In most cases it is desirable to present the results of a repeated measures ANOVA visually, by plotting the factor level means of the dependent variable. Additionally it is particular instructive (and therefore often required e.g. by many scientific journals) to present some depiction of the inferential accuracy. In ANOVA designs without repeated measures factors this is often accomplished by the inclusion of error bars which display the associated confidence intervals. These confidence intervals (CI) are computed by

$$\bar{y}_j \pm t_{n_j-1,(1-\alpha/2)} \times SE(\bar{y}_j)$$

where

$$\bar{y}_j = \frac{1}{n_j}\sum_{i=1}^{n_j} y_{ji}$$

is the factor level mean and

$$SE(\bar{y}_j) = \frac{\frac{1}{n-1}\sum_{i=1}^{n_j}\left(y_{ji} - \bar{y}_j\right)^2}{\sqrt{n}}$$

is its standard error. This can be computed with R in the following way.

```
# Standard errors of the conditional means
SE = tapply(rma_data_long$value, rma_data_long$condition, sd)/sqrt(n)

# CI for ANOVA without repeated measures
CIdist_unadj = abs(qt((1 - C_level)/2, (n - 1))) * SE

# Compute upper and lower bound
up_unadj = MeFlm$Flm + CIdist_unadj
low_unadj = MeFlm$Flm - CIdist_unadj
```

However in ANOVA designs which incorporate a repeated measures factor, this method is no longer applicable. That's because this computational method includes the variance between entities into the standard error of the factor level mean, which the F-test of the ANOVA with a repeated measures factor doesn't.

O'Brien und Cousineau (2014) suggested a method for the computation of adjusted confidence Intervals based on methods described by Loftus & Masson (1994), Cousineau (2005) and Morey (2008) which is conducted by the following function.

```
rma_ci(rma_data, C_level = 0.95, id = 1, print_plot = TRUE)
```

As input parameter it needs a repeated measures data file which meets the above described requirements. It also contains the **id = 1** and **print_plot = TRUE** arguments. By the argument **C_level = 0.95** it is also possible to select the desired alpha level of the confidence interval.

For the method of O'Brien und Cousineau (2014) the corresponding individual subject means are subtracted from every value of the depended variable and afterwards the grand mean is added.

$$y'_{ji} = y_{ji} - \bar{y}_i + \bar{y}$$

Thereby all between subject variation is removed from the resulting values. Afterwards a correction factor has to be applied (see Morey, 2008) by

$$\sqrt{\frac{k}{k-1}} \times (y'_{ji} - \bar{y}_j) + \bar{y}_j \,.$$

```
# Correction factor etablished by Morey (2008)
cf = sqrt(k/(k - 1))

AdjVal = data.frame(Adj =
        (cf * ((rma_data_long$value - EEmlong$Em + Gm) - MeFlmlong$Flm)) + MeFlmlong$Flm)
rma_data_long_adj = cbind.data.frame(rma_data_long, AdjVal)
```

The adjusted values can be used to compute confidence Intervals in the same way as in the case of an ANOVA without repeated Measures.

```
# Standard errors of the conditional means adjusted with the method of O'Brien and Cousineau
        (2014)
SE_adj = (tapply(rma_data_long_adj$Adj, rma_data_long_adj$condition, sd)/sqrt(n))
CIdist_adj = abs(qt((1 - C_level)/2, (n - 1))) * SE_adj

# Compute upper and lower bound
up_adj = MeFlm$Flm + CIdist_adj
low_adj = MeFlm$Flm - CIdist_adj
```

The adjusted and unadjusted confidence intervals are summarized in a table, which is later returned by the function.

```
lu_adj_CI = cbind(low_adj, up_adj)
lu_unadj_CI = cbind(low_unadj, up_unadj)
colnames(lu_adj_CI) = colnames(lu_unadj_CI) = c("Lower bound", "Upper bound")
```

Error bar plots which show the adjusted and unadjusted confidence intervals are constructed using ggplot.

```
# create two vectors for lower ci values and upper ci values respectively
lower = c(low_adj, low_unadj)
upper = c(up_adj, up_unadj)

# create vector that is used for facetting i.e. for assigning the correct values to each plot
plot_nr = rep(c("Adjusted CI", "Unadjusted CI"), each = k)

# create data frame for ggplot: comparison of ci
ci_plot_data = data.frame(plot_nr, rbind(MeFlm, MeFlm), lower, upper)

# create plot with adjusted ci values
ci_plot = ggplot(data = ci_plot_data, aes(Me, Flm)) + geom_point(size = 2) +
        geom_errorbar(aes(ymax = upper, ymin = lower), width = 0.1) + facet_grid(~plot_nr) +
        labs(x = "Condition", y = "Value", title =
        "Comparison of adjusted and unadjusted (standard) confidence intervals") + theme_bw() +
```

```
theme(panel.grid.major = element_blank(), panel.grid.minor = element_blank(),
legend.key = element_rect(colour = "black"), plot.title =
element_text(face="bold", hjust = .5))
```

The function will eventually create this plot and return the table with the adjusted and unadjusted confidence intervals.

```
if (print_plot == TRUE){
        print(ci_plot)}
return(list(confidence_intervals = data.frame(adjusted_CI = lu_adj_CI,
        unadjusted_CI = lu_unadj_CI), ci_plot = ci_plot))
```

As expected the application of this function on the Ringelmann-data revealed that the adjusted confidence regions become narrower then there unadjusted counterpart.

Plot

An important remark is that these confidence intervals should not be used to assess whether the sphericity assumption is violated as pointed out by Franz and Loftus (2012). The issues regarding sphericity will be discussed later on in greater detail.

Literature

Cousineau, D. (2005). Confidence intervals in withinsubjects designs: A simpler solution to Loftus and Masson's method. *Tutorials in Quantitative Methods for Psychology*, 1(1), 42-45.

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