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BA.plot: An R function for Bland-Altman analysisKalesh M. Karun^a, Amitha Puranik^{b,*}^a Division of Biostatistics, MOSC Medical College, Kolenchery, Kerala, India^b Department of Data Science, Prasanna School of Public Health, Manipal Academy of Higher Education, Karnataka, India

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ABSTRACT

Bland-Altman analysis is a very commonly used method in the biomedical research. This method is used to study the agreement between two measurements that are in continuous scale. Although this method is commonly used in medical research, the statistical software packages do not have the menu-driven operation for the Bland-Altman analysis. Hence this paper intends to provide an R function (*BA.plot*) for Bland-Altman analysis.

1. Introduction

In many situations the researcher may be interested to know whether measurements made by two (sometimes more than two) different observers or by two different techniques produce similar results. This is referred to as agreement or concordance or reproducibility between measurements. Here the researcher is concerned both with accuracy (the way in which an observed value of a quantity agrees with the true value) and precision (a measure of the extent to which repeated observations conform). Such agreement checking analysis looks at pairs of measurements, either both categorical or both numerics. In the agreement studies, the two measurements relate to the same variable. For example, chest radiographs rated by two radiologists or blood pressure measured by two methods. Based on the number of observers and type of variable, the method of agreement also varies. Kappa statistic¹ is used to study the agreement of categorical variables and Bland-Altman analysis or intra-class correlation (ICC)² is used for continuous variables.

Even though Bland-Altman analysis is very common in the biomedical research, many of the commonly used statistical software packages do not provide the menu-driven operation for Bland-Altman plot. Hence this paper aims to provide an R function for Bland-Altman analysis.

2. Bland-Altman analysis

Bland-Altman analysis is a method to quantify agreement between two quantitative measurements by constructing limits of agreement,³ introduced by Bland and Altman in 1983.⁴ Bland-Altman plot is used to detect the presence of systematic difference between the measurements

(i.e. fixed bias) or possible outliers. The steps to construct a Bland-Altman plot are.

Step 1: Calculate the difference between the measurements of method one and method two.

Step 2: Calculate the mean of the measurements of method one and method two.

Step 3: Calculate the limits of agreement:

Lower Limit (LL) = Mean of difference

$$- (1.96 \times \text{Standard deviation of difference}) \quad (1)$$

Upper Limit (UL) = Mean of difference

$$+ (1.96 \times \text{Standard deviation of difference}) \quad (2)$$

Step 4: Plot scatter diagram with mean (x axis) and difference (y axis); mark the LL, UL and mean of difference, as given in Fig. 1.

If the data points in the plot are very close to the zero line, it indicates that there is a good level of agreement between two methods. The data points far from zero line indicate weak agreement between the methods. If the constructed limits of agreement are within the clinical acceptable differences, the two methods can be used interchangeably. In other words, if the clinician/researcher is ready to accept the variability in the measurements between two methods up to the constructed limits, then the two methods are substitutable.

To demonstrate the calculations involved in Bland-Altman analysis, an example of a hypothetical data is given as follows. Weight of 14 patients

* Corresponding author.

E-mail address: amitha.puranik@manipal.edu (A. Puranik).

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Fig. 1. Bland-Altman plot.

$$\begin{aligned} \text{LowerLimit (LL)} &= \text{Mean of difference} - (1.96 \times \text{Standard deviation of difference}) \\ &= 0.095 - 1.96 \times 0.295 = -0.484 \end{aligned}$$

(3)

$$\begin{aligned} \text{UpperLimit (UL)} &= \text{Mean of difference} + (1.96 \times \text{Standard deviation of difference}) \\ &= 0.095 + 1.96 \times 0.295 = 0.674 \end{aligned}$$

(4)

were assessed using two weighing machines and Bland-Altman analysis was performed to quantify the agreement. Here the weighing machine I is considered as the gold standard. The data is provided in Table 1.

3. Calculation of limits of agreement

The difference between the measurements and mean (average) of measurements are calculated as given in Table 2.

Limits of agreement are,

If the estimated limits $[-0.484, 0.674]$ are clinically acceptable, then the weighing machine I (gold standard) can be replaced by weighing

Table 1

Hypothetical data to demonstrate the calculations involved in Bland-Altman analysis.

SI	Weighing machine I (m_1)	Weighing machine II (m_2)
1	70.11	70.10
2	70.35	70.12
3	70.06	69.72
4	69.91	69.81
5	70.15	70.07
6	69.69	69.41
7	69.95	69.43
8	69.89	70.36
9	70.18	69.82
10	70.28	70.11
11	70.08	69.69
12	70.27	70.57
13	69.61	69.93
14	69.99	70.05

Table 2

Difference between the measurements and average of measurements of the hypothetical data.

SI	Weighing machine I (m_1)	Weighing machine II (m_2)	Difference ($m_1 - m_2$)	Average $[(m_1 + m_2)/2]$
1	70.11	70.10	0.01	70.11
2	70.35	70.12	0.23	70.24
3	70.06	69.72	0.34	69.89
4	69.91	69.81	0.10	69.86
5	70.15	70.07	0.08	70.11
6	69.69	69.41	0.28	69.55
7	69.95	69.43	0.52	69.69
8	69.89	70.36	-0.47	70.13
9	70.18	69.82	0.36	70.00
10	70.28	70.11	0.17	70.19
11	70.08	69.69	0.39	69.89
12	70.27	70.57	-0.30	70.42
13	69.61	69.93	-0.32	69.77
14	69.99	70.05	-0.06	70.02

machine II. The Bland-Altman plot for this data is given in Fig. 2.

4. BA.plot function

To generate the Bland-Altman plot using *BA.plot* function, load the data sheet with variable names say *m1* and *m2* (two methods) in R and use the code given below. The *BA.plot* function is validated using simulated data.

5. R code (BA.plot function)

R code (BA.plot function)

```
BA.plot <- function(m1, m2) {
  means <- (m1 + m2) / 2
  diffs <- m1 - m2; mdiff <- mean(diffs); sddiff <- sd(diffs)
  # Positioning of labels on the lines
  xmax = max(means)
  xmin = min(means)
  x1 = (xmax - xmin) * 0.10
```

Fig. 2. Bland-Altman plot for the hypothetical example.

```

x2=xmax-x1
# Adding space for legend
ylimh <- mdiff + (3.5* sddiff)
yliml <- mdiff - (3 * sddiff)
# Plot data
plot(diffs ~ means, xlab = "Average of two methods", ylab = "Difference of two methods", ylim = c(yliml, ylimh))
abline(h = mdiff, col='blue', lty = 2)
text(x2, mdiff, "Mean")
abline(h = 0)
# Standard deviations lines & legend
abline(h = mdiff + 1.96 * sddiff, col='blue', lty = 2)
text(x2, mdiff + 1.96 * sddiff, "Upper Limit")
abline(h = mdiff - 1.96 * sddiff, col='blue', lty = 2)
text(x2, mdiff - 1.96 * sddiff, "Lower Limit")
paramX =round(mdiff,2); paramY =round(sddiff,2)
UL=mdiff + 1.96 * sddiff; UL=round(UL,2)
LL=mdiff - 1.96 * sddiff; LL=round(LL,2)
expr <- vector("expression", 4)
expr[[1]] <- bquote(Mean[diff]==.(paramX))
expr[[2]] <- bquote(SD[diff]==.(paramY))
expr[[3]] <- bquote(LL==.(LL))
expr[[4]] <- bquote(UL==.(UL))
legend("topright", bty = "n", legend = expr) }

```

```

# Usage
BA.plot(m1,m2)

```

6. Conclusion

Bland-Altman analysis is very common in the biomedical research. In this paper, the Bland-Altman analysis is illustrated in a simplified way to help the researchers. Also, the **BA. plot** function provided in this paper will help to generate the Bland-Altman plot.

Declaration of competing interest

The authors declare that there is no conflict of interest.

References

- 1 Viera AJ, Garrett JM. Understanding interobserver agreement: the kappa statistic. *Fam Med.* 2005 May;37(5):360–363.
- 2 Bartko JJ. The intraclass correlation coefficient as a measure of reliability. *Psychol Rep.* 1966 Aug;19(1):3–11.
- 3 Sedgwick P. Limits of agreement (Bland-Altman method). *Br Med J.* 2013 Mar 15;346:f1630.
- 4 Bland JM, Altman DG. Measuring agreement in method comparison studies. *Stat Methods Med Res.* 1999 Apr;8(2):135–160.