptions?

Different statistical models assume different things.

The assumptions need to be true when statistical models are going to reflect reality accurately.

5.3. Assumptions of parametric data

Parametric statistics are based on assumption about the distribution of population from which the sample was taken.

Nonparametric statistics are not based on assumptions, that is, the data can be collected from a sample that does not follow a specific distribution.

Parametric test requires data from one of the large catalogue of distributions that statisticians have described.

According to the **central limit theorem**, as samples get large, the sampling distribution has a normal distribution with a mean equal to the population mean.

Most parametric tests based on the normal distribution have four basic assumptions that must be met for the test to be accurate.

1) **Normally distributed data**
2) **Homogeneity of variance**: Variances should be the dame throughout the data.
3) **Interval data**: Data should be measured at least at the interval level.
4) **Independence** (This assumption is different depending on the test we're using)

5.4. Packages used in this chapter

`car`, `ggplot2`, `pastecs`, `psych`, `Rcmdr`

5.5. The assumption of normality

We assume that the sampling distribution is normally distributed, but we don't have access to this distribution.

Central limit theorem: If the sample data are approximately normal then the sampling distribution will be also normal.

General linear models assume that errors in the model are normally distributed.

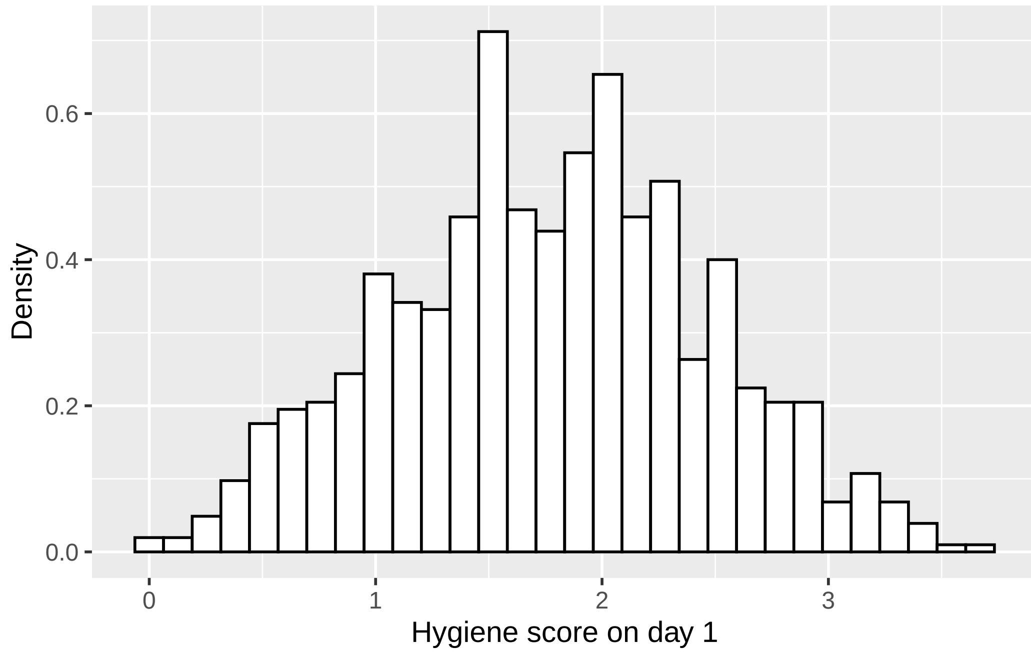
5.5.1. Oh no, it's that pesky frequency distribution again: checking normality visually

First, let's plot a histogram of **DownloadFestival.dat**:

```r
dlf <- read.delim("dfno.dat", header = TRUE)
  hist.day1 <- ggplot(dlf, aes(day1)) +
  geom_histogram(aes(y = ..density..),
                 color = "black",
                 fill = "white"
                 ) +
  labs(x = "Hygiene score on day 1", y = "Density")
hist.day1
```

```
Warning: The dot-dot notation (`..density..`) was deprecated in ggplot2 3.4.0.
i Please use `after_stat(density)` instead.
```

```
`stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```



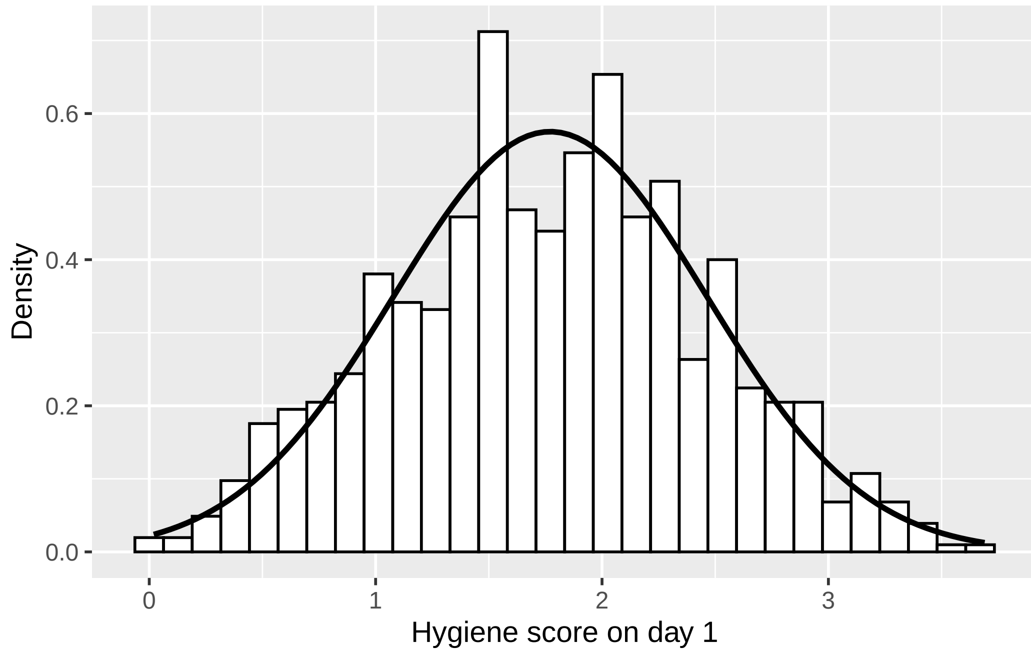
We can add a normal curve, and we need to tell *ggplot2* what mean and SD we'd like on that curve.

The `stat_function()` command draws the normal curve using the function `dnorm()`:

```
hist.day1 +
  stat_function(fun = dnorm,
                args = list(mean = mean(dlf$day1, na.rm = TRUE),
                            sd = sd(dlf$day1, na.rm = TRUE)),
                            color = "black",
                            size = 1
               )
```

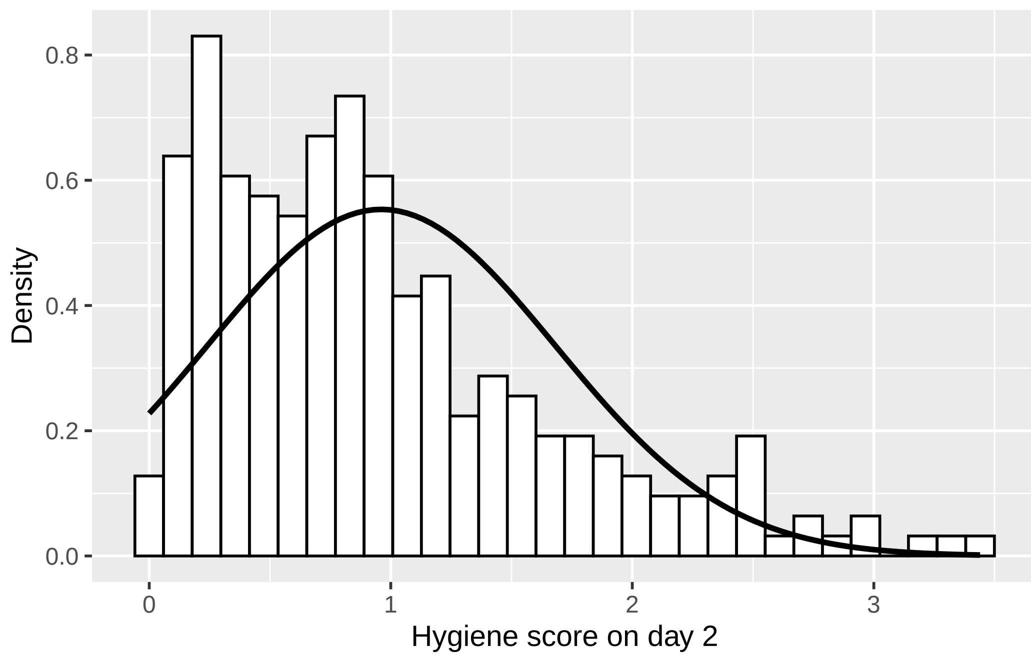
```
Warning: Using `size` aesthetic for lines was deprecated in ggplot2 3.4.0.
i Please use `linewidth` instead.
```

```
`stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```




```
### SELF-TEST

# DAY 2
hist.day2 <- ggplot(dlf, aes(day2)) +
  geom_histogram(aes(y = ..density..),
                 color = "black",
                 fill = "white"
                 ) +
  labs(x = "Hygiene score on day 2", y = "Density")
hist.day2 +
  stat_function(fun = dnorm,
                args = list(mean = mean(dlf$day2, na.rm = TRUE),
                            sd = sd(dlf$day2, na.rm = TRUE)),
                            color = "black",
                            size = 1
               )
```

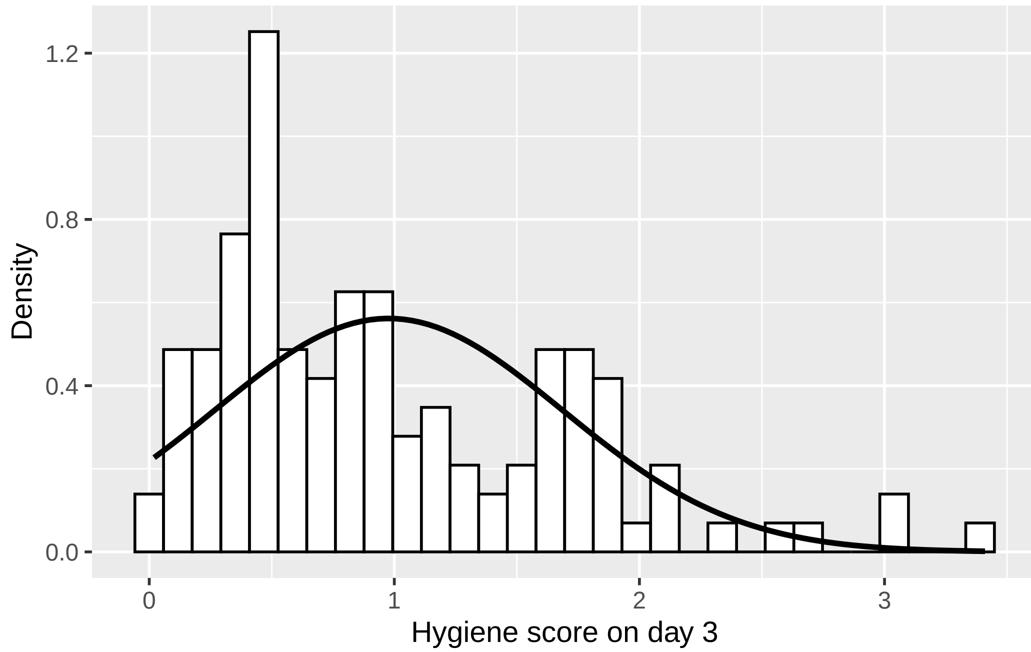
```
`stat_bin()` using `bins = 30`. Pick better value with `binwidth`.

Warning: Removed 546 rows containing non-finite values (`stat_bin()`).
```




```
# DAY 3
hist.day3 <- ggplot(dlf, aes(day3)) +
  geom_histogram(aes(y = ..density..),
                 color = "black",
                 fill = "white"
                 ) +
  labs(x = "Hygiene score on day 3", y = "Density")
hist.day3 +
  stat_function(fun = dnorm,
                args = list(mean = mean(dlf$day3, na.rm = TRUE),
                            sd = sd(dlf$day3, na.rm = TRUE)),
                            color = "black",
                            size = 1
               )
```

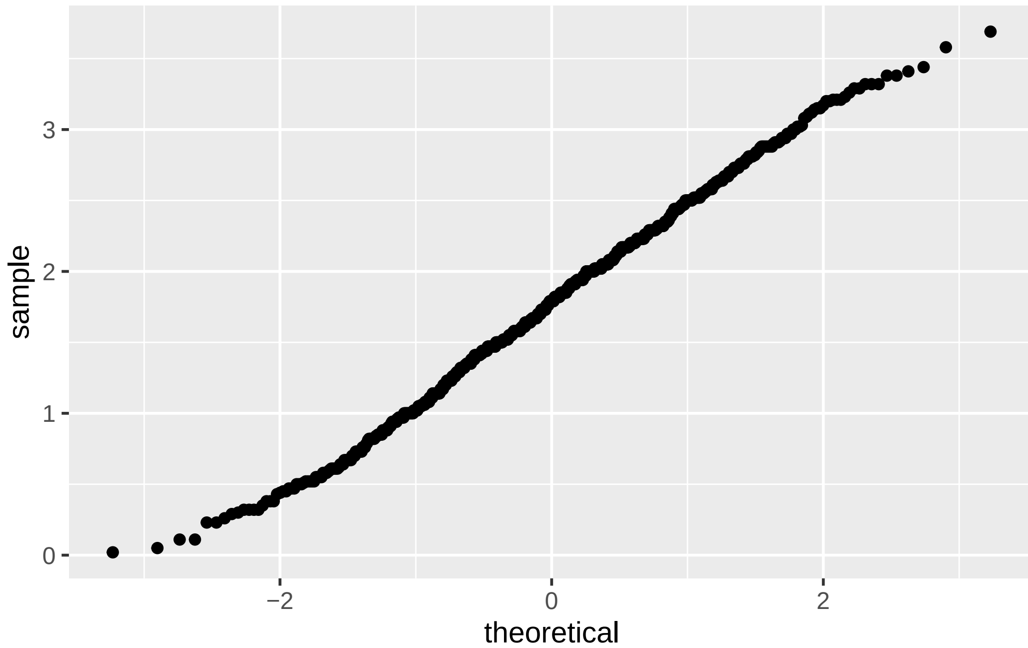
```
`stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```

```
Warning: Removed 687 rows containing non-finite values (`stat_bin()`).
```



Q-Q plot (quantile-quantile plot) is another useful graph that we can inspect to see if a distribution is normal. Q-Q plots the cumulative values we have in our data against the cumulative probability of a particular distribution. Each value is compared to the expected value that the score should have in a normal distribution and they are plotted against one another. The x axis of Q-Q plot represents the z-scores of each point:

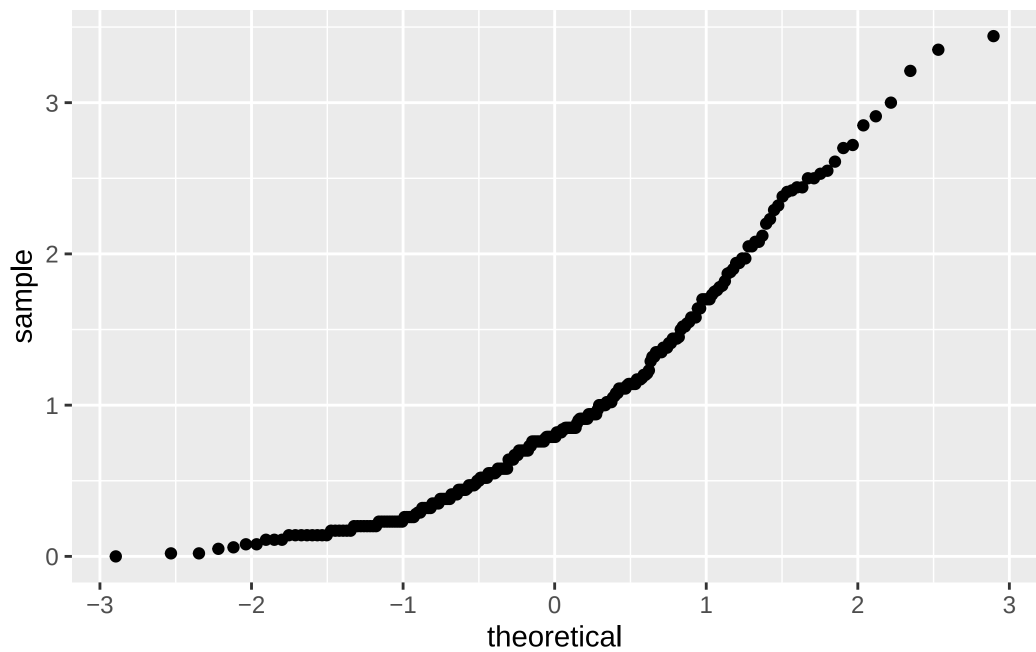
```
qqplot.day1 <- ggplot(data = dlf, aes(sample = day1)) +
  geom_qq()
qqplot.day1 # Updated code
```



For day 2 and day 3:

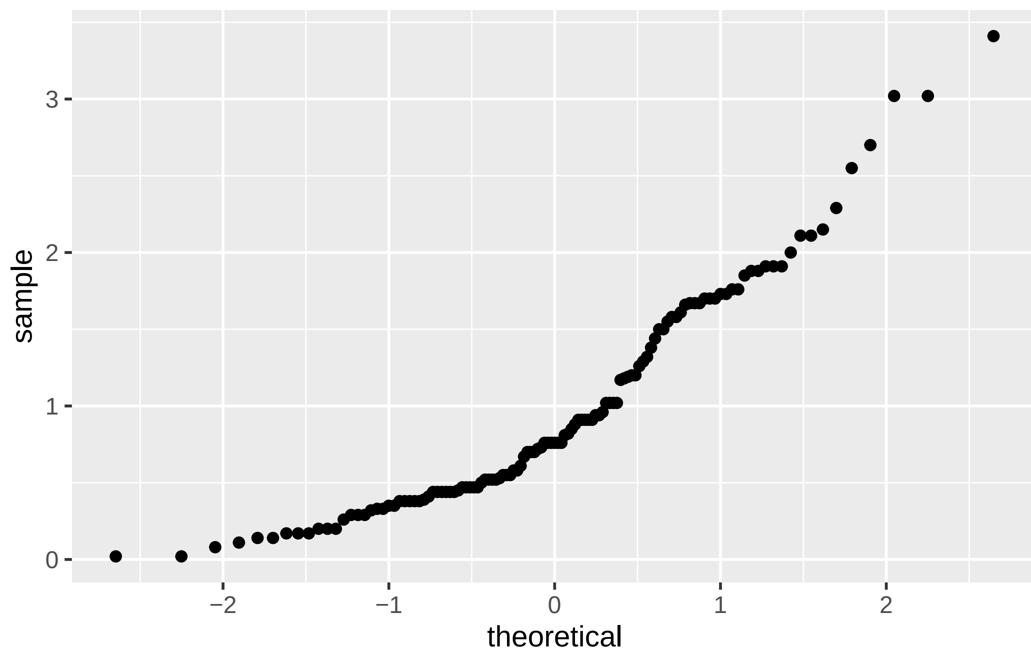
```
qqplot.day2 <- ggplot(data = dlf, aes(sample = day2)) +
  geom_qq()
qqplot.day2
```

```
Warning: Removed 546 rows containing non-finite values (`stat_qq()`).
```




```r
qqplot.day3 <- ggplot(data = dlf, aes(sample = day3)) +
  geom_qq()
qqplot.day3
```

```
Warning: Removed 687 rows containing non-finite values (`stat_qq()`).
```



5.5.2. Quantifying normality with numbers

We can explore the distribution of the variables using the `describe()` function in the *psych* package, or the `stat.desc()` function of the *pastecs* package:

```
describe(dlf$day1)
```

```
   vars   n mean   sd median trimmed mad  min  max range skew kurtosis   se
X1    1 810 1.77 0.69   1.79    1.77 0.7 0.02 3.69  3.67    0    -0.42 0.02
```

```
stat.desc(dlf$day1, basic = FALSE, norm = TRUE)
```

```
     median        mean     SE.mean CI.mean.0.95         var     std.dev
 1.79000000  1.77113580  0.02436847   0.04783289  0.48099624  0.69353892
   coef.var    skewness    skew.2SE     kurtosis    kurt.2SE  normtest.W
 0.39157862 -0.00442835 -0.02577395  -0.42159405 -1.22838457  0.99591522
 normtest.p
 0.03198482
```

We can combine two or more variables by using `cbind()` function.

```r
describe(cbind(dlf$day1, dlf$day2, dlf$day3))
```

```
   vars   n mean   sd median trimmed  mad  min  max range skew kurtosis   se
X1    1 810 1.77 0.69   1.79    1.77 0.70 0.02 3.69  3.67 0.00    -0.42 0.02
X2    2 264 0.96 0.72   0.79    0.87 0.61 0.00 3.44  3.44 1.08     0.76 0.04
X3    3 123 0.98 0.71   0.76    0.90 0.61 0.02 3.41  3.39 1.01     0.59 0.06
```

```r
stat.desc(cbind(dlf$day1, dlf$day2, dlf$day3), basic = FALSE, norm = TRUE)
```

```
                      V1           V2           V3
median        1.79000000 7.900000e-01 7.600000e-01
mean          1.77113580 9.609091e-01 9.765041e-01
SE.mean       0.02436847 4.436095e-02 6.404352e-02
CI.mean.0.95  0.04783289 8.734781e-02 1.267805e-01
var           0.48099624 5.195239e-01 5.044934e-01
std.dev       0.69353892 7.207801e-01 7.102770e-01
coef.var      0.39157862 7.501022e-01 7.273672e-01
skewness     -0.00442835 1.082811e+00 1.007813e+00
skew.2SE     -0.02577395 3.611574e+00 2.309035e+00
kurtosis     -0.42159405 7.554615e-01 5.945454e-01
kurt.2SE     -1.22838457 1.264508e+00 6.862946e-01
normtest.W    0.99591522 9.083191e-01 9.077516e-01
normtest.p    0.03198482 1.281630e-11 3.804486e-07
```

```r
# OR,
describe(dlf[, c("day1", "day2", "day3")])
```

```
     vars   n mean   sd median trimmed  mad  min  max range skew kurtosis   se
day1    1 810 1.77 0.69   1.79    1.77 0.70 0.02 3.69  3.67 0.00    -0.42 0.02
day2    2 264 0.96 0.72   0.79    0.87 0.61 0.00 3.44  3.44 1.08     0.76 0.04
day3    3 123 0.98 0.71   0.76    0.90 0.61 0.02 3.41  3.39 1.01     0.59 0.06
```

```r
stat.desc(dlf[, c("day1", "day2", "day3")], basic = FALSE, norm = TRUE)
```

```
                    day1         day2         day3
median        1.79000000 7.900000e-01 7.600000e-01
mean          1.77113580 9.609091e-01 9.765041e-01
```

```
SE.mean         0.02436847 4.436095e-02 6.404352e-02
CI.mean.0.95    0.04783289 8.734781e-02 1.267805e-01
var             0.48099624 5.195239e-01 5.044934e-01
std.dev         0.69353892 7.207801e-01 7.102770e-01
coef.var        0.39157862 7.501022e-01 7.273672e-01
skewness       -0.00442835 1.082811e+00 1.007813e+00
skew.2SE       -0.02577395 3.611574e+00 2.309035e+00
kurtosis       -0.42159405 7.554615e-01 5.945454e-01
kurt.2SE       -1.22838457 1.264508e+00 6.862946e-01
normtest.W      0.99591522 9.083191e-01 9.077516e-01
normtest.p      0.03198482 1.281630e-11 3.804486e-07
```

We can select rows and columns using `[rows, colomns]`, therefore, `dlf[, c("day1", "day2", "day3")]` means from the `dlf` dataframe select all of the rows **(because nothing is specified before the comma)** and select the columns labelled `day1`, `day2`, `day3` .

If the skew divided by its standard error is greater than 2 then it is significant (at $p < 0.05$).

If we want to change our output's decimal places, we can use the `round()` function.

```
round(stat.desc(dlf[, c("day1", "day2", "day3")],
                basic = FALSE,
                norm = TRUE
                ),
      digits = 3
      )
```

```
                day1  day2  day3
median         1.790 0.790 0.760
mean           1.771 0.961 0.977
SE.mean        0.024 0.044 0.064
CI.mean.0.95   0.048 0.087 0.127
var            0.481 0.520 0.504
std.dev        0.694 0.721 0.710
coef.var       0.392 0.750 0.727
skewness      -0.004 1.083 1.008
skew.2SE      -0.026 3.612 2.309
kurtosis      -0.422 0.755 0.595
kurt.2SE      -1.228 1.265 0.686
normtest.W     0.996 0.908 0.908
normtest.p     0.032 0.000 0.000
```

5.5.3. Exploring groups of data

5.5.3.1. Running the analysis for all data

RExam.dat contains data regarding students' performance on an R exam. There are four variables measured: **exam, computer, lecture** and **numeracy**. A variable **uni** indicates whether the student attended Sussex university of Duncetown university.

Let's open the file and set the variable **uni** to be a factor by executing:

```
rexam <- read.delim("rexam.dat", header = TRUE)
rexam$uni <- factor(rexam$uni,
                    levels = c(0: 1),
                    labels = c("Duncetown University", "Sussex University")
                    )
```

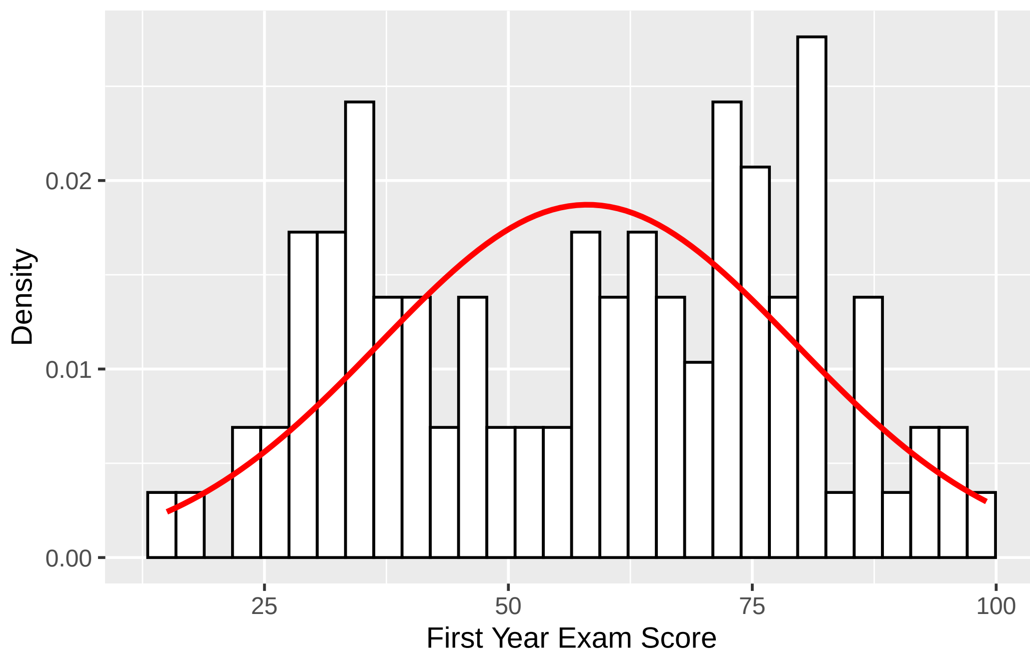
SELF-TEST

```
#Self test task:

round(stat.desc(rexam[, c("exam", "computer", "lectures", "numeracy")],
                basic = FALSE,
                norm = TRUE
                ),
      digits = 3
      )
```

```
                exam computer lectures numeracy
median        60.000   51.500   62.000    4.000
mean          58.100   50.710   59.765    4.850
SE.mean        2.132    0.826    2.168    0.271
CI.mean.0.95   4.229    1.639    4.303    0.537
var          454.354   68.228  470.230    7.321
std.dev       21.316    8.260   21.685    2.706
coef.var       0.367    0.163    0.363    0.558
skewness      -0.104   -0.169   -0.410    0.933
skew.2SE      -0.215   -0.350   -0.849    1.932
kurtosis      -1.148    0.221   -0.285    0.763
kurt.2SE      -1.200    0.231   -0.298    0.798
normtest.W     0.961    0.987    0.977    0.924
normtest.p     0.005    0.441    0.077    0.000
```

```r
hexam <- ggplot(rexam, aes(exam)) +
  geom_histogram(aes(y=..density..),
                 colour="black",
                 fill="white"
                 ) +
  labs(x = "First Year Exam Score", y = "Density") +
  stat_function(fun = dnorm,
                args = list(mean = mean(rexam$exam, na.rm = TRUE),
                            sd = sd(rexam$exam, na.rm = TRUE)),
                colour = "red",
                size = 1
                )
hexam
```

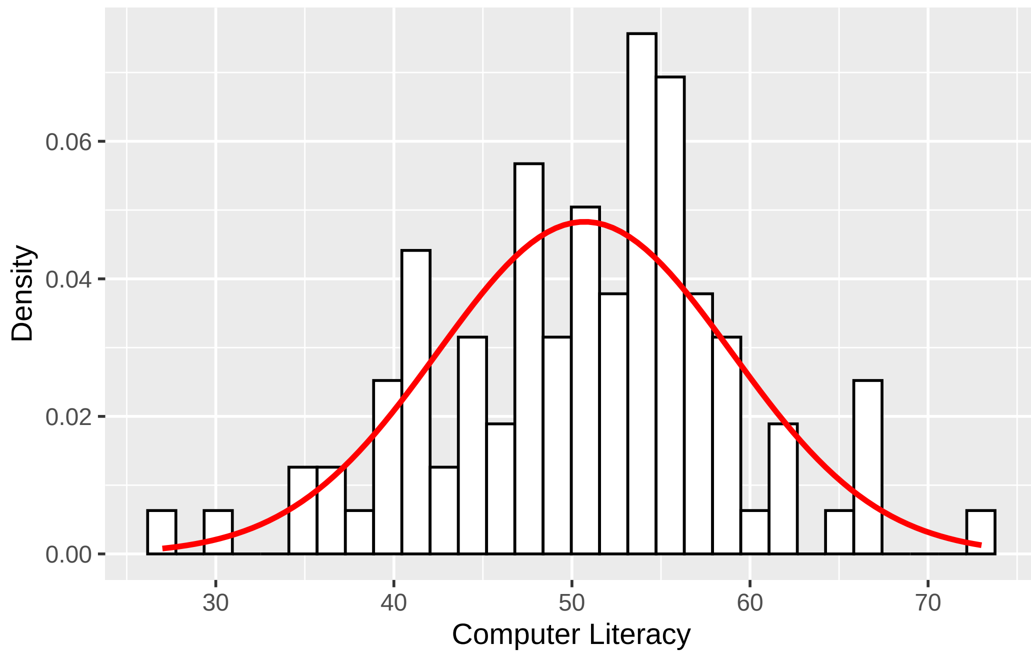
```
`stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```




```r
hcomputer <- ggplot(rexam, aes(computer)) +
  geom_histogram(aes(y=..density..),
                 colour="black",
                 fill="white"
                 ) +
```

```
  labs(x = "Computer Literacy", y = "Density") +
  stat_function(fun = dnorm,
                args = list(mean = mean(rexam$computer, na.rm = TRUE),
                            sd = sd(rexam$computer, na.rm = TRUE)),
                colour = "red",
                size = 1
                )
hcomputer
```

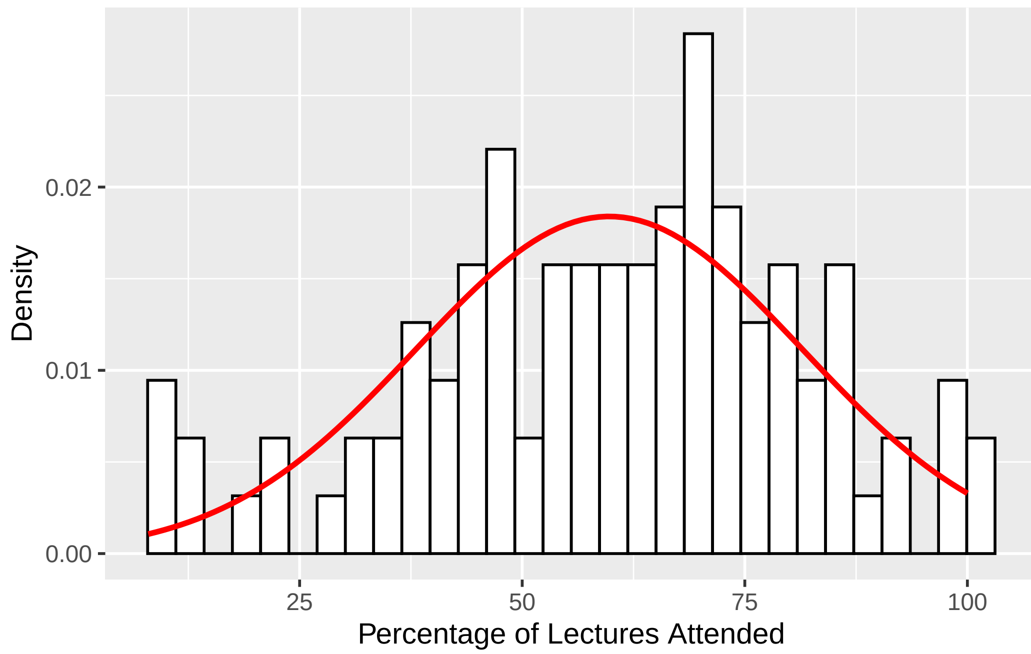
```
`stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```




```
hlectures <- ggplot(rexam, aes(lectures)) +
  geom_histogram(aes(y=..density..),
                 colour="black",
                 fill="white"
                 ) +
  labs(x = "Percentage of Lectures Attended", y = "Density") +
  stat_function(fun = dnorm,
                args = list(mean = mean(rexam$lectures, na.rm = TRUE),
                            sd = sd(rexam$lectures, na.rm = TRUE)),
```

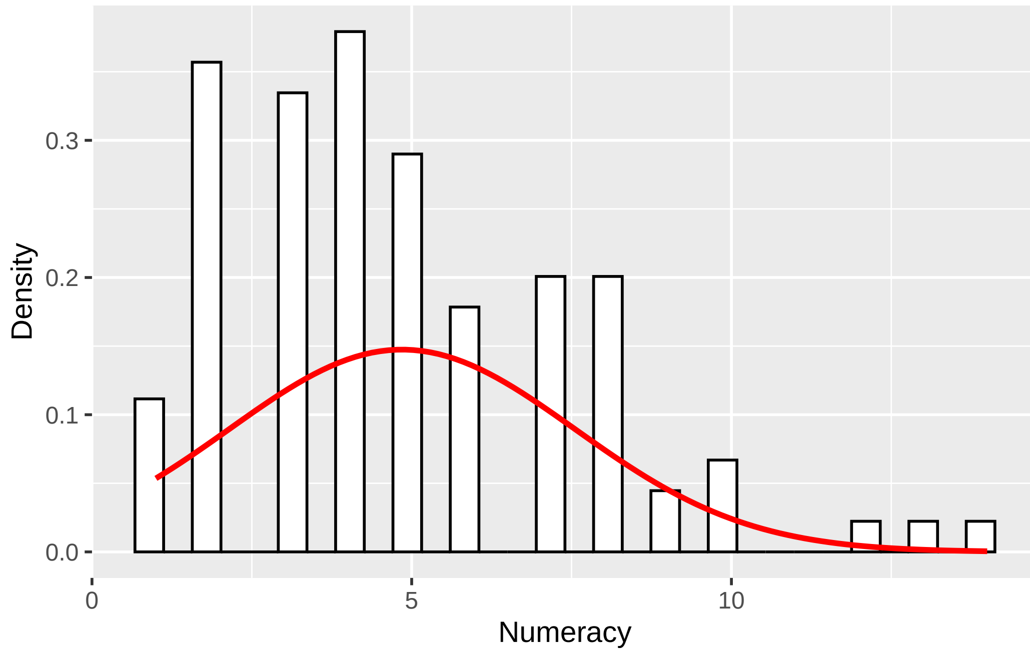
```
                 colour = "red",
                 size = 1
                 )
hlectures
```

```
`stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```




```
hnumeracy <- ggplot(rexam, aes(numeracy)) +
  geom_histogram(aes(y=..density..),
                 colour="black",
                 fill="white") +
  labs(x = "Numeracy", y = "Density") +
  stat_function(fun = dnorm,
                args = list(mean = mean(rexam$numeracy, na.rm = TRUE),
                            sd = sd(rexam$numeracy, na.rm = TRUE)),
                colour = "red",
                size = 1
                )
hnumeracy
```

```
`stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```



The exam scores' distribution is quite not normal; it looks bimodal (two peaks).

The bimodal distribution of R exam scores instantly indicates a trend that students are typically either very good at statistics or struggle with it.

5.5.3.2. Running the analysis for different groups

If we want to obtain separate descriptive statistics for each of the universities, we can use the `by()`function. We can simply enter the name of our dataframe or variables that we'd like to analyse, we can specify a variable by which we want to split the output (in this case, it's **uni**). We then tell it which function we want to apply to the data:

```
by(data = rexam$exam, INDICES = rexam$uni, FUN = describe)
```

```
rexam$uni: Duncetown University
   vars  n  mean    sd median trimmed  mad min max range skew kurtosis   se
X1    1 50 40.18 12.59     38   39.85 12.6  15  66    51 0.29    -0.72 1.78
------------------------------------------------------------
rexam$uni: Sussex University
   vars  n  mean    sd median trimmed mad min max range skew kurtosis   se
X1    1 50 76.02 10.21     75    75.7 8.9  56  99    43 0.26    -0.46 1.44
```

We can do the same thing by executing:

```
by(data = rexam$exam, INDICES = rexam$uni, FUN = stat.desc)
```

```
rexam$uni: Duncetown University
     nbr.val     nbr.null       nbr.na          min          max        range 
  50.0000000    0.0000000    0.0000000   15.0000000   66.0000000   51.0000000 
         sum       median         mean      SE.mean CI.mean.0.95          var 
2009.0000000   38.0000000   40.1800000    1.7803210    3.5776890  158.4771429 
     std.dev     coef.var 
  12.5887705    0.3133094 
------------------------------------------------------------ 
rexam$uni: Sussex University
     nbr.val     nbr.null       nbr.na          min          max        range 
  50.0000000    0.0000000    0.0000000   56.0000000   99.0000000   43.0000000 
         sum       median         mean      SE.mean CI.mean.0.95          var 
3801.0000000   75.0000000   76.0200000    1.4432079    2.9002348  104.1424490 
     std.dev     coef.var 
  10.2050208    0.1342413 
```

`by(rexam$exam, rexam$uni, describe)` and `by(rexam$exam, rexam$uni, stat.desc` have the same effect as those above.

We can also include any options for the function we're using by adding them in at the end. For example:

```
by(rexam$exam, rexam$uni, stat.desc, basic = FALSE, norm = TRUE)
```

```
rexam$uni: Duncetown University
      median         mean      SE.mean CI.mean.0.95          var      std.dev 
  38.0000000   40.1800000    1.7803210    3.5776890  158.4771429   12.5887705 
    coef.var     skewness     skew.2SE     kurtosis     kurt.2SE   normtest.W 
   0.3133094    0.2906760    0.4317816   -0.7230849   -0.5462122    0.9721662 
  normtest.p 
   0.2828984 
------------------------------------------------------------ 
rexam$uni: Sussex University
      median         mean      SE.mean CI.mean.0.95          var      std.dev 
  75.0000000   76.0200000    1.4432079    2.9002348  104.1424490   10.2050208 
    coef.var     skewness     skew.2SE     kurtosis     kurt.2SE   normtest.W 
   0.1342413    0.2559866    0.3802527   -0.4609644   -0.3482086    0.9837115 
```

```
  normtest.p
   0.7151182
```

If we want descriptive statistics for multiple variables, then we can use `cbind()` to include them within the `by()` function:

```
by(rexam[, c("exam", "numeracy")],
   rexam$uni,
   stat.desc,
   basic = FALSE,
   norm = TRUE
   )
```

```
rexam$uni: Duncetown University
                    exam    numeracy
median        38.0000000  4.00000000
mean          40.1800000  4.12000000
SE.mean        1.7803210  0.29226770
CI.mean.0.95   3.5776890  0.58733393
var          158.4771429  4.27102041
std.dev       12.5887705  2.06664472
coef.var       0.3133094  0.50161280
skewness       0.2906760  0.48165960
skew.2SE       0.4317816  0.71547621
kurtosis      -0.7230849 -0.65166313
kurt.2SE      -0.5462122 -0.49226083
normtest.W     0.9721662  0.94081692
normtest.p     0.2828984  0.01451518
------------------------------------------------------------
rexam$uni: Sussex University
                    exam     numeracy
median        75.0000000  5.000000000
mean          76.0200000  5.580000000
SE.mean        1.4432079  0.434332704
CI.mean.0.95   2.9002348  0.872824247
var          104.1424490  9.432244898
std.dev       10.2050208  3.071196004
coef.var       0.1342413  0.550393549
skewness       0.2559866  0.746369109
skew.2SE       0.3802527  1.108686183
kurtosis      -0.4609644 -0.006440059
kurt.2SE      -0.3482086 -0.004864766
```

```
normtest.W     0.9837115  0.932346126
normtest.p     0.7151182  0.006786803
```

Now, let's look at the histograms. We can create plots for different groups by using the `subset()` function:

```r
dunceData <- subset(rexam, rexam$uni == "Duncetown University")
sussexData <- subset(rexam, rexam$uni == "Sussex University")
dunceData
```

```
   exam computer lectures numeracy                  uni
1    18       54     75.0        7 Duncetown University
2    30       47      8.5        1 Duncetown University
3    40       58     69.5        6 Duncetown University
4    30       37     67.0        6 Duncetown University
5    40       53     44.5        2 Duncetown University
6    15       48     76.5        8 Duncetown University
7    36       49     70.0        3 Duncetown University
8    40       49     18.5        7 Duncetown University
9    63       45     43.5        4 Duncetown University
10   31       62    100.0        6 Duncetown University
11   22       67     48.0        3 Duncetown University
12   47       62     10.5        3 Duncetown University
13   38       38     57.5        1 Duncetown University
14   34       37     61.5        8 Duncetown University
15   54       54     54.0        4 Duncetown University
16   35       48     71.0        5 Duncetown University
17   33       48     14.0        9 Duncetown University
18   38       42     55.5        3 Duncetown University
19   29       57     72.5        2 Duncetown University
20   36       55     38.0        4 Duncetown University
21   59       41     40.0        1 Duncetown University
22   31       42     85.5        4 Duncetown University
23   34       48     52.0        4 Duncetown University
24   28       44      8.0        3 Duncetown University
25   50       42     62.5        6 Duncetown University
26   59       42     70.5        3 Duncetown University
27   33       40     98.0        4 Duncetown University
28   57       52     34.5        2 Duncetown University
29   25       56     62.5        3 Duncetown University
30   53       54     91.5        2 Duncetown University
31   65       52     97.5        7 Duncetown University
```

```
32   47         55     31.5         2 Duncetown University
33   28         61     80.5         7 Duncetown University
34   43         56     66.5         4 Duncetown University
35   47         52     57.5         2 Duncetown University
36   60         49     67.0         4 Duncetown University
37   45         43     48.5         4 Duncetown University
38   22         51     61.0         4 Duncetown University
39   39         49     76.0         3 Duncetown University
40   43         56     30.5         2 Duncetown University
41   66         41     45.0         2 Duncetown University
42   36         67     21.5         4 Duncetown University
43   26         35     72.5         5 Duncetown University
44   58         49     66.0         8 Duncetown University
45   53         62     90.5         6 Duncetown University
46   37         66     48.5         4 Duncetown University
47   48         48     62.0         3 Duncetown University
48   32         46     49.0         1 Duncetown University
49   42         46     60.0         5 Duncetown University
50   34         58     21.0         5 Duncetown University
```

```
sussexData
```

```
   exam computer lectures numeracy              uni
51   56       30     84.5        7 Sussex University
52   76       48     51.0        8 Sussex University
53   72       54     58.5        5 Sussex University
54   77       44     42.0        6 Sussex University
55   77       54     65.5        9 Sussex University
56   66       58     56.0        7 Sussex University
57   62       59     71.5        2 Sussex University
58   86       54     48.5        5 Sussex University
59   97       35     84.5        5 Sussex University
60   72       56     47.5        2 Sussex University
61   69       53     54.0        3 Sussex University
62   87       56     70.5        6 Sussex University
63   88       65     73.0        5 Sussex University
64   72       50     79.0       12 Sussex University
65   75       39     82.5        8 Sussex University
66   74       40     74.5        3 Sussex University
67   68       50     85.0        2 Sussex University
68   81       57     69.5       10 Sussex University
69   77       39     42.0        7 Sussex University
```

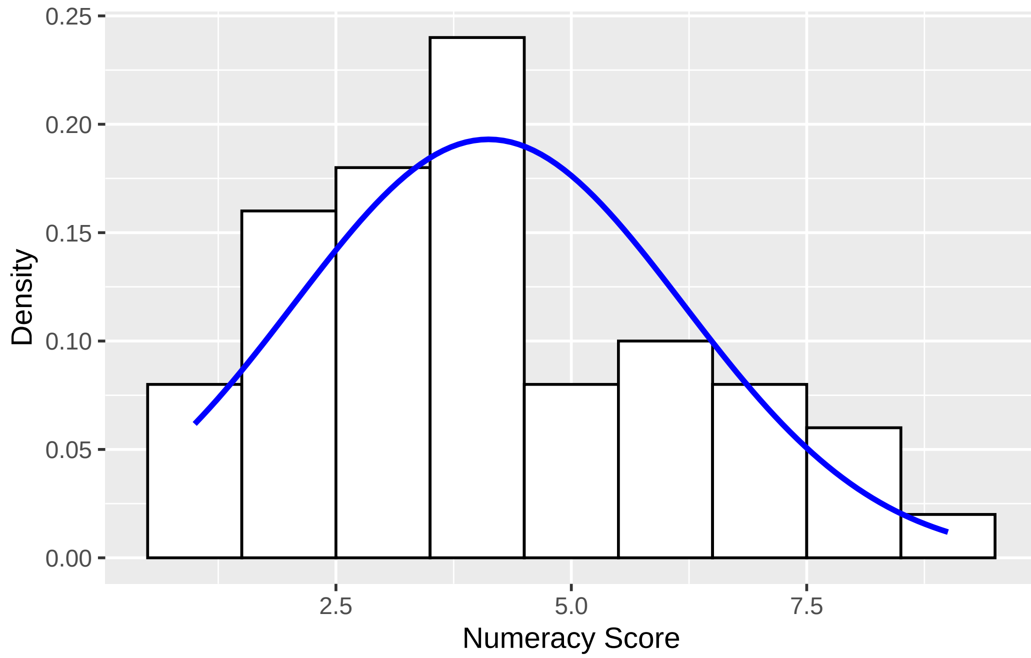
```
70     71         41      43.0          8 Sussex University
71     60         48      46.5          6 Sussex University
72     74         46      36.5          8 Sussex University
73     80         54      72.5          4 Sussex University
74     68         55      62.0          4 Sussex University
75     64         27      81.5          5 Sussex University
76     94         57     100.0         13 Sussex University
77     65         73      27.0         14 Sussex University
78     72         54      59.5          2 Sussex University
79     75         54      75.0          3 Sussex University
80     92         50      34.0          2 Sussex University
81     89         56      78.0          4 Sussex University
82     83         57      80.5          5 Sussex University
83     80         54      84.0          2 Sussex University
84     95         55      37.5          4 Sussex University
85     99         54      57.0          3 Sussex University
86     80         52      66.0          8 Sussex University
87     81         67      59.0         10 Sussex University
88     75         44      68.5          5 Sussex University
89     78         57      88.5          3 Sussex University
90     65         54      55.0          8 Sussex University
91     80         51      86.0          5 Sussex University
92     86         55      68.5         10 Sussex University
93     73         51      64.0          7 Sussex University
94     81         45      12.5          1 Sussex University
95     69         59      52.5          7 Sussex University
96     60         43      37.0          5 Sussex University
97     69         57      46.0          2 Sussex University
98     71         50      97.5          2 Sussex University
99     82         50      70.5          4 Sussex University
100    58         47      78.0          3 Sussex University
```

These commands each create a new dataframe that is based on a subset of the *rexam* dataframe. We need to be careful that the term we specify to select cases exactly matches the labelling in the dataset otherwise we'll end up with an empty dataset.

Having created our separate dataframes, we can generate histograms using the same commands as before, but specifying the dataframe for the subset of data:

```
hist.numeracy.duncetown <- ggplot(dunceData, aes(numeracy)) +
  geom_histogram(aes(y = ..density..),
                 fill = "white",
```

```
                    color = "black",
                    binwidth = 1
                    ) +
  labs(x = "Numeracy Score" , y = "Density") +
  stat_function(fun = dnorm,
                   args = list(mean = mean(dunceData$numeracy, na.rm = TRUE),
                               sd = sd(dunceData$numeracy, na.rm = TRUE)),
                   color = "blue",
                   size = 1
                   )
hist.numeracy.duncetown
```

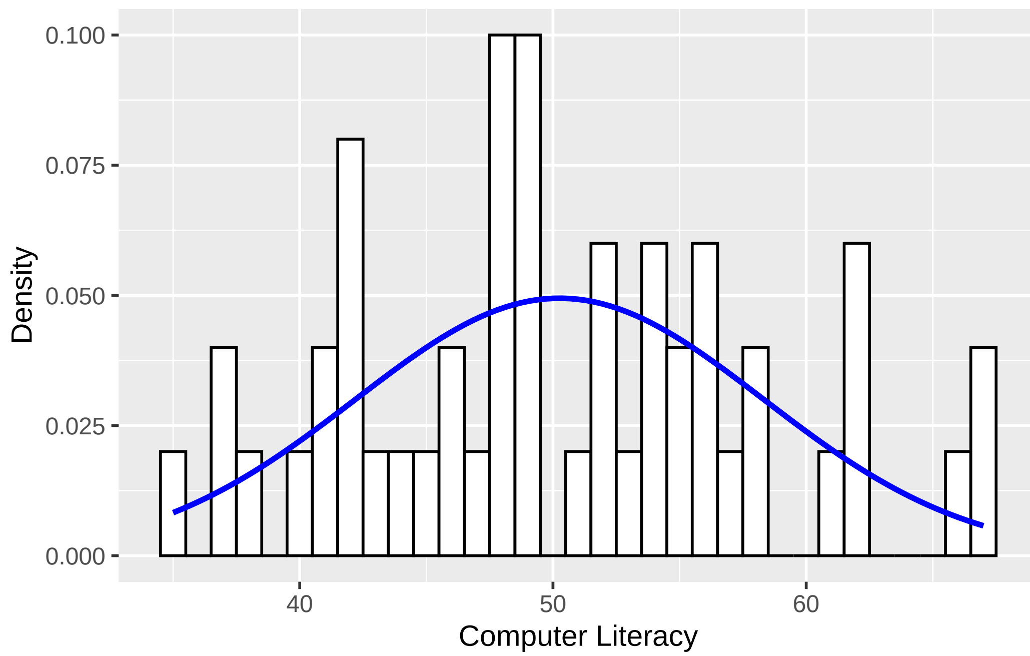


We can see that for exam marks the distributions are both fairly normal. This is because the two samples are combined and these two normal distributions created a bimodal one at the previous figure.

SELF-TEST

```
hist.computer.duncetown <- ggplot(dunceData, aes(computer)) +
  geom_histogram(aes(y = ..density..),
```

```
                   fill = "white",
                   color = "black",
                   binwidth = 1
                   ) +
  labs(x = "Computer Literacy" , y = "Density") +
  stat_function(fun = dnorm,
                  args = list(mean = mean(dunceData$computer, na.rm = TRUE),
                              sd = sd(dunceData$computer, na.rm = TRUE)),
                  color = "blue",
                  size = 1
                  )
hist.computer.duncetown
```



5.6. Testing whether a distribution is normal

The **Shapiro-Wilk** test compares the scores in the sample to a normally distributed set of scores with the same mean and standard deviation. If the test is significant ($p < .05$), then the distribution in question is significantly different from a normal distribution.

5.6.1. Doing the Shapiro-Wilk test in R

`shapiro.test()` function tests the variables for normality:

```
shapiro.test(rexam$exam)
```

```

	Shapiro-Wilk normality test

data:  rexam$exam
W = 0.96131, p-value = 0.004991
```

```
shapiro.test(rexam$numeracy)
```

```

	Shapiro-Wilk normality test

data:  rexam$numeracy
W = 0.92439, p-value = 2.424e-05
```

Although the distributions seemed quite normal, the Shapiro-Wilk tests was highly significant, indicating that both distributions are not normal. The value of W corresponds to the value of *normtest.W*, and the p-value corresponds to *normtest.p* from the `stat.desc` function.

We can adjust `shapiro.test` to `by()` function we came across earlier, using it instead of FUN:

```
by(rexam$exam, rexam$uni, shapiro.test)
```

```
rexam$uni: Duncetown University

	Shapiro-Wilk normality test

data:  dd[x, ]
W = 0.97217, p-value = 0.2829

------------------------------------------------------------
rexam$uni: Sussex University

	Shapiro-Wilk normality test

data:  dd[x, ]
W = 0.98371, p-value = 0.7151
```

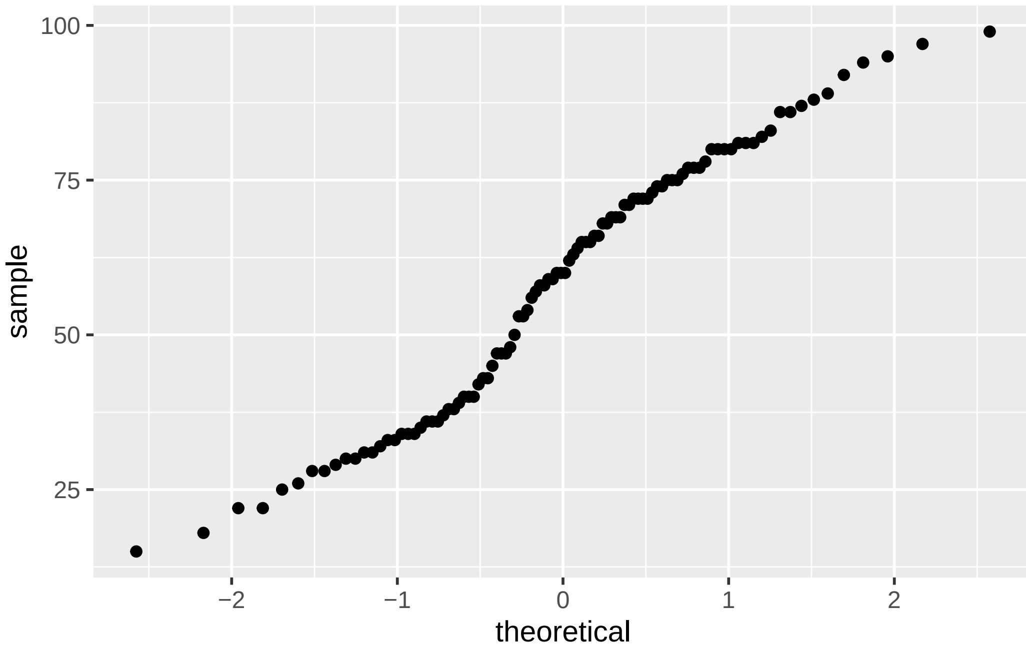
```r
by(rexam$numeracy, rexam$uni, shapiro.test)
```

```
rexam$uni: Duncetown University

    Shapiro-Wilk normality test

data:  dd[x, ]
W = 0.94082, p-value = 0.01452

------------------------------------------------------------
rexam$uni: Sussex University

    Shapiro-Wilk normality test

data:  dd[x, ]
W = 0.93235, p-value = 0.006787
```

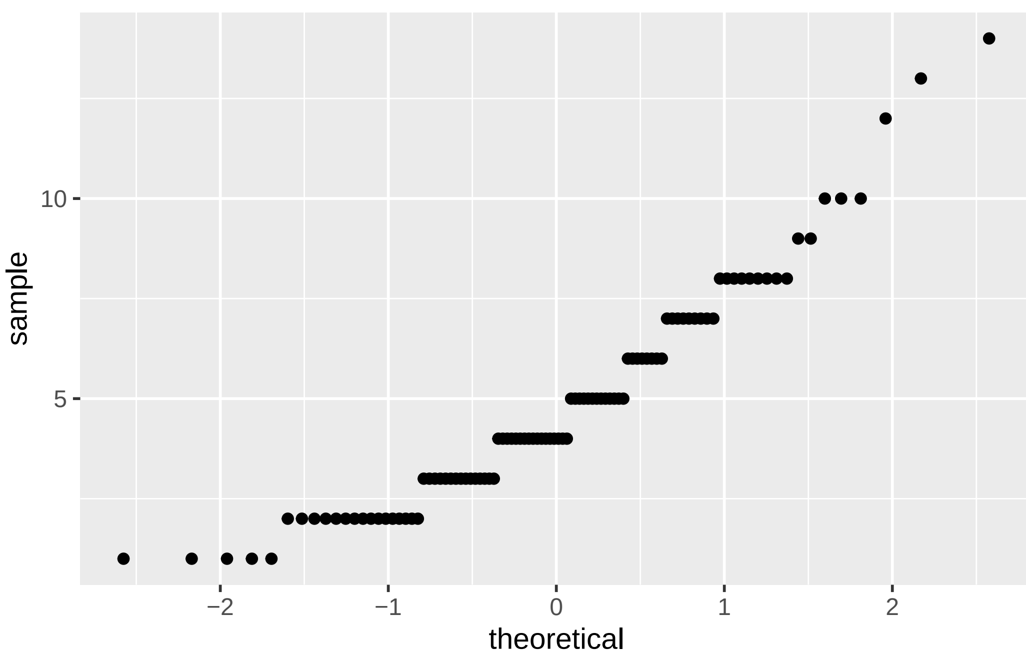
This result shows that the percentages on the R exam are indeed normal within the two groups.

We can also draw Q-Q plots for the variables to help us to interpret the results of the Shapiro-Wilk test.

```r
ggplot(data = rexam, aes(sample = exam)) +
  geom_qq()
```




```
ggplot(data = rexam, aes(sample = numeracy)) +
  geom_qq()
```



If the data are normally distributed (Numeracy), then the observed values should fall exactly along a straight line.

5.6.2. Reporting the Shapiro-Wilk test

" The percentage on the R exam, $W = 0.96$, $p = 0.005$, and the numeracy scores, $W = 0.92$, $p < .001$, were both significantly non-normal."

5.7. Testing for homogeneity of variance

The *homogeneity of variance*: Although the means increase, the spread of scores is the same at each level of the concert variable.

The *heterogeneity of variance*: At some levels of the variable the variance of scores is different than other levels.

5.7.1. Levene's test

Levene's test tests the null hypothesis that the variances in different groups are equal. If Levene's test is significant at $p <= .05$ then we can conclude that the null hypothesis is incorrect and that the variances are significantly different.

5.7.1.1. Levene's test with R Commander

Data -> Import data -> from text file, clipboard, or URL ..., and then select the file **RExam.dat**

We need to convert **uni** to a factor because at the moment it is simply 0s and 1s so **R** doesn't know that it's a factor.

Data -> Manage variables in active data set -> Convert numeric variables to factors

Statistics -> Variances -> Levene's test, and select a grouping variable, which is **uni** here. For the centring, the median tends to be more accurate and is the default.

5.7.1.2. Levene's test with R

To use Levene's test, we use the `leveneTest()` function from the *car* package. This function takes the general form: `leveneTest(outcome variable, group, center = median/mean)`. The outcome variable is what we want to test the variances. The grouping variable must be a factor:

```r
leveneTest(rexam$exam, rexam$uni)
```

```
Levene's Test for Homogeneity of Variance (center = median)
      Df F value Pr(>F)
group  1  2.0886 0.1516
      98
```

```r
leveneTest(rexam$exam, rexam$uni, center = mean)
```

```
Levene's Test for Homogeneity of Variance (center = mean)
      Df F value Pr(>F)
group  1  2.5841 0.1112
      98
```

5.7.1.3. Levene's test output

The result is non-significant for the **R** exam scores. This indicates that the variances are not significantly different. However, for the numeracy scores, Levene's test is significant, indicating that the variances are significantly different.

5.7.2. Reporting Levene's test

For the percentage on the **R** exam, the variances were similar for Duncetown and Sussex University students, $F(1, 98) = 2.09$, *ns*, but for numeracy scores the variances were significantly different in the two groups, $F(1, 98) = 5.37$, $p = .023$

5.7.3. Hartley's F_max: the variance ratio

As with the Shapiro-Wilk test, when the sample size is large, small differences in group variances can produce a Levene's test that is significant. We can double check by looking at Hartley's F_max, which is the ratio of the variances between the group with the biggest variance and the group with the smallest variance.

5.8. Correcting problems in the data

What can we do about outliers and heterogeneity of variance?

5.8.1. Dealing with outliers

There are three main options dealing with outliers

1. Remove the case: If we have a good reason to believe that a case is not from the population that we intended to sample, we can delete that case.
2. Transform the data: The skew occurred by the outlier can be reduced by applying **transformations** to the data.
3. Change the score: If transformation fails, we can consider replacing the score. There are three options: The next highest score plus one, Convert back from a z-score, and The mean plus two standard deviations.

5.8.2. Dealing with non-normality and unequal variances

5.8.2.1. Transforming data

The idea behind transformations is that we do something to every score to correct for distributional problems, outliers or unequal variances. Transforming the data won't change the relationships between variables, but it does change the differences between different variables. If we are looking at differences within variables, then we need to transform all levels of those variables.

Data transformations and their uses

- Log transformation: It reduces positive skew by squashing the right tail of the distribution. We need to set all numbers positive because we can't take the log of zero or negative numbers.
- Square root transformation: It brings any large scores closer to the center, rather like the log transformation.
- Reciprocal transformation: It reduces the impact of large scores, but it reverses the scores.
- Reverse score transformations: Any one of the above transformations can be used to correct negatively skewed data, but first we have to reverse the scores. To do this, we can subtract each score from the highest score obtained.

We need to know whether the statistical models we apply perform better on transformed data than they do when applied to data that violate the assumption that the transformation corrects. If a statistical model is still accurate even when its assumptions are broken it is said to be a **robust test**.

5.8.2.2. Choosing a transformation

We have to decide which transformation is best by trial and error.

5.8.3. Transforming the data using R

5.8.3.1. Computing new variables

Addition: We can add two variables together, or add a constant to our variables.

Subtraction: We can subtract one variable from another.

Multiply: We can multiply two variables together, or multiply a variable by any number.

Exponentiation: We can raise the preceding term by the power of the succeeding term.

Less than: It gives the answer TRUE (or 1) or FALSE (or 0)

Double equals: It creates a variable **male** in the *dlf* dataframe that contains the value TRUE if the variable **gender** was the word 'Male'

```
# Addition
dlf$day1PlusDay2 <- dlf$day1 + dlf$day2
# Subtraction
dlf$day2MinusDay1 <- dlf$day2 - dlf$day1
# Multiply
dlf$day2Times5 <- dlf$day1 * 5
# Exponentiation
dlf$day2Squared <- dlf$day2 ^ 2
# Less than
dlf$day1LessThenOne <- dlf$day1 < 1
dlf$day1LessThenOne
```

```
  [1] FALSE  TRUE  TRUE FALSE  TRUE  TRUE FALSE FALSE FALSE FALSE FALSE  TRUE
 [13] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
 [25] FALSE FALSE FALSE FALSE FALSE  TRUE FALSE  TRUE  TRUE FALSE FALSE FALSE
 [37] FALSE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
 [49] FALSE FALSE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE
 [61] FALSE FALSE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE
 [73] FALSE FALSE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE
 [85] FALSE FALSE  TRUE FALSE FALSE  TRUE  TRUE FALSE FALSE FALSE FALSE FALSE
 [97] FALSE FALSE FALSE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE FALSE FALSE
[109] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE
[121] FALSE FALSE FALSE FALSE  TRUE FALSE FALSE  TRUE FALSE FALSE FALSE FALSE
[133] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
```

```
[145] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
[157] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
[169] FALSE FALSE FALSE  TRUE FALSE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE
[181]  TRUE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
[193] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE
[205] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
[217] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
[229] FALSE FALSE FALSE FALSE  TRUE FALSE  TRUE FALSE FALSE  TRUE FALSE FALSE
[241] FALSE FALSE FALSE FALSE  TRUE FALSE  TRUE FALSE FALSE  TRUE FALSE  TRUE
[253]  TRUE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
[265] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
[277] FALSE FALSE FALSE  TRUE  TRUE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE
[289]  TRUE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
[301] FALSE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
[313] FALSE FALSE FALSE FALSE  TRUE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE
[325] FALSE FALSE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
[337] FALSE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
[349] FALSE  TRUE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE
[361]  TRUE FALSE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE
[373] FALSE  TRUE FALSE FALSE  TRUE  TRUE FALSE FALSE  TRUE FALSE  TRUE FALSE
[385]  TRUE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE FALSE FALSE  TRUE FALSE
[397] FALSE  TRUE FALSE FALSE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE  TRUE
[409] FALSE FALSE FALSE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE  TRUE FALSE
[421] FALSE FALSE  TRUE FALSE FALSE FALSE FALSE FALSE  TRUE  TRUE FALSE FALSE
[433] FALSE FALSE FALSE FALSE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE FALSE
[445] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
[457] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
[469]  TRUE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
[481] FALSE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
[493] FALSE FALSE FALSE FALSE FALSE  TRUE  TRUE FALSE FALSE FALSE FALSE FALSE
[505]  TRUE FALSE FALSE FALSE FALSE FALSE  TRUE FALSE  TRUE FALSE FALSE FALSE
[517] FALSE FALSE FALSE  TRUE  TRUE FALSE  TRUE FALSE FALSE  TRUE FALSE FALSE
[529] FALSE FALSE  TRUE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE  TRUE FALSE
[541] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
[553] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
[565] FALSE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE FALSE FALSE  TRUE FALSE
[577] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE  TRUE
[589] FALSE  TRUE FALSE  TRUE FALSE FALSE  TRUE FALSE FALSE FALSE FALSE FALSE
[601] FALSE FALSE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
[613]  TRUE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
[625] FALSE FALSE FALSE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE FALSE  TRUE
[637] FALSE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE FALSE  TRUE FALSE  TRUE
[649] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
```

```
[661] FALSE FALSE FALSE FALSE FALSE FALSE FALSE  TRUE FALSE  TRUE FALSE FALSE
[673] FALSE  TRUE FALSE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
[685] FALSE FALSE FALSE FALSE FALSE FALSE  TRUE  TRUE FALSE FALSE FALSE FALSE
[697] FALSE FALSE FALSE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE FALSE  TRUE
[709] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
[721] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
[733] FALSE FALSE  TRUE FALSE FALSE FALSE FALSE  TRUE FALSE  TRUE FALSE FALSE
[745]  TRUE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE  TRUE FALSE
[757]  TRUE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE  TRUE
[769] FALSE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
[781] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
[793] FALSE  TRUE  TRUE FALSE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE  TRUE
[805]  TRUE FALSE FALSE FALSE FALSE FALSE
```

```
# Double equals ("!=" for "Not equal to")
dlf$male <- dlf$gender == "Male"
dlf$male
```

```
  [1]  TRUE FALSE  TRUE FALSE FALSE  TRUE FALSE FALSE  TRUE FALSE  TRUE FALSE
 [13]  TRUE FALSE  TRUE FALSE  TRUE FALSE FALSE  TRUE  TRUE FALSE FALSE FALSE
 [25] FALSE FALSE FALSE FALSE  TRUE  TRUE  TRUE FALSE FALSE FALSE  TRUE  TRUE
 [37] FALSE FALSE FALSE  TRUE FALSE  TRUE  TRUE FALSE  TRUE  TRUE FALSE  TRUE
 [49]  TRUE FALSE FALSE  TRUE FALSE  TRUE FALSE FALSE FALSE  TRUE FALSE FALSE
 [61] FALSE  TRUE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE FALSE  TRUE FALSE
 [73]  TRUE FALSE  TRUE FALSE FALSE  TRUE  TRUE FALSE  TRUE FALSE  TRUE  TRUE
 [85] FALSE  TRUE  TRUE FALSE FALSE FALSE  TRUE  TRUE FALSE FALSE  TRUE FALSE
 [97] FALSE FALSE  TRUE FALSE FALSE  TRUE FALSE  TRUE FALSE  TRUE  TRUE  TRUE
[109] FALSE FALSE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE
[121]  TRUE  TRUE FALSE FALSE  TRUE FALSE FALSE  TRUE FALSE FALSE FALSE FALSE
[133]  TRUE  TRUE FALSE  TRUE FALSE  TRUE  TRUE FALSE FALSE  TRUE  TRUE FALSE
[145] FALSE FALSE FALSE  TRUE  TRUE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE
[157]  TRUE  TRUE  TRUE  TRUE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE FALSE
[169] FALSE  TRUE  TRUE  TRUE FALSE  TRUE FALSE FALSE  TRUE  TRUE FALSE FALSE
[181] FALSE  TRUE  TRUE FALSE  TRUE FALSE FALSE FALSE FALSE FALSE  TRUE  TRUE
[193] FALSE FALSE  TRUE  TRUE FALSE FALSE FALSE  TRUE FALSE  TRUE FALSE  TRUE
[205]  TRUE FALSE  TRUE FALSE  TRUE FALSE  TRUE FALSE FALSE  TRUE  TRUE FALSE
[217] FALSE  TRUE FALSE  TRUE FALSE  TRUE FALSE FALSE  TRUE FALSE FALSE FALSE
[229]  TRUE FALSE FALSE FALSE  TRUE FALSE  TRUE FALSE FALSE FALSE  TRUE  TRUE
[241]  TRUE  TRUE FALSE  TRUE FALSE  TRUE FALSE FALSE FALSE  TRUE  TRUE  TRUE
[253] FALSE FALSE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE FALSE  TRUE FALSE
[265]  TRUE  TRUE  TRUE FALSE  TRUE FALSE FALSE FALSE FALSE  TRUE FALSE FALSE
[277] FALSE FALSE FALSE  TRUE FALSE  TRUE FALSE  TRUE FALSE FALSE FALSE FALSE
```

```
[289]  TRUE FALSE FALSE FALSE FALSE  TRUE  TRUE FALSE FALSE  TRUE FALSE FALSE
[301] FALSE  TRUE  TRUE  TRUE  TRUE FALSE  TRUE FALSE  TRUE FALSE FALSE FALSE
[313]  TRUE FALSE FALSE FALSE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE  TRUE
[325] FALSE  TRUE FALSE  TRUE FALSE FALSE  TRUE FALSE  TRUE FALSE FALSE FALSE
[337] FALSE  TRUE FALSE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE  TRUE FALSE
[349]  TRUE FALSE  TRUE  TRUE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE  TRUE
[361]  TRUE FALSE  TRUE FALSE FALSE FALSE FALSE FALSE  TRUE  TRUE FALSE FALSE
[373]  TRUE  TRUE FALSE FALSE  TRUE  TRUE FALSE  TRUE  TRUE  TRUE FALSE  TRUE
[385]  TRUE  TRUE FALSE  TRUE FALSE FALSE  TRUE FALSE FALSE FALSE FALSE FALSE
[397] FALSE  TRUE  TRUE FALSE FALSE  TRUE FALSE FALSE FALSE  TRUE FALSE FALSE
[409]  TRUE FALSE  TRUE  TRUE FALSE FALSE FALSE FALSE FALSE  TRUE  TRUE  TRUE
[421]  TRUE FALSE FALSE FALSE FALSE  TRUE FALSE FALSE  TRUE FALSE FALSE  TRUE
[433]  TRUE  TRUE FALSE FALSE  TRUE FALSE FALSE  TRUE  TRUE  TRUE  TRUE  TRUE
[445]  TRUE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE FALSE  TRUE FALSE FALSE
[457] FALSE FALSE  TRUE  TRUE  TRUE  TRUE  TRUE FALSE FALSE FALSE  TRUE  TRUE
[469]  TRUE FALSE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE FALSE FALSE  TRUE
[481]  TRUE  TRUE FALSE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE FALSE  TRUE
[493]  TRUE  TRUE  TRUE  TRUE FALSE  TRUE FALSE FALSE FALSE FALSE  TRUE  TRUE
[505]  TRUE FALSE FALSE FALSE  TRUE  TRUE FALSE  TRUE  TRUE FALSE FALSE FALSE
[517]  TRUE FALSE  TRUE  TRUE  TRUE FALSE  TRUE FALSE FALSE FALSE FALSE  TRUE
[529]  TRUE FALSE  TRUE FALSE FALSE FALSE  TRUE  TRUE  TRUE FALSE  TRUE  TRUE
[541] FALSE FALSE  TRUE FALSE  TRUE FALSE FALSE FALSE FALSE  TRUE FALSE  TRUE
[553]  TRUE  TRUE FALSE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE  TRUE  TRUE
[565] FALSE FALSE FALSE  TRUE FALSE FALSE  TRUE  TRUE FALSE FALSE FALSE FALSE
[577] FALSE FALSE  TRUE  TRUE FALSE  TRUE FALSE  TRUE  TRUE  TRUE FALSE  TRUE
[589] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE  TRUE FALSE
[601] FALSE  TRUE  TRUE  TRUE FALSE FALSE FALSE FALSE  TRUE  TRUE FALSE FALSE
[613]  TRUE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE  TRUE
[625]  TRUE  TRUE FALSE  TRUE  TRUE FALSE FALSE  TRUE FALSE FALSE FALSE  TRUE
[637] FALSE FALSE  TRUE FALSE  TRUE  TRUE FALSE FALSE FALSE FALSE  TRUE FALSE
[649] FALSE FALSE FALSE  TRUE  TRUE  TRUE  TRUE FALSE  TRUE FALSE FALSE FALSE
[661]  TRUE  TRUE FALSE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE  TRUE FALSE
[673]  TRUE FALSE FALSE  TRUE  TRUE  TRUE FALSE  TRUE FALSE  TRUE FALSE  TRUE
[685] FALSE FALSE FALSE FALSE FALSE FALSE  TRUE  TRUE FALSE  TRUE  TRUE FALSE
[697] FALSE  TRUE FALSE  TRUE  TRUE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
[709] FALSE FALSE FALSE FALSE FALSE FALSE FALSE  TRUE FALSE FALSE  TRUE FALSE
[721] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE  TRUE  TRUE FALSE FALSE
[733] FALSE  TRUE  TRUE  TRUE FALSE FALSE  TRUE FALSE  TRUE  TRUE  TRUE FALSE
[745]  TRUE FALSE FALSE  TRUE FALSE FALSE FALSE FALSE  TRUE FALSE  TRUE FALSE
[757]  TRUE FALSE FALSE FALSE  TRUE  TRUE FALSE  TRUE  TRUE FALSE FALSE FALSE
[769] FALSE FALSE  TRUE FALSE FALSE FALSE  TRUE FALSE FALSE  TRUE FALSE  TRUE
[781]  TRUE FALSE FALSE  TRUE FALSE FALSE  TRUE  TRUE FALSE FALSE  TRUE  TRUE
[793]  TRUE FALSE  TRUE FALSE FALSE FALSE FALSE  TRUE  TRUE FALSE  TRUE FALSE
```

```
[805] FALSE FALSE FALSE FALSE  TRUE FALSE
```

`rowMeans(cbind(dlf$day1, dlf$day2, dlf$day3), na.rm = TRUE)`: Mean for a row

`rowSums(``cbind(dlf$day1, dlf$day2, dlf$day3), na.rm = TRUE``)`: Sums for a row

`na.rm = TRUE` tells **R** to exclude missing values from the calculation.

`sqrt(dlf$day2)`: Produces a column containing the sqrt of each value in the column labelled *day2*.

`abs(dlf$day1)`: Produces a variable that contains the absolute value of the values in the column labelled *day1*.

`is.na(dlf$day1)`: If a variable is missing, the case will be assigned TRUE (or 1); if the case is not missing, the case will be assigned FALSE (or 0):

```
dlf$missingDay2 <- is.na(dlf$day2)
dlf$missingDay2
```

```
  [1] FALSE FALSE  TRUE  TRUE FALSE  TRUE  TRUE  TRUE  TRUE FALSE  TRUE FALSE
 [13]  TRUE FALSE FALSE  TRUE  TRUE FALSE  TRUE  TRUE FALSE  TRUE  TRUE FALSE
 [25]  TRUE  TRUE  TRUE  TRUE  TRUE FALSE FALSE  TRUE  TRUE  TRUE FALSE  TRUE
 [37] FALSE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE FALSE
 [49]  TRUE  TRUE  TRUE  TRUE  TRUE FALSE FALSE  TRUE  TRUE  TRUE  TRUE FALSE
 [61]  TRUE  TRUE  TRUE FALSE  TRUE  TRUE FALSE  TRUE FALSE FALSE  TRUE FALSE
 [73]  TRUE  TRUE  TRUE  TRUE FALSE FALSE  TRUE  TRUE  TRUE  TRUE  TRUE FALSE
 [85] FALSE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE
 [97] FALSE FALSE  TRUE FALSE  TRUE  TRUE FALSE  TRUE  TRUE  TRUE  TRUE  TRUE
[109]  TRUE FALSE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE FALSE  TRUE
[121]  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE
[133] FALSE FALSE FALSE  TRUE  TRUE  TRUE FALSE FALSE  TRUE  TRUE  TRUE  TRUE
[145]  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE FALSE  TRUE  TRUE  TRUE
[157]  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE FALSE FALSE FALSE  TRUE  TRUE  TRUE
[169]  TRUE  TRUE  TRUE  TRUE FALSE  TRUE  TRUE  TRUE FALSE  TRUE  TRUE  TRUE
[181]  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE FALSE FALSE  TRUE  TRUE FALSE  TRUE
[193]  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE FALSE  TRUE  TRUE
[205]  TRUE  TRUE  TRUE  TRUE FALSE  TRUE  TRUE  TRUE  TRUE  TRUE FALSE FALSE
[217]  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE
[229]  TRUE FALSE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE FALSE  TRUE  TRUE
[241] FALSE  TRUE FALSE  TRUE  TRUE  TRUE FALSE  TRUE FALSE  TRUE  TRUE  TRUE
[253]  TRUE FALSE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE FALSE FALSE  TRUE
[265]  TRUE  TRUE  TRUE FALSE FALSE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE FALSE
[277]  TRUE FALSE  TRUE FALSE FALSE FALSE  TRUE FALSE  TRUE FALSE  TRUE FALSE
```

```
[289] FALSE FALSE FALSE FALSE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE FALSE  TRUE
[301]  TRUE FALSE FALSE  TRUE  TRUE  TRUE  TRUE  TRUE FALSE  TRUE FALSE FALSE
[313]  TRUE  TRUE  TRUE FALSE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE
[325]  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE
[337]  TRUE  TRUE  TRUE FALSE  TRUE  TRUE FALSE FALSE  TRUE FALSE  TRUE  TRUE
[349]  TRUE FALSE  TRUE FALSE  TRUE FALSE  TRUE FALSE FALSE FALSE  TRUE  TRUE
[361]  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE FALSE  TRUE  TRUE FALSE
[373] FALSE FALSE FALSE  TRUE FALSE FALSE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE
[385]  TRUE  TRUE FALSE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE
[397]  TRUE  TRUE  TRUE  TRUE  TRUE FALSE FALSE FALSE FALSE  TRUE  TRUE FALSE
[409] FALSE FALSE FALSE FALSE  TRUE FALSE FALSE  TRUE  TRUE  TRUE  TRUE FALSE
[421]  TRUE FALSE FALSE FALSE FALSE FALSE FALSE  TRUE  TRUE  TRUE  TRUE  TRUE
[433] FALSE  TRUE FALSE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE
[445]  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE FALSE  TRUE  TRUE  TRUE
[457]  TRUE  TRUE FALSE  TRUE FALSE FALSE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE
[469] FALSE  TRUE FALSE FALSE FALSE  TRUE  TRUE FALSE  TRUE FALSE FALSE FALSE
[481]  TRUE FALSE  TRUE  TRUE  TRUE  TRUE  TRUE FALSE FALSE FALSE  TRUE  TRUE
[493]  TRUE  TRUE  TRUE FALSE  TRUE  TRUE  TRUE  TRUE FALSE  TRUE  TRUE FALSE
[505]  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE FALSE  TRUE  TRUE FALSE
[517] FALSE FALSE  TRUE  TRUE FALSE  TRUE  TRUE FALSE  TRUE  TRUE FALSE FALSE
[529]  TRUE  TRUE FALSE FALSE  TRUE  TRUE FALSE FALSE FALSE  TRUE  TRUE FALSE
[541]  TRUE  TRUE FALSE FALSE FALSE FALSE  TRUE  TRUE FALSE  TRUE  TRUE FALSE
[553]  TRUE FALSE  TRUE FALSE  TRUE  TRUE FALSE  TRUE  TRUE  TRUE  TRUE  TRUE
[565] FALSE FALSE FALSE  TRUE FALSE  TRUE FALSE  TRUE  TRUE  TRUE  TRUE  TRUE
[577]  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE FALSE  TRUE  TRUE  TRUE
[589]  TRUE  TRUE  TRUE  TRUE FALSE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE
[601]  TRUE  TRUE  TRUE FALSE FALSE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE
[613] FALSE FALSE FALSE FALSE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE  TRUE
[625] FALSE  TRUE FALSE FALSE  TRUE FALSE FALSE  TRUE FALSE  TRUE  TRUE FALSE
[637] FALSE FALSE  TRUE FALSE  TRUE FALSE  TRUE FALSE  TRUE FALSE FALSE  TRUE
[649]  TRUE  TRUE  TRUE  TRUE  TRUE FALSE  TRUE FALSE  TRUE FALSE FALSE  TRUE
[661]  TRUE FALSE  TRUE FALSE  TRUE  TRUE  TRUE  TRUE FALSE  TRUE FALSE  TRUE
[673]  TRUE FALSE  TRUE  TRUE FALSE FALSE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE
[685]  TRUE  TRUE  TRUE  TRUE  TRUE FALSE  TRUE  TRUE FALSE FALSE FALSE  TRUE
[697]  TRUE  TRUE  TRUE FALSE FALSE FALSE  TRUE  TRUE FALSE  TRUE  TRUE  TRUE
[709]  TRUE  TRUE  TRUE FALSE  TRUE  TRUE  TRUE  TRUE FALSE  TRUE FALSE  TRUE
[721] FALSE FALSE  TRUE FALSE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE
[733]  TRUE FALSE FALSE  TRUE  TRUE FALSE FALSE  TRUE FALSE  TRUE  TRUE FALSE
[745]  TRUE  TRUE  TRUE  TRUE  TRUE FALSE  TRUE FALSE FALSE  TRUE FALSE FALSE
[757]  TRUE FALSE  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE FALSE  TRUE  TRUE  TRUE
[769] FALSE  TRUE  TRUE  TRUE FALSE FALSE FALSE FALSE  TRUE FALSE FALSE  TRUE
[781] FALSE  TRUE FALSE FALSE FALSE  TRUE FALSE FALSE FALSE  TRUE FALSE FALSE
[793]  TRUE FALSE FALSE FALSE FALSE  TRUE  TRUE  TRUE FALSE FALSE FALSE FALSE
```

```
[805]  TRUE FALSE FALSE  TRUE  TRUE  TRUE
```

```
sum(dlf$missingDay2)
```

```
[1] 546
```

```
mean(is.na(dlf$day2))
```

```
[1] 0.6740741
```

`mean(is.na(dlf$day2))` tells us that the mean is 0.674, so 67.4% of people are missing a hygiene score on day2.

5.8.3.2. The log transformation in R

To transform the variable **day1**, and create a new variable **logday1**, we execute this command:

```
dlf$logday1 <- log(dlf$day1)
```

For the day2 hygiene scores there is a value of 0 in the original data, so we can't transform it by taking log. To overcome this, we should add a constant to our original scores before we take the log of those scores:

```
dlf$logday1 <- log(dlf$day1 + 1)
```

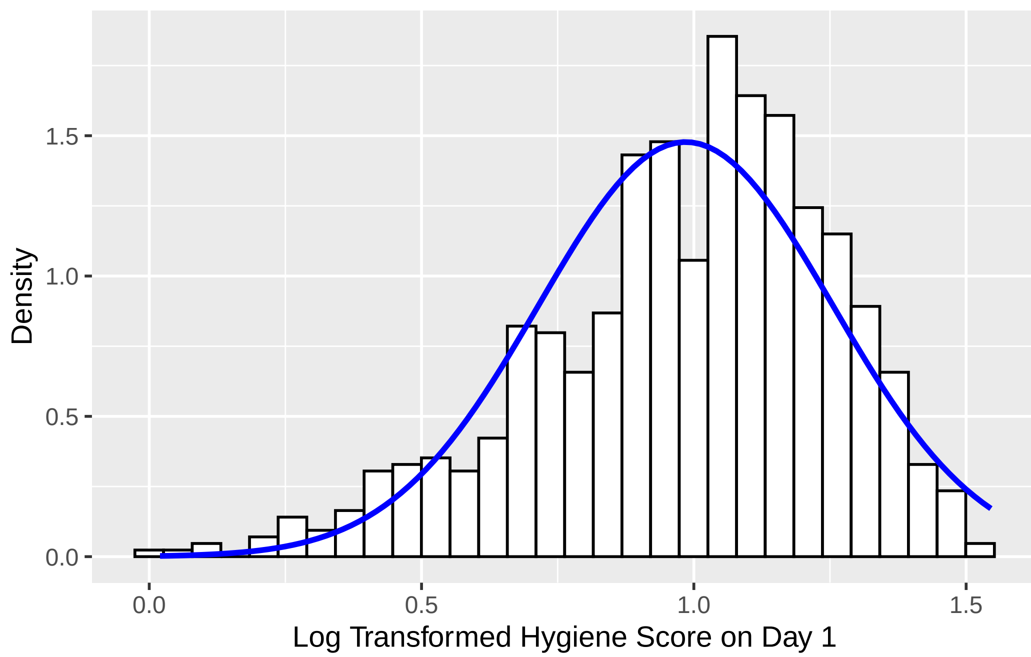
The advantage of adding 1 is that the logarithm of 1 is equal to 0, so people who scored a zero before the transformation score a zero after the transformation.

SELF-TEST

```
dlf$logday1 <- log(dlf$day1 + 1)
dlf$logday2 <- log(dlf$day2 + 1)
dlf$logday3 <- log(dlf$day3 + 1)

hist.logday1 <- ggplot(dlf, aes(logday1)) +
  geom_histogram(aes(y=..density..),
                 colour="black",
                 fill="white"
```

```
                 ) +
  labs(x="Log Transformed Hygiene Score on Day 1", y = "Density") +
  stat_function(fun = dnorm,
                args = list(mean = mean(dlf$logday1, na.rm = TRUE),
                            sd = sd(dlf$logday1, na.rm = TRUE)),
                colour = "blue", size = 1
                )
hist.logday1
```

```
`stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```

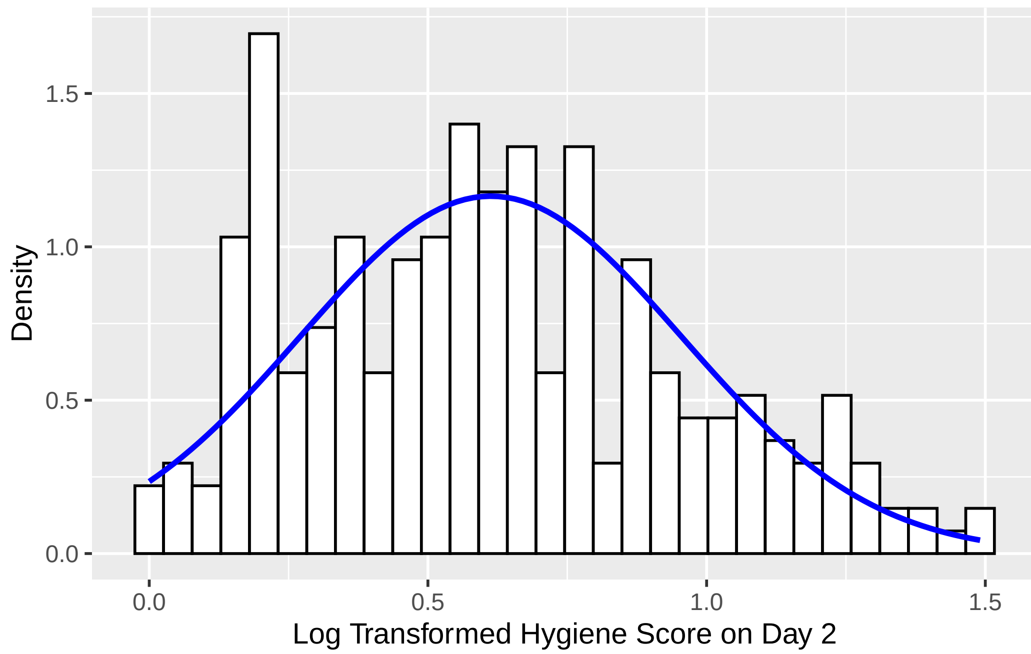



```
hist.logday2 <- ggplot(dlf, aes(logday2)) +
  geom_histogram(aes(y=..density..),
                 colour="black",
                 fill="white"
                 ) +
  labs(x="Log Transformed Hygiene Score on Day 2", y = "Density") +
  stat_function(fun = dnorm,
                args = list(mean = mean(dlf$logday2, na.rm = TRUE),
                            sd = sd(dlf$logday2, na.rm = TRUE)),
```

```
                    colour = "blue", size = 1
                    )
hist.logday2
```

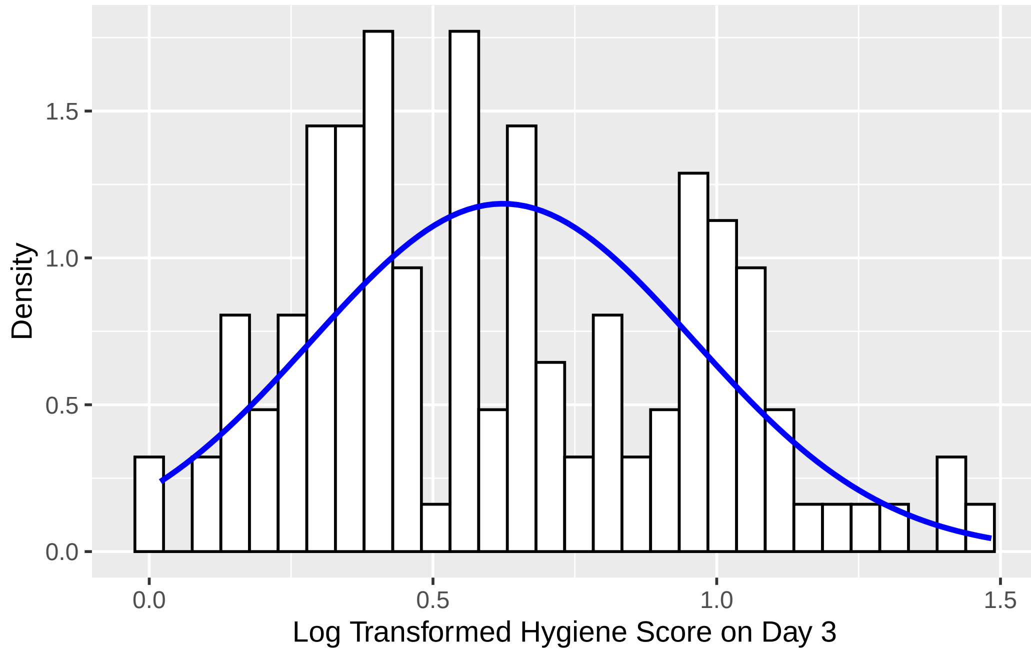
```
`stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```

```
Warning: Removed 546 rows containing non-finite values (`stat_bin()`).
```




```
hist.logday3 <- ggplot(dlf, aes(logday3)) +
  geom_histogram(aes(y=..density..),
                 colour="black",
                 fill="white"
                 ) +
  labs(x="Log Transformed Hygiene Score on Day 3", y = "Density") +
  stat_function(fun = dnorm,
                args = list(mean = mean(dlf$logday3, na.rm = TRUE),
                            sd = sd(dlf$logday3, na.rm = TRUE)),
                colour = "blue", size = 1
                )
hist.logday3
```

```
`stat_bin()` using `bins = 30`. Pick better value with `binwidth`.

Warning: Removed 687 rows containing non-finite values (`stat_bin()`).
```



5.8.3.3. The square root transformation in R

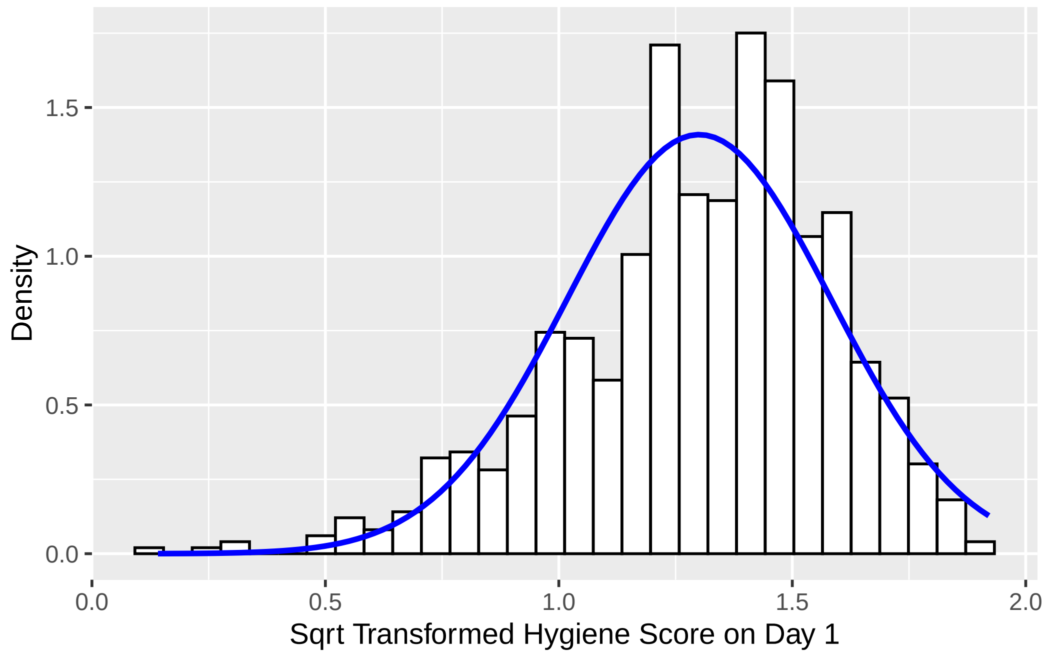
To do a square root transformation, we can execute `dlf$sqrtday1 <- sqrt(dlf$day1)`.

SELF-TEST

```
dlf$sqrtday1 <- sqrt(dlf$day1)
dlf$sqrtday2 <- sqrt(dlf$day2)
dlf$sqrtday3 <- sqrt(dlf$day3)

hist.sqrtday1 <- ggplot(dlf, aes(sqrtday1)) +
  geom_histogram(aes(y=..density..),
                 colour="black",
                 fill="white"
                 ) +
  labs(x="Sqrt Transformed Hygiene Score on Day 1", y = "Density") +
  stat_function(fun = dnorm,
```

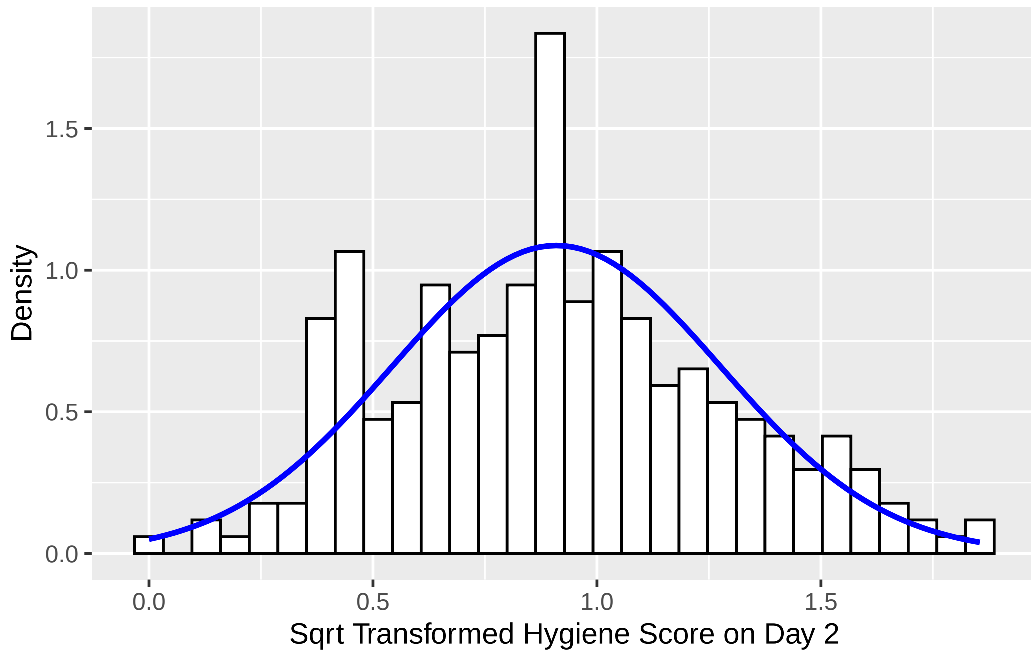
```
                 args = list(mean = mean(dlf$sqrtday1, na.rm = TRUE),
                             sd = sd(dlf$sqrtday1, na.rm = TRUE)),
                 colour = "blue", size = 1
                 )
hist.sqrtday1
```

```
`stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```



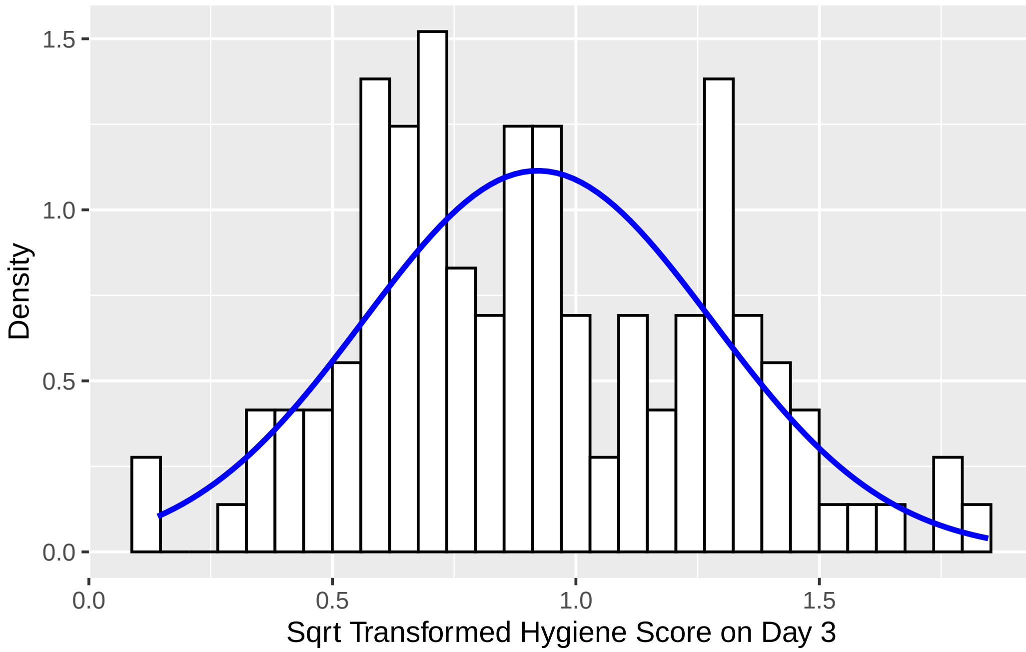

```
hist.sqrtday2 <- ggplot(dlf, aes(sqrtday2)) +
  geom_histogram(aes(y=..density..),
                 colour="black",
                 fill="white"
                 ) +
  labs(x="Sqrt Transformed Hygiene Score on Day 2", y = "Density") +
  stat_function(fun = dnorm,
                 args = list(mean = mean(dlf$sqrtday2, na.rm = TRUE),
                             sd = sd(dlf$sqrtday2, na.rm = TRUE)),
                 colour = "blue", size = 1
                 )
hist.sqrtday2
```

```
`stat_bin()` using `bins = 30`. Pick better value with `binwidth`.

Warning: Removed 546 rows containing non-finite values (`stat_bin()`).
```




```r
hist.sqrtday3 <- ggplot(dlf, aes(sqrtday3)) +
  geom_histogram(aes(y=..density..),
                 colour="black",
                 fill="white"
                 ) +
  labs(x="Sqrt Transformed Hygiene Score on Day 3", y = "Density") +
  stat_function(fun = dnorm,
                args = list(mean = mean(dlf$sqrtday3, na.rm = TRUE),
                            sd = sd(dlf$sqrtday3, na.rm = TRUE)),
                colour = "blue", size = 1
                )
hist.sqrtday3
```

```
`stat_bin()` using `bins = 30`. Pick better value with `binwidth`.

Warning: Removed 687 rows containing non-finite values (`stat_bin()`).
```



5.8.3.4. The reciprocal transformation in R

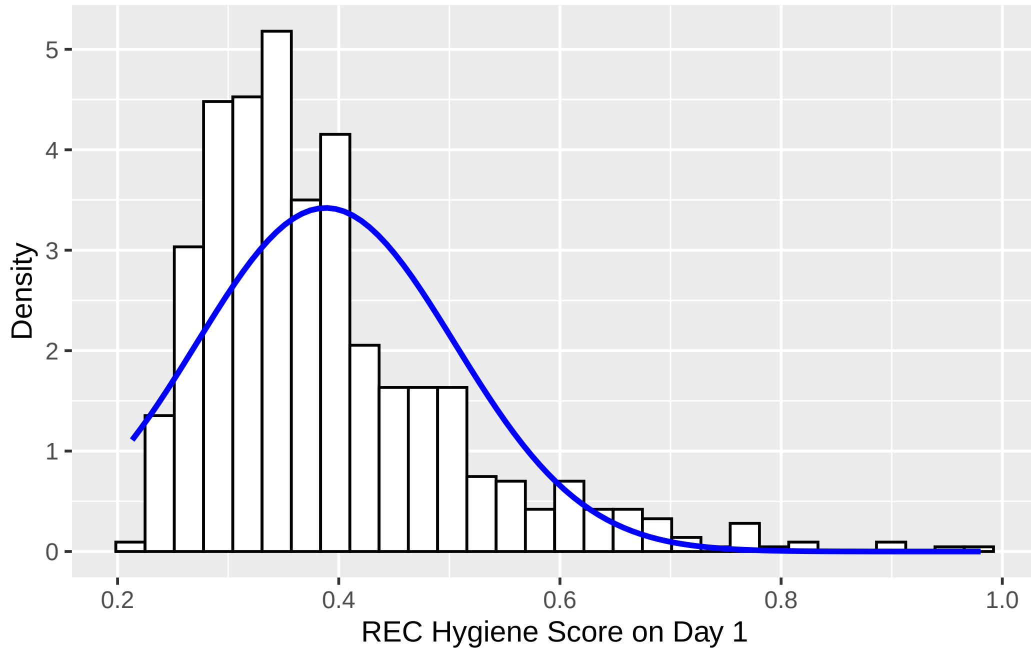
To do a reciprocal transformation, we use '1/variable'. However, if the data contain a zero value, we can add a constant to our variable and then divide it.

SELF-TEST

```
dlf$recday1 <- 1/(dlf$day1 + 1)
dlf$recday2 <- 1/(dlf$day1 + 1)
dlf$recday3 <- 1/(dlf$day1 + 1)

hist.recday1 <- ggplot(dlf, aes(recday1)) +
  geom_histogram(aes(y=..density..),
                 color="black",
                 fill="white"
                 ) +
  labs(x="REC Hygiene Score on Day 1", y = "Density") +
  stat_function(fun = dnorm,
                args = list(mean = mean(dlf$recday1, na.rm = TRUE),
                            sd = sd(dlf$recday1, na.rm = TRUE)),
                color = "blue", size = 1
```

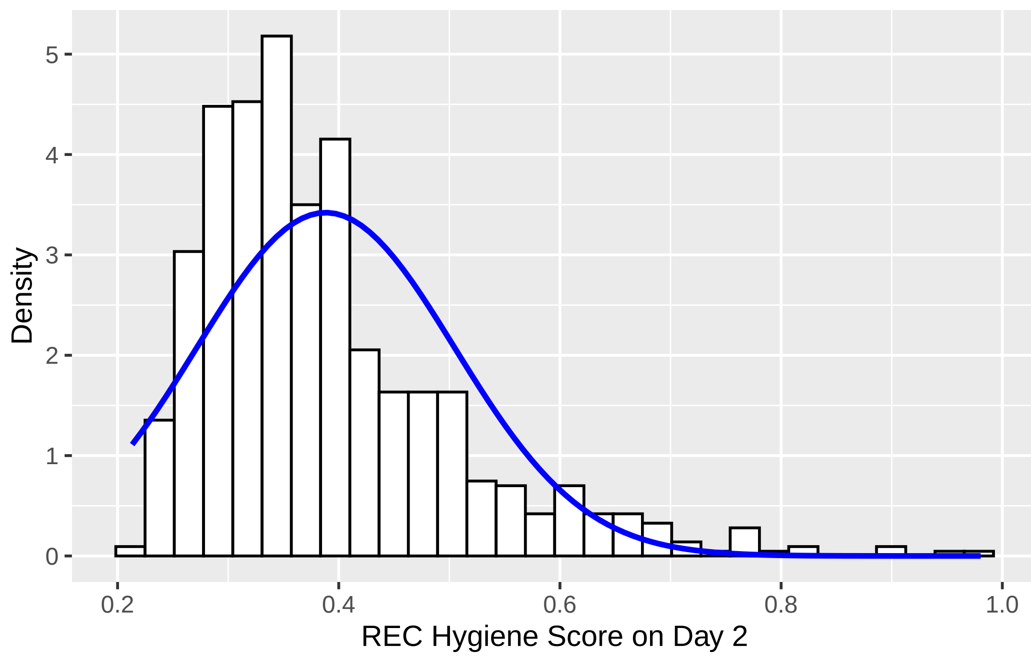
```
                )
hist.recday1
```

```
`stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```



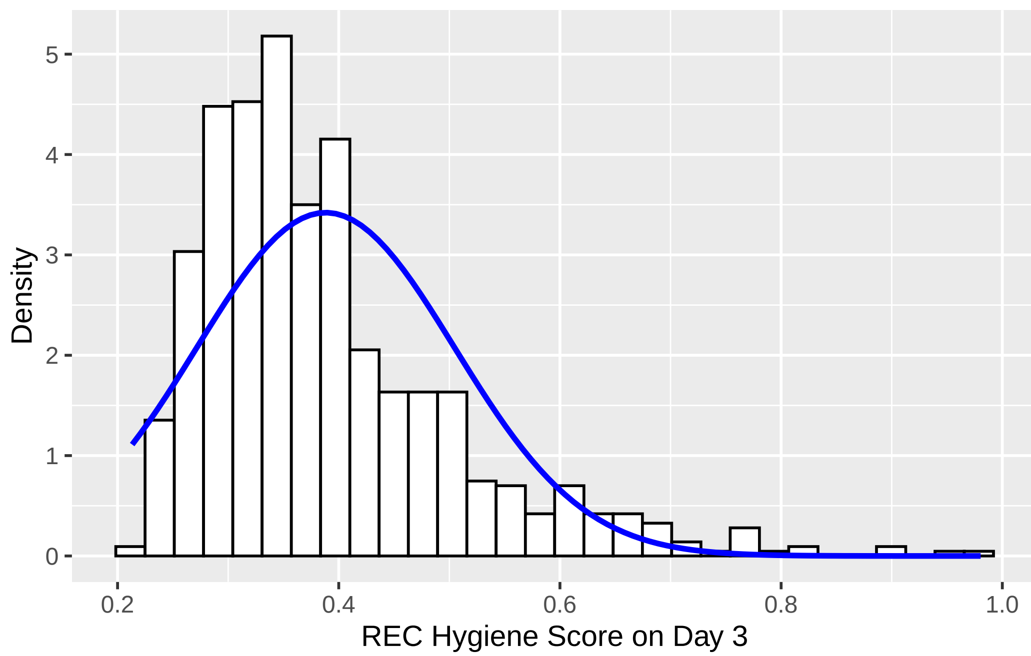

```
hist.recday2 <- ggplot(dlf, aes(recday2)) +
  geom_histogram(aes(y=..density..),
                 color="black",
                 fill="white"
                 ) +
  labs(x="REC Hygiene Score on Day 2", y = "Density") +
  stat_function(fun = dnorm,
                args = list(mean = mean(dlf$recday2, na.rm = TRUE),
                            sd = sd(dlf$recday2, na.rm = TRUE)),
                color = "blue", size = 1
                )
hist.recday2
```

```
`stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```




```
hist.recday3 <- ggplot(dlf, aes(recday3)) +
  geom_histogram(aes(y=..density..),
                 color="black",
                 fill="white"
                 ) +
  labs(x="REC Hygiene Score on Day 3", y = "Density") +
  stat_function(fun = dnorm,
                args = list(mean = mean(dlf$recday3, na.rm = TRUE),
                            sd = sd(dlf$recday3, na.rm = TRUE)),
                color = "blue", size = 1
                )
hist.recday3
```

```
`stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```



5.8.3.5. The ifelse() function in R

The *ifelse()* function is used to create a new variable, or change an old variable, depending on some other values. This function needs three arguments: a conditional argument to test, what to do if the test is true, and what to do if the test is false.

For example, to remove the outliers in the **day1** hygiene score:

```
dlf$day1NoOutlier <- ifelse(dlf$day1 > 4, NA, dlf$day1)
dlf$day1NoOutlier
```

```
  [1] 2.64 0.97 0.84 3.03 0.88 0.85 1.56 3.02 2.29 1.11 2.17 0.82 1.41 1.76 1.38
 [16] 2.79 1.50 1.91 2.32 2.05 2.17 2.05 1.61 1.66 2.30 2.76 1.44 1.06 3.23 0.97
 [31] 2.57 0.26 0.47 1.73 1.94 1.91 2.08 1.91 1.42 1.50 0.11 1.67 2.08 2.05 2.00
 [46] 1.52 1.58 1.28 1.88 1.32 2.09 2.00 2.64 0.85 2.47 1.79 1.64 1.32 2.97 1.44
 [61] 2.02 1.79 1.34 2.29 1.66 0.60 1.76 1.50 2.08 1.00 1.73 1.05 2.81 1.52 1.47
 [76] 2.64 2.20 0.55 2.29 2.00 2.23 2.45 1.20 2.91 1.14 1.88 0.94 1.85 2.58 0.61
 [91] 0.70 1.38 1.94 2.29 1.59 2.46 1.67 2.02 1.50 2.70 1.61 2.29 0.97 1.85 2.76
[106] 1.64 1.17 1.57 2.23 2.05 2.05 2.94 2.39 1.94 2.12 1.11 0.97 1.35 2.81 2.50
[121] 1.87 1.33 1.26 1.44 0.55 1.75 2.08 0.85 2.52 3.00 1.41 1.08 1.20 1.94 2.26
[136] 1.41 2.50 2.17 1.82 1.44 1.66 1.82 1.26 2.67 1.47 1.84 2.58 1.73 1.23 2.32
[151] 2.67 1.02 1.66 1.88 1.91 1.64 1.34 1.85 2.08 1.02 1.79 1.94 3.26 1.14 1.50
```

```
[166] 2.03 2.24 1.11 2.21 1.94 2.41 0.88 1.17 2.23 1.64 2.14 0.11 2.17 1.67 1.00
[181] 0.88 2.20 2.17 2.32 1.64 3.00 2.38 1.60 1.58 2.61 1.44 1.57 2.32 1.14 1.93
[196] 2.47 2.29 1.00 1.58 2.44 0.83 2.71 1.73 1.58 1.50 1.05 2.05 2.63 2.55 2.00
[211] 2.00 1.32 3.14 1.44 1.85 1.41 1.94 2.91 1.85 1.70 2.23 1.11 1.47 2.20 1.82
[226] 1.42 2.44 2.66 1.52 1.35 1.29 2.32 0.78 2.84 0.97 1.52 1.70 0.94 1.41 1.79
[241] 1.08 1.47 1.79 2.00 0.76 2.20 0.94 1.38 1.38 0.32 2.58 0.51 0.32 0.91 1.51
[256] 1.47 2.50 2.26 2.81 1.87 2.00 2.23 2.00 1.41 1.64 1.64 1.26 1.52 2.44 2.18
[271] 3.02 1.02 2.88 1.54 1.64 2.44 1.29 1.61 1.77 0.91 0.85 0.85 1.50 1.05 3.38
[286] 1.42 1.85 1.91 0.82 1.32 2.23 1.47 2.70 1.58 1.00 1.44 2.00 1.60 2.32 3.41
[301] 2.02 0.64 3.58 1.50 1.08 1.52 1.26 1.68 1.47 1.47 1.67 2.47 1.82 2.17 3.21
[316] 1.60 0.32 0.55 1.42 1.14 2.64 2.58 2.02 2.00 2.90 1.82 0.50 1.53 2.48 2.05
[331] 2.52 1.88 2.73 2.88 1.67 1.93 1.67 1.20 2.75 1.94 0.59 1.50 1.58 2.23 2.35
[346] 2.55 1.55 2.31 2.23 0.67 2.51 1.08 2.44 0.23 2.17 1.90 1.67 2.00 2.44 1.44
[361] 0.82 2.50 1.82 1.97 2.52 0.05 2.08 2.39 1.45 2.58 2.12 2.02 1.78 0.73 2.26
[376] 2.79 0.43 0.52 2.32 2.22 0.58 2.00 0.70 1.00 0.30 1.52 1.58 2.34 0.79 2.26
[391] 2.35 1.70 3.09 1.52 0.35 2.70 1.64 0.82 2.73 2.23 1.06 2.05 1.73 0.93 2.50
[406] 1.44 2.88 0.67 1.85 1.21 1.06 0.61 2.00 1.17 1.48 1.55 3.29 1.47 0.96 1.00
[421] 1.47 2.55 0.44 2.35 1.71 1.84 1.11 1.38 0.88 0.94 1.91 2.76 1.55 2.67 1.03
[436] 2.50 1.64 2.26 2.14 0.52 1.08 1.69 2.73 1.91 1.73 3.21 2.11 2.05 2.17 2.17
[451] 2.30 2.56 2.11 1.70 1.23 3.20 2.02 2.64 2.52 1.61 1.50 1.15 1.82 1.50 2.32
[466] 2.92 1.41 1.35 0.61 0.73 2.23 1.32 2.94 1.61 1.00 3.15 2.88 2.09 1.32 1.47
[481] 1.61 2.20 2.78 2.06 0.47 2.87 1.14 3.32 2.08 2.38 2.08 1.85 1.38 1.14 1.58
[496] 1.23 2.53 0.67 0.73 1.34 2.14 1.00 1.35 1.94 0.50 3.08 2.88 1.91 1.41 2.02
[511] 0.76 1.94 0.67 2.41 2.17 2.67 1.94 2.05 2.17 0.47 0.62 2.00 0.45 2.29 2.55
[526] 0.82 3.12 2.50 1.79 2.28 0.58 2.50 1.41 2.14 0.76 1.79 1.02 2.62 0.88 1.58
[541] 2.20 1.14 1.47 1.41 1.44 1.23 1.82 2.44 1.94 2.41 2.27 1.79 1.88 1.85 2.21
[556] 1.97 2.51 2.05 1.29 2.05 2.23 1.76 1.05 1.79 1.02 2.76 1.67 2.85 0.23 1.90
[571] 1.23 1.97 1.50 3.69 0.50 2.18 2.17 1.58 2.88 2.52 2.20 1.73 2.23 1.97 1.20
[586] 2.00 1.91 0.81 1.31 0.38 1.97 0.38 2.11 3.20 0.02 2.56 2.02 2.30 2.02 2.05
[601] 1.70 1.61 0.73 2.50 2.18 2.46 1.50 1.73 1.44 1.64 2.02 1.20 0.38 1.58 1.67
[616] 1.00 2.58 2.82 2.29 1.14 1.64 1.82 3.32 3.32 1.85 2.29 1.47 2.08 2.20 1.06
[631] 0.97 2.00 1.67 2.94 1.55 0.88 1.35 0.61 1.00 1.52 1.00 1.76 2.52 2.00 2.63
[646] 0.73 1.58 0.58 1.67 1.47 1.81 1.91 1.06 1.47 2.52 1.85 3.44 1.55 2.29 1.76
[661] 1.90 2.52 2.52 2.82 2.02 1.29 1.26 0.94 2.00 0.73 2.26 2.23 2.35 0.55 1.85
[676] 0.67 1.85 1.23 2.35 1.35 1.94 1.55 1.29 2.17 1.91 2.88 2.36 2.36 2.20 2.17
[691] 0.52 0.32 1.52 2.00 1.32 2.05 1.73 1.94 1.81 0.90 1.58 2.29 2.57 1.58 2.33
[706] 3.15 2.29 0.82 1.93 1.82 1.96 1.32 1.02 1.14 2.32 2.16 2.42 1.14 1.55 1.17
[721] 1.00 1.05 1.38 1.93 2.73 2.02 2.81 2.47 1.35 2.08 2.50 2.45 2.17 1.70 0.70
[736] 1.51 1.23 2.14 1.14 0.96 1.52 0.52 1.56 3.29 0.45 2.63 1.70 3.11 1.82 1.58
[751] 2.73 1.50 1.78 2.02 0.67 1.41 0.90 1.23 2.70 1.97 0.84 1.79 2.84 2.02 1.64
[766] 1.08 2.97 0.94 2.97 0.97 1.47 2.61 1.73 3.38 3.17 2.20 2.14 1.29 3.21 2.67
[781] 1.85 1.35 2.14 1.24 2.02 2.32 1.08 1.14 2.14 2.88 1.35 1.00 2.02 0.64 0.29
[796] 1.73 1.82 2.11 1.23 0.64 2.23 2.44 1.17 0.61 0.52 2.91 2.61 1.47 1.28 1.26
```

This command creates a new variable called **day1NoOutlier** which takes the value NA if **day1** is greater than 4, but is the value of day1 if day1 is less than 4.

The `rowSums()` and `rowMeans()` functions allow us to choose what to do with missing data, by using the `na.rm` option, which asks 'should missing values (na) be removed (rm)?'.

To obtain the mean hygiene score across three days, removing anyone with any missing values, we would use:

```
dlf$meanHygiene <- rowMeans(cbind(dlf$day1, dlf$day2, dlf$day3))
dlf$meanHygiene
```

```
  [1] 1.8666667 0.8900000        NA        NA        NA        NA        NA
  [8]        NA        NA 0.7000000        NA 0.4966667        NA 1.6600000
 [15]        NA        NA        NA        NA        NA        NA 1.2100000
 [22]        NA        NA        NA        NA        NA        NA        NA
 [29]        NA 0.7033333 0.9000000        NA        NA        NA 1.4766667
 [36]        NA 1.3166667        NA        NA        NA        NA        NA
 [43]        NA        NA        NA        NA        NA 0.6000000        NA
 [50]        NA        NA        NA        NA 0.5633333 1.0266667        NA
 [57]        NA        NA        NA        NA        NA        NA        NA
 [64]        NA        NA        NA 0.9366667        NA        NA        NA
 [71]        NA        NA        NA        NA        NA        NA        NA
 [78]        NA        NA        NA        NA        NA        NA 2.3666667
 [85]        NA        NA        NA        NA        NA        NA        NA
 [92]        NA        NA        NA        NA        NA        NA 1.0333333
 [99]        NA 2.1033333        NA        NA 0.9300000        NA        NA
[106]        NA        NA        NA        NA 1.9266667        NA        NA
[113]        NA        NA        NA        NA        NA        NA        NA
[120]        NA        NA        NA        NA        NA        NA        NA
[127]        NA        NA        NA        NA        NA        NA 1.3600000
[134]        NA 1.9066667        NA        NA        NA        NA        NA
[141]        NA        NA        NA        NA        NA        NA        NA
[148]        NA        NA        NA        NA        NA 2.1600000        NA
[155]        NA        NA        NA        NA        NA        NA        NA
[162]        NA 2.3000000 0.6100000 0.8600000        NA        NA        NA
[169]        NA        NA        NA        NA        NA        NA        NA
[176]        NA        NA        NA        NA        NA        NA        NA
[183]        NA        NA        NA        NA        NA        NA        NA
[190]        NA 0.5633333        NA        NA        NA        NA        NA
[197]        NA        NA        NA        NA        NA 1.2733333        NA
[204]        NA        NA        NA        NA        NA        NA        NA
[211]        NA        NA        NA        NA        NA        NA        NA
```

```
[218]        NA        NA        NA        NA        NA        NA        NA
[225]        NA        NA        NA        NA        NA 0.8500000        NA
[232]        NA        NA        NA        NA        NA        NA 1.1333333
[239]        NA        NA 0.6533333        NA        NA        NA        NA
[246]        NA        NA        NA        NA        NA        NA        NA
[253]        NA 1.2400000        NA        NA        NA        NA        NA
[260]        NA        NA 1.2200000        NA        NA        NA        NA
[267]        NA 1.3166667 1.4066667        NA        NA        NA        NA
[274]        NA        NA 2.2133333        NA 0.7300000        NA        NA
[281] 0.4766667 0.6033333        NA        NA        NA 1.3133333        NA
[288]        NA        NA        NA 1.1566667 1.0533333        NA        NA
[295]        NA        NA        NA        NA 2.1733333        NA        NA
[302]        NA        NA        NA        NA        NA        NA        NA
[309] 1.0433333        NA        NA        NA        NA        NA        NA
[316] 1.3333333        NA        NA        NA        NA        NA        NA
[323]        NA        NA        NA        NA        NA        NA        NA
[330]        NA        NA        NA        NA        NA        NA        NA
[337]        NA        NA        NA        NA        NA        NA 1.1533333
[344] 0.8366667        NA 1.2200000        NA        NA        NA        NA
[351]        NA 0.7566667        NA        NA        NA        NA        NA
[358] 1.0333333        NA        NA        NA        NA        NA        NA
[365]        NA        NA        NA        NA        NA        NA        NA
[372] 1.1100000 1.1200000 0.5533333 1.6700000        NA 0.4133333 0.5333333
[379]        NA        NA        NA        NA        NA        NA        NA
[386]        NA        NA        NA        NA        NA        NA        NA
[393]        NA        NA        NA        NA        NA        NA        NA
[400]        NA        NA 0.8666667        NA        NA        NA        NA
[407]        NA 0.4466667        NA        NA 0.8400000 0.4000000        NA
[414] 1.0233333 1.2733333        NA        NA        NA        NA 1.1033333
[421]        NA        NA        NA        NA        NA 1.0400000 0.6300000
[428]        NA        NA        NA        NA        NA 0.7800000        NA
[435] 0.6800000        NA        NA        NA        NA        NA        NA
[442]        NA        NA        NA        NA        NA        NA        NA
[449]        NA        NA        NA        NA 0.9966667        NA        NA
[456]        NA        NA        NA        NA        NA 1.2033333 0.6800000
[463]        NA        NA        NA        NA        NA        NA        NA
[470]        NA        NA        NA        NA        NA        NA        NA
[477]        NA        NA 1.7700000        NA        NA 1.8600000        NA
[484]        NA        NA        NA        NA        NA        NA        NA
[491]        NA        NA        NA        NA        NA 0.9833333        NA
[498]        NA        NA        NA        NA        NA        NA        NA
[505]        NA        NA        NA        NA        NA        NA        NA
[512]        NA        NA        NA        NA        NA        NA 1.5333333
```

```
[519]        NA        NA        NA        NA        NA 1.5266667        NA
[526]        NA        NA 1.7133333        NA        NA 0.7366667        NA
[533]        NA        NA        NA        NA        NA        NA        NA
[540] 0.6600000        NA        NA 0.7800000 0.6733333 1.4600000        NA
[547]        NA        NA        NA        NA        NA        NA        NA
[554] 1.2700000        NA        NA        NA        NA 1.0366667        NA
[561]        NA        NA        NA        NA 0.7400000        NA        NA
[568]        NA        NA        NA        NA        NA        NA        NA
[575]        NA        NA        NA        NA        NA        NA        NA
[582]        NA        NA        NA 0.9266667        NA        NA        NA
[589]        NA        NA        NA        NA 1.2400000        NA        NA
[596]        NA        NA        NA        NA        NA        NA        NA
[603]        NA        NA 1.9466667 1.8166667        NA        NA        NA
[610] 0.8266667        NA 0.5233333        NA 1.6266667        NA        NA
[617]        NA 2.8166667        NA        NA        NA        NA 3.0833333
[624]        NA 1.4500000        NA 1.1733333 1.1500000        NA        NA
[631] 0.3766667        NA        NA        NA        NA        NA        NA
[638] 0.3266667        NA 1.5866667        NA 1.0166667        NA 1.4400000
[645]        NA        NA 1.1566667        NA        NA        NA        NA
[652]        NA        NA 1.2133333        NA        NA        NA 1.3533333
[659]        NA        NA        NA        NA        NA        NA        NA
[666]        NA        NA        NA 1.2200000        NA        NA        NA
[673]        NA        NA        NA        NA        NA        NA        NA
[680]        NA        NA        NA        NA        NA        NA        NA
[687]        NA        NA        NA 1.0066667        NA        NA        NA
[694] 1.0066667 1.1800000        NA        NA        NA        NA        NA
[701]        NA 1.6900000        NA        NA        NA        NA        NA
[708]        NA        NA        NA        NA 0.8100000        NA        NA
[715]        NA        NA        NA        NA 1.3666667        NA 0.6333333
[722]        NA        NA        NA        NA        NA        NA        NA
[729]        NA        NA        NA        NA        NA        NA 0.4600000
[736]        NA        NA        NA        NA        NA 1.3066667        NA
[743]        NA        NA        NA        NA        NA        NA        NA
[750]        NA        NA        NA        NA        NA 0.8400000        NA
[757]        NA 1.0333333        NA        NA        NA        NA        NA
[764]        NA        NA        NA        NA        NA        NA        NA
[771]        NA        NA 0.9466667 3.4100000 1.9666667        NA        NA
[778] 1.2266667        NA        NA        NA        NA        NA        NA
[785] 2.1166667        NA        NA 1.1700000        NA        NA 0.6533333
[792]        NA        NA        NA        NA        NA        NA        NA
[799]        NA        NA 1.9166667        NA        NA        NA        NA
[806]        NA        NA        NA        NA        NA
```

But, a lot of people would be missing. If we want to use everyone who had at least one score for the three days, we can add `na.rm = TRUE`:

```
dlf$meanHygiene <- rowMeans(cbind(dlf$day1, dlf$day2, dlf$day3), na.rm = TRUE)
dlf$meanHygiene
```

```
  [1] 1.8666667 0.8900000 0.8400000 3.0300000 0.4800000 0.8500000 1.5600000
  [8] 3.0200000 2.2900000 0.7000000 2.1700000 0.4966667 1.4100000 1.6600000
 [15] 0.7000000 2.7900000 1.5000000 1.9800000 2.3200000 2.0500000 1.2100000
 [22] 2.0500000 1.6100000 1.2550000 2.3000000 2.7600000 1.4400000 1.0600000
 [29] 3.2300000 0.7033333 0.9000000 0.2600000 0.4700000 1.7300000 1.4766667
 [36] 1.9100000 1.3166667 1.9100000 1.4200000 1.5000000 0.1100000 1.6700000
 [43] 2.0800000 2.0500000 2.0000000 1.5200000 1.5800000 0.6000000 1.8800000
 [50] 1.3200000 2.0900000 2.0000000 2.6400000 0.5633333 1.0266667 1.7900000
 [57] 1.6400000 1.3200000 2.9700000 0.7900000 2.0200000 1.7900000 1.3400000
 [64] 2.0950000 1.6600000 0.6000000 0.9366667 1.5000000 1.3900000 0.7750000
 [71] 1.7300000 0.7150000 2.8100000 1.5200000 1.4700000 2.6400000 1.6900000
 [78] 0.6700000 2.2900000 2.0000000 2.2300000 2.4500000 1.2000000 2.3666667
 [85] 1.0700000 1.8800000 0.9400000 1.8500000 2.5800000 0.6100000 0.7000000
 [92] 1.3800000 1.9400000 2.2900000 1.5900000 2.4600000 0.9050000 1.0333333
 [99] 1.5000000 2.1033333 1.6100000 2.2900000 0.9300000 1.8500000 2.7600000
[106] 1.6400000 1.1700000 1.5700000 2.2300000 1.9266667 2.0500000 2.9400000
[113] 2.3900000 1.9400000 2.1200000 1.1100000 0.9700000 1.3500000 2.4450000
[120] 2.5000000 1.8700000 1.3300000 1.2600000 1.4400000 0.5500000 1.7500000
[127] 2.0800000 0.8500000 2.5200000 3.0000000 1.4100000 1.0800000 1.3600000
[134] 1.6900000 1.9066667 1.4100000 2.5000000 2.1700000 1.4650000 1.2900000
[141] 1.6600000 1.8200000 1.2600000 2.6700000 1.4700000 1.8400000 2.5800000
[148] 1.7300000 1.2300000 2.3200000 2.6700000 1.0200000 2.1600000 1.8800000
[155] 1.9100000 1.6400000 1.3400000 1.8500000 2.0800000 1.0200000 1.7900000
[162] 1.9400000 2.3000000 0.6100000 0.8600000 2.0300000 2.2400000 1.1100000
[169] 2.2100000 1.9400000 2.4100000 0.8800000 1.2600000 2.2300000 1.6400000
[176] 2.1400000 0.2000000 2.1700000 1.6700000 1.0000000 0.8800000 2.2000000
[183] 2.1700000 2.3200000 1.6400000 3.0000000 1.6150000 1.3100000 1.5800000
[190] 2.6100000 0.5633333 1.5700000 2.3200000 1.1400000 1.9300000 2.4700000
[197] 2.2900000 1.0000000 1.5800000 2.4400000 0.8300000 1.2733333 1.7300000
[204] 1.5800000 1.5000000 1.0500000 2.0500000 2.6300000 2.4200000 2.0000000
[211] 2.0000000 1.3200000 3.1400000 1.4400000 1.0400000 0.9250000 1.9400000
[218] 2.9100000 1.8500000 1.7000000 2.2300000 1.1100000 1.4700000 2.2000000
[225] 1.8200000 1.4200000 2.4400000 2.6600000 1.5200000 0.8500000 1.2900000
[232] 2.3200000 0.7800000 2.8400000 0.9700000 1.5200000 1.7000000 1.1333333
[239] 1.4100000 1.7900000 0.6533333 1.4700000 1.1300000 2.0000000 0.7600000
[246] 2.2000000 0.5550000 1.3800000 1.1150000 0.3200000 2.5800000 0.5100000
```

```
[253] 0.3200000 1.2400000 1.5100000 1.4700000 2.5000000 2.2600000 2.8100000
[260] 1.8700000 2.0000000 1.2200000 1.3800000 1.4100000 1.6400000 1.6400000
[267] 1.2600000 1.3166667 1.4066667 2.1800000 3.0200000 1.0200000 2.8800000
[274] 1.5400000 1.6400000 2.2133333 1.2900000 0.7300000 1.7700000 0.5400000
[281] 0.4766667 0.6033333 1.5000000 0.6400000 3.3800000 1.3133333 1.8500000
[288] 1.3750000 0.5400000 1.0400000 1.1566667 1.0533333 2.7000000 1.5800000
[295] 1.0000000 1.4400000 2.0000000 1.6000000 2.1733333 3.4100000 2.0200000
[302] 0.5800000 3.4650000 1.5000000 1.0800000 1.5200000 1.2600000 1.6800000
[309] 1.0433333 1.4700000 1.6100000 2.2200000 1.8200000 2.1700000 3.2100000
[316] 1.3333333 0.3200000 0.5500000 1.4200000 1.1400000 2.6400000 2.5800000
[323] 2.0200000 2.0000000 2.9000000 1.8200000 0.5000000 1.5300000 2.4800000
[330] 2.0500000 2.5200000 1.8800000 2.7300000 2.8800000 1.6700000 1.9300000
[337] 1.6700000 1.2000000 2.7500000 1.4550000 0.5900000 1.5000000 1.1533333
[344] 0.8366667 2.3500000 1.2200000 1.5500000 2.3100000 2.2300000 0.5850000
[351] 2.5100000 0.7566667 2.4400000 0.1850000 2.1700000 1.5350000 1.0550000
[358] 1.0333333 2.4400000 1.4400000 0.8200000 2.5000000 1.8200000 1.9700000
[365] 2.5200000 0.0500000 2.0800000 2.3900000 1.1350000 2.5800000 2.1200000
[372] 1.1100000 1.1200000 0.5533333 1.6700000 2.7900000 0.4133333 0.5333333
[379] 2.3200000 2.2200000 0.5800000 2.0000000 0.7000000 1.0000000 0.3000000
[386] 1.5200000 0.9650000 2.3400000 0.7900000 2.2600000 2.3500000 1.7000000
[393] 3.0900000 1.5200000 0.3500000 2.7000000 1.6400000 0.8200000 2.7300000
[400] 2.2300000 1.0600000 0.8666667 1.5850000 0.9200000 2.4700000 1.4400000
[407] 2.8800000 0.4466667 1.1000000 1.0000000 0.8400000 0.4000000 2.0000000
[414] 1.0233333 1.2733333 1.5500000 3.2900000 1.4700000 0.9600000 1.1033333
[421] 1.4700000 2.4650000 0.2500000 2.3800000 1.2800000 1.0400000 0.6300000
[428] 1.3800000 0.8800000 0.9400000 1.9100000 2.7600000 0.7800000 2.6700000
[435] 0.6800000 2.5000000 1.6400000 2.2600000 2.1400000 0.5200000 1.0800000
[442] 1.6900000 2.7300000 1.9100000 1.7300000 3.2100000 2.1100000 2.0500000
[449] 2.1700000 2.1700000 2.3000000 2.5600000 0.9966667 1.7000000 1.2300000
[456] 3.2000000 2.0200000 2.6400000 1.3300000 1.6100000 1.2033333 0.6800000
[463] 1.8200000 1.5000000 2.3200000 2.9200000 1.4100000 1.3500000 0.3750000
[470] 0.7300000 2.0550000 1.1150000 2.3650000 1.6100000 1.0000000 3.0750000
[477] 2.8800000 1.6500000 1.7700000 0.9100000 1.6100000 1.8600000 2.7800000
[484] 2.0600000 0.4700000 2.8700000 1.1400000 3.2650000 1.7300000 2.4400000
[491] 2.0800000 1.8500000 1.3800000 1.1400000 1.5800000 0.9833333 2.5300000
[498] 0.6700000 0.7300000 1.3400000 1.4200000 1.0000000 1.3500000 1.3650000
[505] 0.5000000 3.0800000 2.8800000 1.9100000 1.4100000 2.0200000 0.7600000
[512] 1.9400000 0.4750000 2.4100000 2.1700000 1.5400000 1.2900000 1.5333333
[519] 2.1700000 0.4700000 0.6900000 2.0000000 0.4500000 1.5266667 2.5500000
[526] 0.8200000 2.6600000 1.7133333 1.7900000 2.2800000 0.7366667 1.8950000
[533] 1.4100000 2.1400000 0.5100000 1.4500000 0.6850000 2.6200000 0.8800000
[540] 0.6600000 2.2000000 1.1400000 0.7800000 0.6733333 1.4600000 1.2000000
[547] 1.8200000 2.4400000 1.5700000 2.4100000 2.2700000 1.0100000 1.8800000
```

```
[554] 1.2700000 2.2100000 1.9550000 2.5100000 2.0500000 1.0366667 2.0500000
[561] 2.2300000 1.7600000 1.0500000 1.7900000 0.7400000 2.1700000 1.1100000
[568] 2.8500000 0.5350000 1.9000000 0.8750000 1.9700000 1.5000000 3.6900000
[575] 0.5000000 2.1800000 2.1700000 1.5800000 2.8800000 2.5200000 2.2000000
[582] 1.7300000 2.2300000 1.9700000 0.9266667 2.0000000 1.9100000 0.8100000
[589] 1.3100000 0.3800000 1.9700000 0.3800000 1.2400000 3.2000000 0.0200000
[596] 2.5600000 2.0200000 2.3000000 2.0200000 2.0500000 1.7000000 1.6100000
[603] 0.7300000 2.0700000 1.9466667 1.8166667 1.2050000 1.3350000 1.4400000
[610] 0.8266667 2.2300000 0.5233333 0.2000000 1.6266667 1.0850000 0.7400000
[617] 1.9650000 2.8166667 2.1700000 1.1400000 1.2000000 0.9500000 3.0833333
[624] 3.3200000 1.4500000 2.2900000 1.1733333 1.1500000 2.2000000 1.2550000
[631] 0.3766667 2.0000000 1.0250000 2.9400000 1.5500000 0.5700000 1.8350000
[638] 0.3266667 1.0000000 1.5866667 1.0000000 1.0166667 2.5200000 1.4400000
[645] 2.6300000 0.7900000 1.1566667 0.5800000 1.6700000 1.4700000 1.8100000
[652] 1.9100000 1.0600000 1.2133333 2.5200000 1.0250000 3.4400000 1.3533333
[659] 2.4950000 1.7600000 1.9000000 2.5350000 2.5200000 1.4950000 2.0200000
[666] 1.2900000 1.2600000 0.9400000 1.2200000 0.7300000 1.5250000 2.2300000
[673] 2.3500000 0.4650000 1.8500000 0.6700000 1.4250000 0.7150000 2.3500000
[680] 1.3500000 1.9400000 1.5500000 1.2900000 2.1700000 1.9100000 2.8800000
[687] 2.3600000 2.3600000 2.2000000 1.0066667 0.5200000 0.3200000 1.0350000
[694] 1.0066667 1.1800000 2.0500000 1.7300000 1.9400000 1.8100000 0.7700000
[701] 1.1250000 1.6900000 2.5700000 1.5800000 1.5750000 3.1500000 2.2900000
[708] 0.8200000 1.9300000 1.8200000 1.9600000 0.8100000 1.0200000 1.1400000
[715] 2.3200000 2.1600000 2.0600000 1.1400000 1.3666667 1.1700000 0.6333333
[722] 0.5800000 1.3800000 2.1750000 2.7300000 2.0200000 2.8100000 2.4700000
[729] 1.3500000 2.0800000 2.5000000 2.4500000 2.1700000 0.8500000 0.4600000
[736] 1.5100000 1.2300000 1.4950000 1.1400000 0.9600000 1.3066667 0.5200000
[743] 1.5600000 1.7750000 0.4500000 2.6300000 1.7000000 3.1100000 1.8200000
[750] 0.8600000 2.7300000 1.3200000 1.4000000 2.0200000 0.8400000 0.9800000
[757] 0.9000000 1.0333333 2.7000000 1.9700000 0.8400000 1.7900000 2.8400000
[764] 2.0200000 1.1700000 1.0800000 2.9700000 0.9400000 2.4550000 0.9700000
[771] 1.4700000 2.6100000 0.9466667 3.4100000 1.9666667 1.5550000 2.1400000
[778] 1.2266667 3.0300000 2.6700000 1.3200000 1.3500000 1.4500000 0.9000000
[785] 2.1166667 2.3200000 0.6550000 1.1700000 1.9800000 2.8800000 0.6533333
[792] 1.3500000 2.0200000 0.9800000 0.2150000 1.3350000 1.6700000 2.1100000
[799] 1.2300000 0.6400000 1.9166667 1.3800000 0.8750000 0.5250000 0.5200000
[806] 1.9250000 2.0250000 1.4700000 1.2800000 1.2600000
```

If we don't mind if people were missing one or two scores, but we do not want to calculate a mean for people who only had one score, we can use the `is.na()` function first:

```r
dlf$daysMissing <- rowSums(cbind(is.na(dlf$day1),
                                 is.na(dlf$day2),
                                 is.na(dlf$day3)
                                 )
                           )
dlf$daysMissing
```

```
  [1] 0 0 2 2 1 2 2 2 2 0 2 0 2 0 1 2 2 1 2 2 0 2 2 1 2 2 2 2 2 0 0 2 2 2 0 2 0
 [38] 2 2 2 2 2 2 2 2 2 2 0 2 2 2 2 2 0 0 2 2 2 2 1 2 2 2 1 2 2 0 2 1 1 2 1 2 2
 [75] 2 2 1 1 2 2 2 2 2 0 1 2 2 2 2 2 2 2 2 2 2 2 1 0 2 0 2 2 0 2 2 2 2 2 2 0 2
[112] 2 2 2 2 2 2 2 1 2 2 2 2 2 2 2 2 2 2 2 2 2 0 1 0 2 2 2 1 1 2 2 2 2 2 2 2 2
[149] 2 2 2 2 0 2 2 2 2 2 2 2 2 2 0 0 0 2 2 2 2 2 2 2 1 2 2 2 1 2 2 2 2 2 2 2 2
[186] 2 1 1 2 2 0 2 2 2 2 2 2 2 2 2 2 0 2 2 2 2 2 2 1 2 2 2 2 2 1 1 2 2 2 2 2 2
[223] 2 2 2 2 2 2 2 0 2 2 2 2 2 2 2 0 2 2 0 2 1 2 2 2 1 2 1 2 2 2 2 0 2 2 2 2 2
[260] 2 2 0 1 2 2 2 2 0 0 2 2 2 2 2 2 0 2 0 2 1 0 0 2 1 2 0 2 1 1 1 0 0 2 2 2 2
[297] 2 2 0 2 2 1 1 2 2 2 2 2 0 2 1 1 2 2 2 0 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
[334] 2 2 2 2 2 2 1 2 2 0 0 2 0 2 2 2 1 2 0 2 1 2 1 1 0 2 2 2 2 2 2 2 2 2 2 1 2
[371] 2 0 0 0 0 2 0 0 2 2 2 2 2 2 2 2 1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 0 1 1 1 2 2
[408] 0 1 1 0 0 2 0 0 2 2 2 2 0 2 1 1 1 1 0 0 2 2 2 2 2 0 2 0 2 2 2 2 2 2 2 2 2
[445] 2 2 2 2 2 2 2 2 0 2 2 2 2 2 1 2 0 0 2 2 2 2 2 2 1 2 1 1 1 2 2 1 2 1 0 1 2
[482] 0 2 2 2 2 2 1 1 1 2 2 2 2 2 0 2 2 2 2 1 2 2 1 2 2 2 2 2 2 2 2 1 2 2 1 1 0
[519] 2 2 1 2 2 0 2 2 1 0 2 2 0 1 2 2 1 1 1 2 2 0 2 2 0 0 0 1 2 2 1 2 2 1 2 0 2
[556] 1 2 2 0 2 2 2 2 2 0 1 1 2 1 2 1 2 2 2 2 2 2 2 2 2 2 2 2 2 0 2 2 2 2 2 2 2
[593] 0 2 2 2 2 2 2 2 2 2 2 1 0 0 1 1 2 0 1 0 1 0 1 1 1 0 1 2 1 1 0 2 0 2 0 0 2
[630] 1 0 2 1 2 2 1 1 0 2 0 2 0 2 0 2 1 0 2 2 2 2 2 2 0 2 1 2 0 1 2 2 1 2 1 2 2
[667] 2 2 0 2 1 2 2 1 2 2 1 1 2 2 2 2 2 2 2 2 2 2 2 0 2 2 1 0 0 2 2 2 2 1 1 0 2
[704] 2 1 2 2 2 2 2 2 0 2 2 2 2 1 2 0 2 0 1 2 1 2 2 2 2 2 2 2 2 2 1 0 2 2 1 1 2
[741] 0 2 2 1 2 2 2 2 2 1 2 1 1 2 0 1 2 0 2 2 2 2 2 2 1 2 2 2 1 2 2 2 0 0 0 1 2
[778] 0 1 2 1 2 1 1 0 2 1 0 1 2 0 1 2 1 1 1 1 2 2 2 0 1 1 1 2 1 1 2 2 2
```

We also can use the `ifelse()` function to calculate values only for those people who have a score on at least two days:

```r
dlf$meanHygiene <- ifelse(dlf$daysMissing < 2, NA,
                          rowMeans(cbind(dlf$day1,
                                         dlf$day2,
                                         dlf$day3
                                         ),
                                   na.rm = TRUE)
                          )
dlf$meanHygiene
```

```
  [1]   NA   NA 0.84 3.03   NA 0.85 1.56 3.02 2.29   NA 2.17   NA 1.41   NA   NA
 [16] 2.79 1.50   NA 2.32 2.05   NA 2.05 1.61   NA 2.30 2.76 1.44 1.06 3.23   NA
 [31]   NA 0.26 0.47 1.73   NA 1.91   NA 1.91 1.42 1.50 0.11 1.67 2.08 2.05 2.00
 [46] 1.52 1.58   NA 1.88 1.32 2.09 2.00 2.64   NA   NA 1.79 1.64 1.32 2.97   NA
 [61] 2.02 1.79 1.34   NA 1.66 0.60   NA 1.50   NA   NA 1.73   NA 2.81 1.52 1.47
 [76] 2.64   NA   NA 2.29 2.00 2.23 2.45 1.20   NA   NA 1.88 0.94 1.85 2.58 0.61
 [91] 0.70 1.38 1.94 2.29 1.59 2.46   NA   NA 1.50   NA 1.61 2.29   NA 1.85 2.76
[106] 1.64 1.17 1.57 2.23   NA 2.05 2.94 2.39 1.94 2.12 1.11 0.97 1.35   NA 2.50
[121] 1.87 1.33 1.26 1.44 0.55 1.75 2.08 0.85 2.52 3.00 1.41 1.08   NA   NA   NA
[136] 1.41 2.50 2.17   NA   NA 1.66 1.82 1.26 2.67 1.47 1.84 2.58 1.73 1.23 2.32
[151] 2.67 1.02   NA 1.88 1.91 1.64 1.34 1.85 2.08 1.02 1.79 1.94   NA   NA   NA
[166] 2.03 2.24 1.11 2.21 1.94 2.41 0.88   NA 2.23 1.64 2.14   NA 2.17 1.67 1.00
[181] 0.88 2.20 2.17 2.32 1.64 3.00   NA   NA 1.58 2.61   NA 1.57 2.32 1.14 1.93
[196] 2.47 2.29 1.00 1.58 2.44 0.83   NA 1.73 1.58 1.50 1.05 2.05 2.63   NA 2.00
[211] 2.00 1.32 3.14 1.44   NA   NA 1.94 2.91 1.85 1.70 2.23 1.11 1.47 2.20 1.82
[226] 1.42 2.44 2.66 1.52   NA 1.29 2.32 0.78 2.84 0.97 1.52 1.70   NA 1.41 1.79
[241]   NA 1.47   NA 2.00 0.76 2.20   NA 1.38   NA 0.32 2.58 0.51 0.32   NA 1.51
[256] 1.47 2.50 2.26 2.81 1.87 2.00   NA   NA 1.41 1.64 1.64 1.26   NA   NA 2.18
[271] 3.02 1.02 2.88 1.54 1.64   NA 1.29   NA 1.77   NA   NA   NA 1.50   NA 3.38
[286]   NA 1.85   NA   NA   NA   NA   NA 2.70 1.58 1.00 1.44 2.00 1.60   NA 3.41
[301] 2.02   NA   NA 1.50 1.08 1.52 1.26 1.68   NA 1.47   NA   NA 1.82 2.17 3.21
[316]   NA 0.32 0.55 1.42 1.14 2.64 2.58 2.02 2.00 2.90 1.82 0.50 1.53 2.48 2.05
[331] 2.52 1.88 2.73 2.88 1.67 1.93 1.67 1.20 2.75   NA 0.59 1.50   NA   NA 2.35
[346]   NA 1.55 2.31 2.23   NA 2.51   NA 2.44   NA 2.17   NA   NA   NA 2.44 1.44
[361] 0.82 2.50 1.82 1.97 2.52 0.05 2.08 2.39   NA 2.58 2.12   NA   NA   NA   NA
[376] 2.79   NA   NA 2.32 2.22 0.58 2.00 0.70 1.00 0.30 1.52   NA 2.34 0.79 2.26
[391] 2.35 1.70 3.09 1.52 0.35 2.70 1.64 0.82 2.73 2.23 1.06   NA   NA   NA   NA
[406] 1.44 2.88   NA   NA   NA   NA   NA 2.00   NA   NA 1.55 3.29 1.47 0.96   NA
[421] 1.47   NA   NA   NA   NA   NA   NA 1.38 0.88 0.94 1.91 2.76   NA 2.67   NA
[436] 2.50 1.64 2.26 2.14 0.52 1.08 1.69 2.73 1.91 1.73 3.21 2.11 2.05 2.17 2.17
[451] 2.30 2.56   NA 1.70 1.23 3.20 2.02 2.64   NA 1.61   NA   NA 1.82 1.50 2.32
[466] 2.92 1.41 1.35   NA 0.73   NA   NA   NA 1.61 1.00   NA 2.88   NA   NA   NA
[481] 1.61   NA 2.78 2.06 0.47 2.87 1.14   NA   NA   NA 2.08 1.85 1.38 1.14 1.58
[496]   NA 2.53 0.67 0.73 1.34   NA 1.00 1.35   NA 0.50 3.08 2.88 1.91 1.41 2.02
[511] 0.76 1.94   NA 2.41 2.17   NA   NA   NA 2.17 0.47   NA 2.00 0.45   NA 2.55
[526] 0.82   NA   NA 1.79 2.28   NA   NA 1.41 2.14   NA   NA   NA 2.62 0.88   NA
[541] 2.20 1.14   NA   NA   NA   NA 1.82 2.44   NA 2.41 2.27   NA 1.88   NA 2.21
[556]   NA 2.51 2.05   NA 2.05 2.23 1.76 1.05 1.79   NA   NA   NA 2.85   NA 1.90
[571]   NA 1.97 1.50 3.69 0.50 2.18 2.17 1.58 2.88 2.52 2.20 1.73 2.23 1.97   NA
[586] 2.00 1.91 0.81 1.31 0.38 1.97 0.38   NA 3.20 0.02 2.56 2.02 2.30 2.02 2.05
[601] 1.70 1.61 0.73   NA   NA   NA   NA   NA 1.44   NA   NA   NA   NA   NA   NA
[616]   NA   NA   NA   NA 1.14   NA   NA   NA 3.32   NA 2.29   NA   NA 2.20   NA
[631]   NA 2.00   NA 2.94 1.55   NA   NA   NA 1.00   NA 1.00   NA 2.52   NA 2.63
```

```
[646]   NA   NA 0.58 1.67 1.47 1.81 1.91 1.06   NA 2.52   NA 3.44   NA   NA 1.76
[661] 1.90   NA 2.52   NA 2.02 1.29 1.26 0.94   NA 0.73   NA 2.23 2.35   NA 1.85
[676] 0.67   NA   NA 2.35 1.35 1.94 1.55 1.29 2.17 1.91 2.88 2.36 2.36 2.20   NA
[691] 0.52 0.32   NA   NA   NA 2.05 1.73 1.94 1.81   NA   NA   NA 2.57 1.58   NA
[706] 3.15 2.29 0.82 1.93 1.82 1.96   NA 1.02 1.14 2.32 2.16   NA 1.14   NA 1.17
[721]   NA   NA 1.38   NA 2.73 2.02 2.81 2.47 1.35 2.08 2.50 2.45 2.17   NA   NA
[736] 1.51 1.23   NA   NA 0.96   NA 0.52 1.56   NA 0.45 2.63 1.70 3.11 1.82   NA
[751] 2.73   NA   NA 2.02   NA   NA 0.90   NA 2.70 1.97 0.84 1.79 2.84 2.02   NA
[766] 1.08 2.97 0.94   NA 0.97 1.47 2.61   NA   NA   NA   NA 2.14   NA   NA 2.67
[781]   NA 1.35   NA   NA   NA 2.32   NA   NA   NA 2.88   NA   NA 2.02   NA   NA
[796]   NA   NA 2.11 1.23 0.64   NA   NA   NA   NA 0.52   NA   NA 1.47 1.28 1.26
```

5.8.4. When it all goes horribly wrong

If transformations don't work, there are some other options.

The first is to use a test that does not rely on the assumption of normally distributed data.

Another approach is to use robust methods.

- **Trimmed mean** is simply a mean based on the distribution of scores after some percentage of scores has been removed from each extreme of the distribution.
- **M-estimator** determines the optimal amount of trimming necessary to give a robust estimation, rather than the researcher deciding before the analysis how much of the data to trim.

Trimmed mean and M-estimator produces accurate results even when the distribution is not symmetrical, because by trimming the ends of the distribution we remove outliers and skew.

The second general procedure is the **bootstrap**. Lack of normality prevents us from knowing the shape of the sampling distribution unless we have big samples. In bootstrapping, the sample data are treated as a population from which smaller samples (= bootstrap samples) are taken. The statistic interest is calculated in each sample, and by taking many samples the sampling distribution can be estimated. The SE of the statistic is estimated from the SD of this sampling distribution created from the bootstrap samples.