

Open-visualizations tutorial for repeated measures in R

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January 26, 2021

Background

This tutorial is partly inspired by work from [Allen et al. \(2019\)](#) and was initially created to contribute to a GitHub repository called ‘[open-visualizations](#)’. The idea behind the ‘[open-visualizations](#)’ repository stems from the fact that (open) science - in general - lacks ‘fully’ transparent and robust visualizations, i.e., figures have always some form of ‘hidden-data’. To overcome this issue, I started experimenting with some code in Python and R and after posting a [Tweet](#), in which I stated that I was working on ‘[open-visualizations](#)’, Neuroscientist Micah Allen [replied](#) and advised me to check out his work on Rainclouds. After performing two of their tutorials, in [R](#) and [Python](#) respectively, I thought of a way to combine the raincloud approach with my own work performed in [Python](#). Shortly after posting another [Tweet](#), which included some figures that I produced in [R](#), I received a huge amount of encouraging feedback which led me to writing this markdown document. Next to this markdown document, I have created two other tutorials in Python. Both tutorials are available in my repository [open-visualizations](#).

If you have any questions, suggestions for improvement or identify bugs, please open an issue in the GitHub repository [open-visualizations](#).

If you use my repository for your research, please reference it.

R-version check

```
R.version$version.string
```

```
## [1] "R version 4.0.3 (2020-10-10)"
```

Package dependencies

Make sure you have the packages that are needed for this tutorial.

- Install **plyr** before **dplyr**. If you need functions from both **plyr** and **dplyr**, please load **plyr** first, then **dplyr**, otherwise error messages might occur (source: R console). **Rmisc** also depends on this package.
- Install **lattice** since **Rmisc** depends on this package.
- Install **ggplot2**, **dplyr**, and **readr**.
- Install **rmarkdown** to convert this .Rmd template into a variety of formats including HTML, MS Word, PDF, and Beamer (Only required if you do not work in Rstudio).
- Install **Rmisc** to perform some basic statistical computations (e.g., calculate mean, median, sd, se, ci).
- Install **gghalves** from their GitHub repository since it features the newest options as opposed to the version on CRAN. To install from GitHub, the **devtools** package needs to be installed first. **gghalves** is a **ggplot2** extension for easy plotting of half-half geom combinations. Think half boxplot and half jitterplot, or half violinplot and half dotplot.

Package references

- `plyr` - [Wickham, 2019](#)
- `lattice` - [Sarkar, 2019](#)
- `rmarkdown` - [Allaire & Xie, 2020](#)
- `ggplot2` - [Wickham et al., 2020](#)
- `dplyr` - [Wickham et al., 2020](#)
- `readr` - [Wickham et al., 2020](#)
- `Rmisc` - [Hope, 2013](#)
- `devtools` - [Wickham & Hester, 2020](#)
- `gghalves` - [Tiedemann, 2020](#)

Install packages

```
packages <- c("plyr", "lattice", "ggplot2", "dplyr", "readr", "rmarkdown", "Rmisc")
if (length(setdiff(packages, rownames(installed.packages()))) > 0) {
  install.packages(setdiff(packages, rownames(installed.packages())))
}
if (!require(devtools)) {
  install.packages("devtools")
}
devtools::install_github('erocoar/gghalves')
```

Load packages

```
library("plyr")
library("lattice")
library("ggplot2")
library("dplyr")
library("readr")
library("rmarkdown")
library("Rmisc")
library("devtools")
library("gghalves")
# width and height variables for saved plots
w = 6
h = 4
# Define limits of y-axis
y_lim_min = 4
y_lim_max = 7.5
# Make the figure folder if it doesn't exist yet
dir.create('../tutorial_R/figs_repmes/', showWarnings = FALSE)
save_image = FALSE
```

For this tutorial, we make use of the package `gghalves`.

The main idea behind `gghalves` is that standard `geom`'s aggregate data e.g., `geom_boxplot`, `geom_violin` and `geom_dotplot` who all tend to be an approximation of symmetry. Given that the space to display information is limited, we can make better use of it by cutting the `geoms` in half and displaying additional `geoms` that e.g. give information about the sample size [Tiedemann, 2020](#).

Figure 1

For this example, we make use of the *iris* dataset, which is freely available in R.

We manipulate the dataset by creating two variables (1) **before** and (2) **after**. Specify the variable **n** and create a dataframe **d** which includes the variables **y**, **x** and **id**.

```
before = iris$Sepal.Length[1:50]
after = iris$Sepal.Length[51:100]
n <- length(before)
d <- data.frame(y = c(before, after),
               x = rep(c(1,2), each=n),
               id = factor(rep(1:n,2)))
```

Let's create a first very basic figure only showing the individual datapoints.

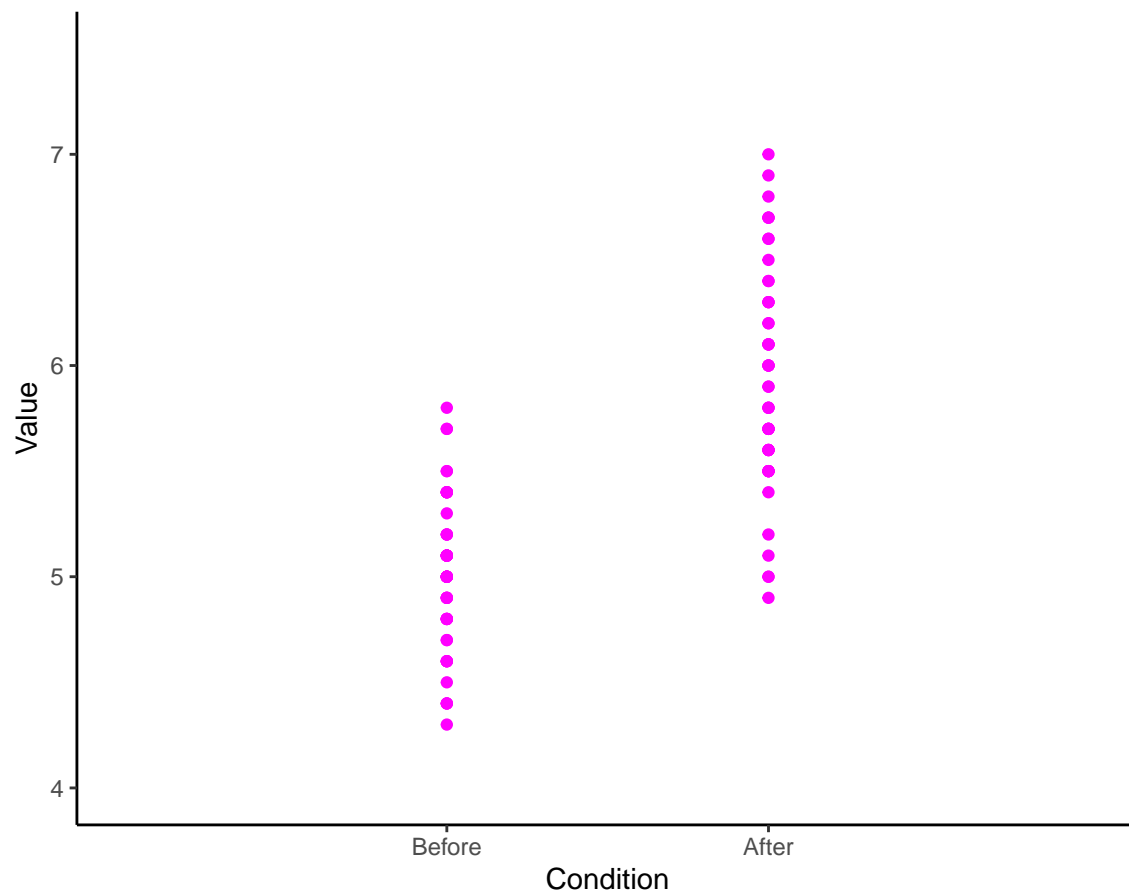
```
f1 <- ggplot(data=d, aes(y=y)) +

  #Add geom_() objects
  geom_point(aes(x=x), color = "magenta", size = 1.5) +

  #Define additional settings
  scale_x_continuous(breaks=c(1,2), labels=c("Before", "After"), limits=c(0, 3)) +
  xlab("Condition") + ylab("Value") +
  ggtitle('Figure 1: Repeated measures individual datapoints') +
  theme_classic() +
  coord_cartesian(ylim=c(y_lim_min, y_lim_max))

f1
```

Figure 1: Repeated measures individual datapoints



```
if (save_image == TRUE) {
  ggsave('../tutorial_R/figs_repmes/figure1.png', width = w, height = h, dpi = 150, units = 'in')
}
```

Figure 2

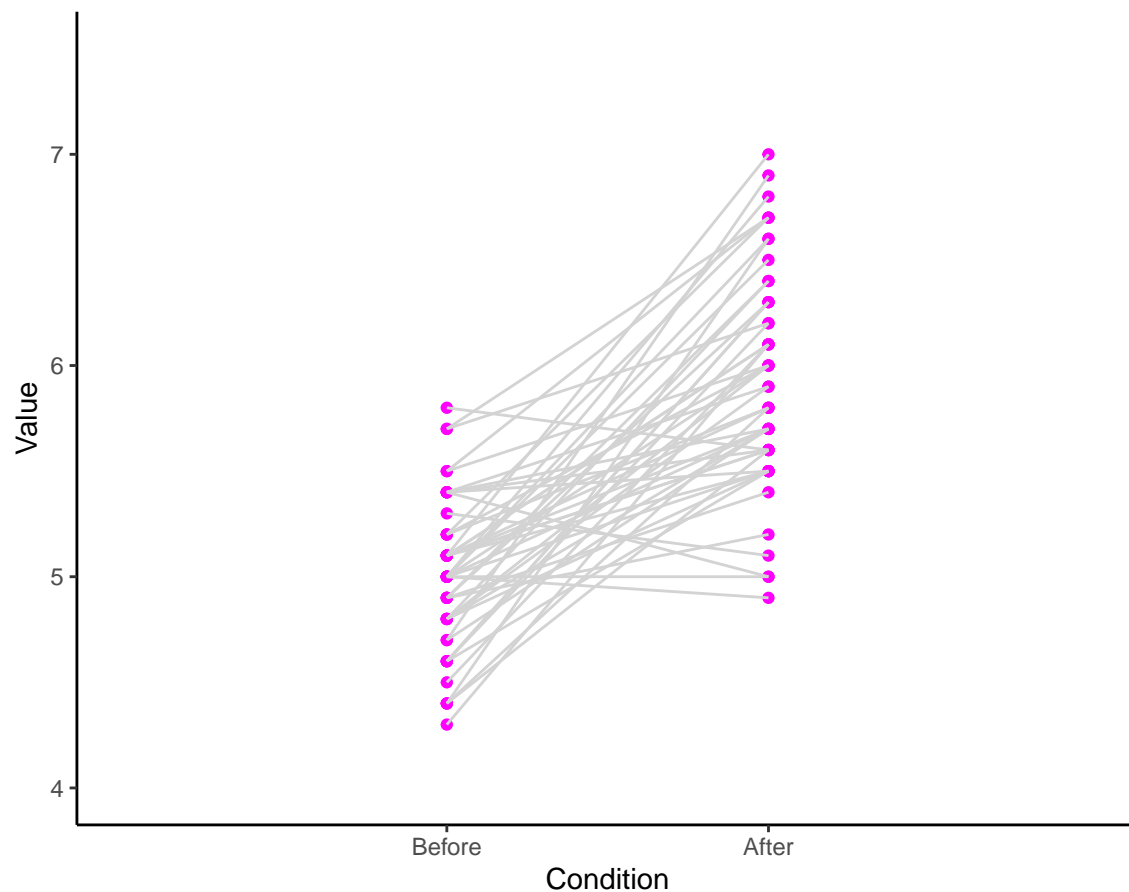
Let's again create a simple figure, but now with the datapoints connected (i.e., intra-individual trends).

```
f2 <- ggplot(data=d, aes(y=y)) +

  #Add geom_() objects
  geom_point(aes(x=x), color = "magenta", size = 1.5) +
  geom_line(aes(x=x, group=id), color = 'lightgray') +

  #Define additional settings
  scale_x_continuous(breaks=c(1,2), labels=c("Before", "After"), limits=c(0, 3)) +
  xlab("Condition") + ylab("Value") +
  ggtitle('Figure 2: Repeated measures with connecting lines') +
  theme_classic()+
  coord_cartesian(ylim=c(y_lim_min, y_lim_max))
f2
```

Figure 2: Repeated measures with connecting lines



```
if (save_image == TRUE) {  
  ggsave('../tutorial_R/figs_repmes/figure2.png', width = w, height = h)  
}
```

Figure 3

Let's add some jitter to avoid that datapoints overlap.

```
set.seed(321)  
d$xj <- jitter(d$x, amount=.09)
```

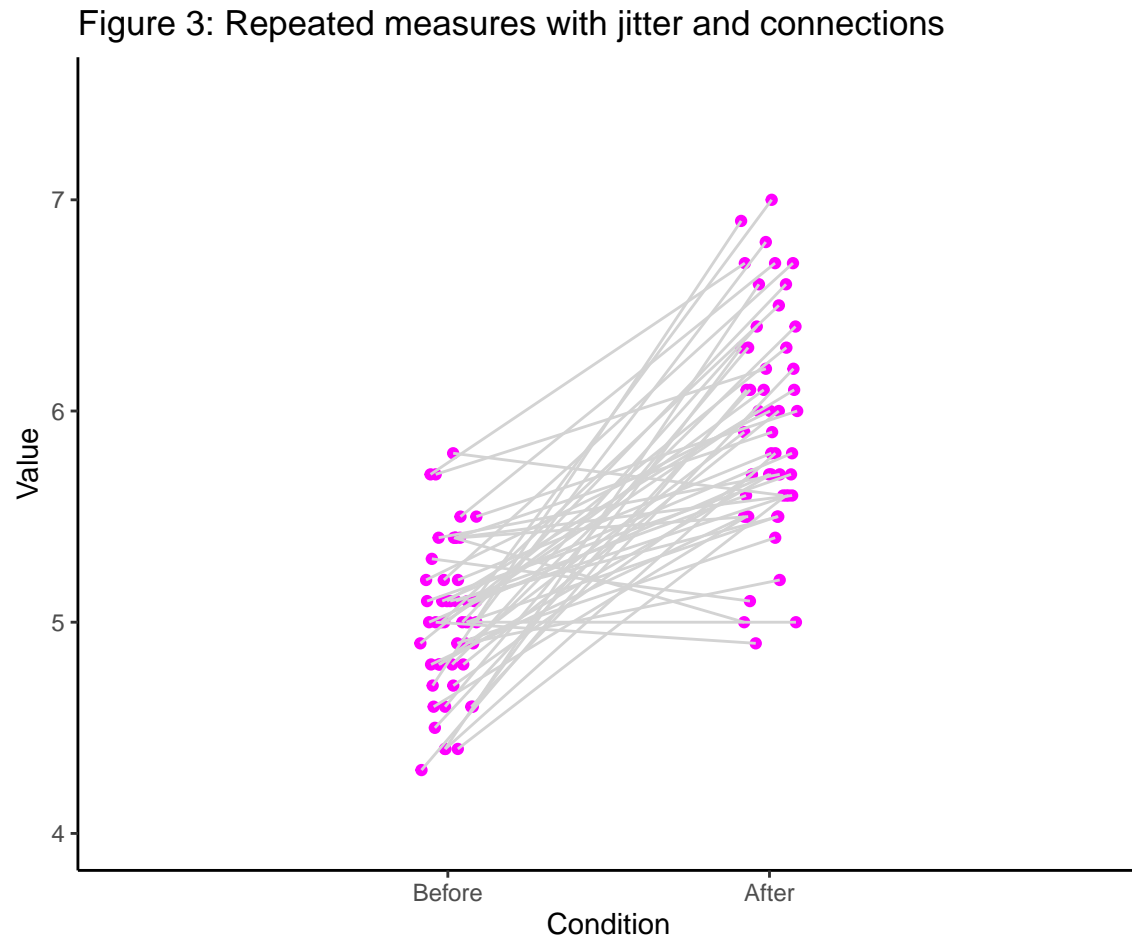
Now we create the the figure again, including jitter.

```
f3 <- ggplot(data=d, aes(y=y)) +  
  
  #Add geom_() objects  
  geom_point(aes(x=xj), color = "magenta", size = 1.5) +  
  geom_line(aes(x=xj, group=id), color = 'lightgray') +  
  
  #Define additional settings  
  scale_x_continuous(breaks=c(1,2), labels=c("Before", "After"), limits=c(0, 3)) +
```

```

xlab("Condition") + ylab("Value") +
ggtitle('Figure 3: Repeated measures with jitter and connections') +
theme_classic()+
coord_cartesian(ylim=c(y_lim_min, y_lim_max))
f3

```



```

if (save_image == TRUE) {
ggsave('../tutorial_R/figs_repmes/figure3.png', width = w, height = h)
}

```

Figure 4

Produce another figure, but now defined by different colors for Before and After. Just for illustrative purposes, `alpha` was used in `geom_line`.

```

f4 <- ggplot(data=d, aes(y=y)) +

  #Add geom_() objects
  geom_point(data = d %>% filter(x=="1"), aes(x=xj), color = 'dodgerblue', size = 1.5,
            alpha = .6) +
  geom_point(data = d %>% filter(x=="2"), aes(x=xj), color = 'darkorange', size = 1.5,

```

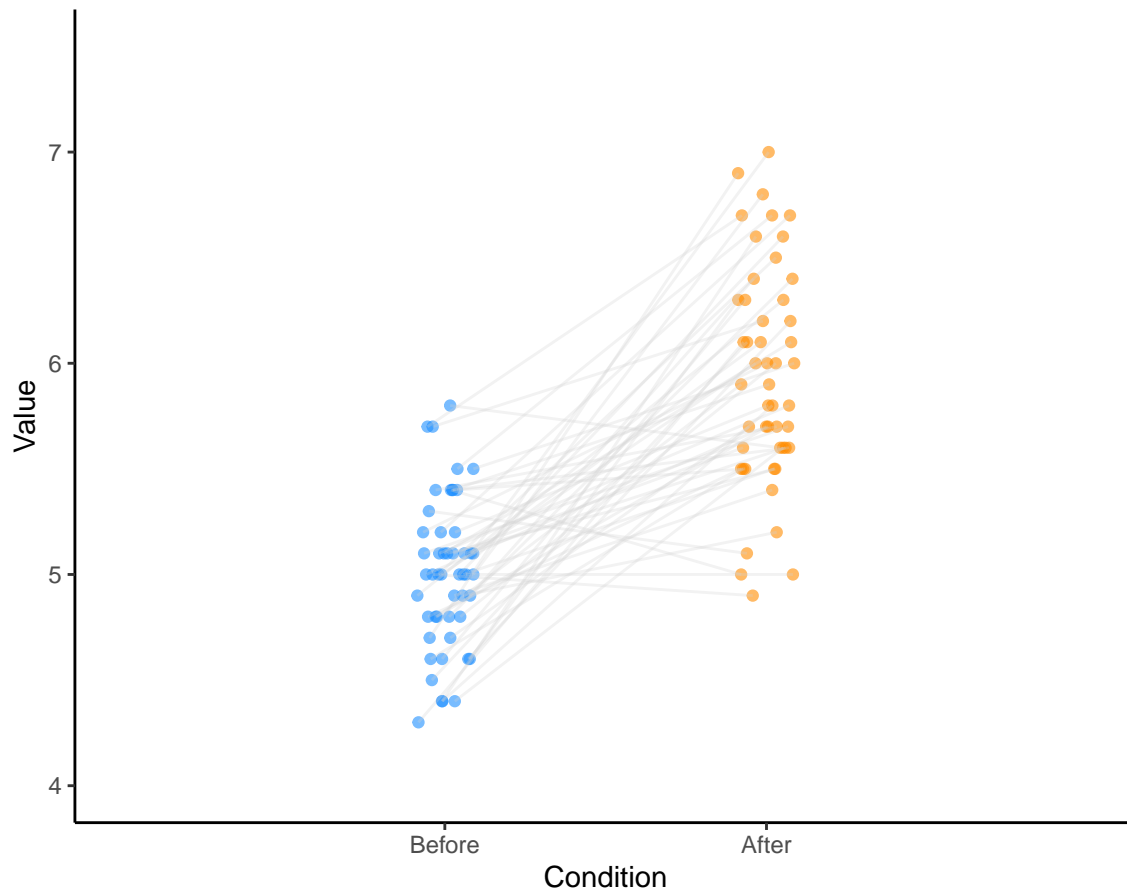
```

      alpha = .6) +
geom_line(aes(x=xj, group=id), color = 'lightgray', alpha = .3) +

#Define additional settings
scale_x_continuous(breaks=c(1,2), labels=c("Before", "After"), limits=c(0, 3)) +
xlab("Condition") + ylab("Value") +
ggtitle('Figure 4: Repeated measures with jittered datapoints and connections') +
theme_classic()+
coord_cartesian(ylim=c(y_lim_min, y_lim_max))
f4

```

Figure 4: Repeated measures with jittered datapoints and connections



```

if (save_image == TRUE) {
ggsave('../tutorial_R/figs_repmes/figure4.png', width = w, height = h)
}

```

Figure 5

Let's add box- and violinplots to create `raincloud` like plots.

```

f5 <- ggplot(data = d, aes(y = y)) +

```

```

#Add geom_() objects
geom_point(data = d %>% filter(x=="1"), aes(x = xj), color = 'dodgerblue', size = 1.5,
           alpha = .6) +
geom_point(data = d %>% filter(x=="2"), aes(x = xj), color = 'darkorange', size = 1.5,
           alpha = .6) +
geom_line(aes(x = xj, group = id), color = 'lightgray', alpha = .3) +

geom_half_boxplot(
  data = d %>% filter(x=="1"), aes(x=x, y = y), position = position_nudge(x = -.25),
  side = "r", outlier.shape = NA, center = TRUE, errorbar.draw = FALSE, width = .2,
  fill = 'dodgerblue') +

geom_half_boxplot(
  data = d %>% filter(x=="2"), aes(x=x, y = y), position = position_nudge(x = .15),
  side = "r", outlier.shape = NA, center = TRUE, errorbar.draw = FALSE, width = .2,
  fill = 'darkorange') +

geom_half_violin(
  data = d %>% filter(x=="1"), aes(x = x, y = y), position = position_nudge(x = -.3),
  side = "l", fill = 'dodgerblue') +

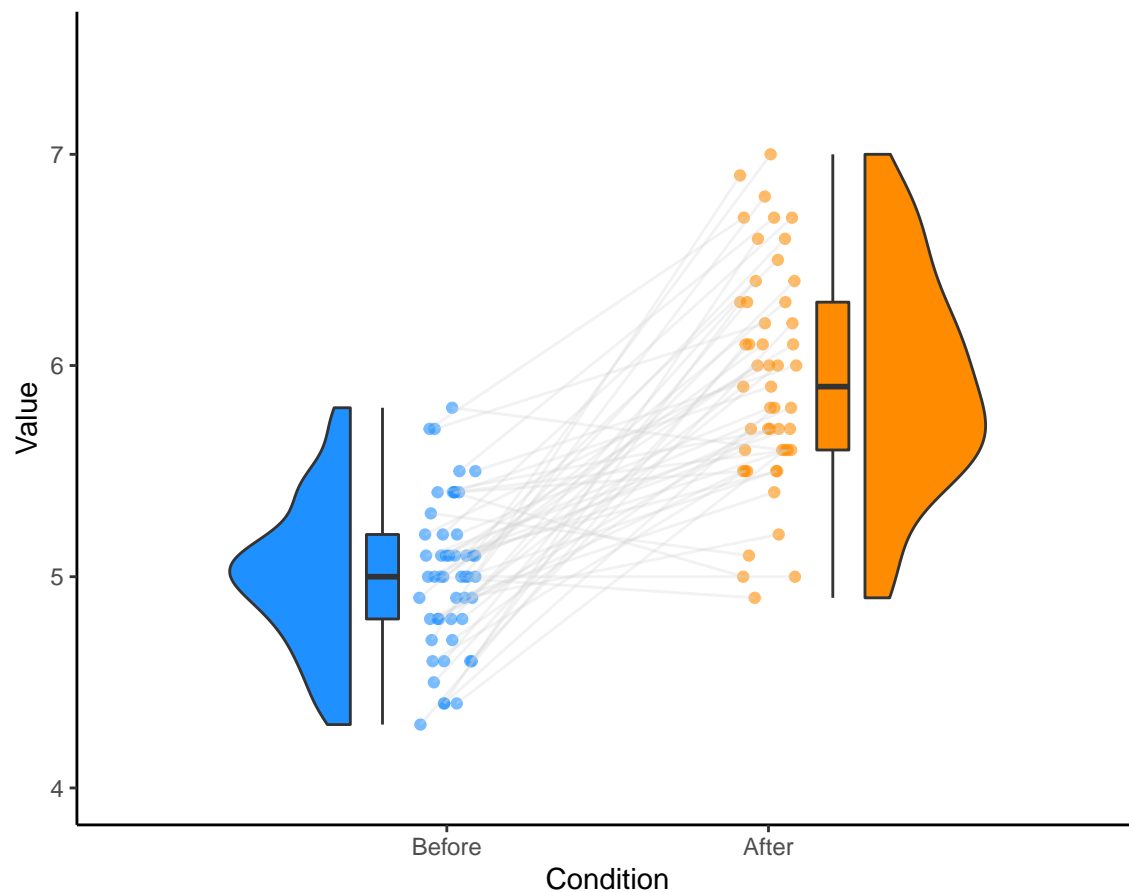
geom_half_violin(
  data = d %>% filter(x=="2"), aes(x = x, y = y), position = position_nudge(x = .3),
  side = "r", fill = "darkorange") +

#Define additional settings
scale_x_continuous(breaks=c(1,2), labels=c("Before", "After"), limits=c(0, 3)) +
xlab("Condition") + ylab("Value") +
ggtitle('Figure 5: Repeated measures with box- and violin plots') +
theme_classic()+
coord_cartesian(ylim=c(y_lim_min, y_lim_max))

```

f5

Figure 5: Repeated measures with box- and violin plots



```
if (save_image == TRUE) {
  ggsave('../tutorial_R/figs_repmes/figure5.png', width = w, height = h)
}
```

Figure 5b

```
f5b <- ggplot(data = d, aes(y = y)) +

  #Add geom_() objects
  geom_point(data = d %>% filter(x == "1"), aes(x = xj), color = 'dodgerblue', size = 1.5,
            alpha = .5) +
  geom_point(data = d %>% filter(x == "2"), aes(x = xj), color = 'darkorange', size = 1.5,
            alpha = .5) +
  geom_line(aes(x = xj, group = id), color = 'lightgray', alpha = .5) +

  geom_half_boxplot(
    data = d %>% filter(x == "1"), aes(x = x, y = y), position = position_nudge(x = -.25),
    side = "r", outlier.shape = NA, center = TRUE, errorbar.draw = TRUE, width = .1,
    fill = 'dodgerblue', alpha = .5) +

  geom_half_boxplot(
```

```

data = d %>% filter(x=="2"), aes(x=x, y = y), position = position_nudge(x = .15),
side = "r", outlier.shape = NA, center = TRUE, errorbar.draw = TRUE, width = .1,
fill = 'darkorange', alpha = .5) +

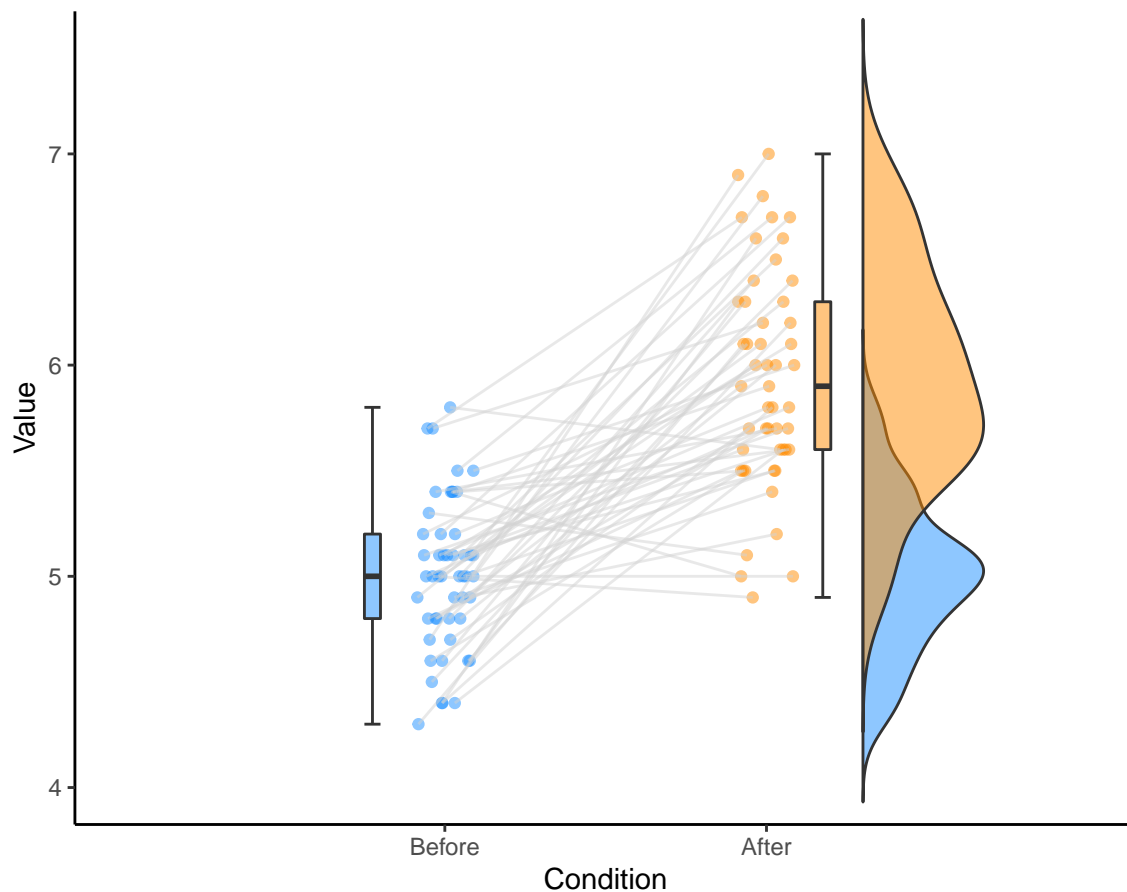
geom_half_violin(
  data = d %>% filter(x=="1"), aes(x = x, y = y), position = position_nudge(x = 1.3),
  side = "r", fill = 'dodgerblue', alpha = .5, trim = FALSE) +

geom_half_violin(
  data = d %>% filter(x=="2"), aes(x = x, y = y), position = position_nudge(x = .3),
  side = "r", fill = "darkorange", alpha = .5, trim = FALSE) +

#Define additional settings
scale_x_continuous(breaks=c(1,2), labels=c("Before", "After"), limits=c(0, 3)) +
xlab("Condition") + ylab("Value") +
ggtitle('Figure 5b: Repeated measures with box- and violin plots') +
theme_classic()+
coord_cartesian(ylim=c(y_lim_min, y_lim_max))
f5b

```

Figure 5b: Repeated measures with box- and violin plots



```

if (save_image == TRUE) {
  ggsave('../tutorial_R/figs_repmes/figure5b.png', width = w, height = h)
}

```

```

f5c <- ggplot(data = d, aes(y = y)) +

  #Add geom_() objects
  geom_point(data = d %>% filter(x=="1"), aes(x = xj), color = 'dodgerblue', size = 1.5,
    alpha = .5) +
  geom_point(data = d %>% filter(x=="2"), aes(x = xj), color = 'darkorange', size = 1.5,
    alpha = .5) +
  geom_line(aes(x = xj, group = id), color = 'lightgray', alpha = .5) +

  geom_half_boxplot(
    data = d %>% filter(x=="1"), aes(x=x, y = y), position = position_nudge(x = 1.21),
    side = "r", outlier.shape = NA, center = TRUE, errorbar.draw = TRUE, width = .1,
    fill = 'dodgerblue', alpha = .5) +

  geom_half_boxplot(
    data = d %>% filter(x=="2"), aes(x=x, y = y), position = position_nudge(x = .15),
    side = "r", outlier.shape = NA, center = TRUE, errorbar.draw = TRUE, width = .1,
    fill = 'darkorange', alpha = .5) +

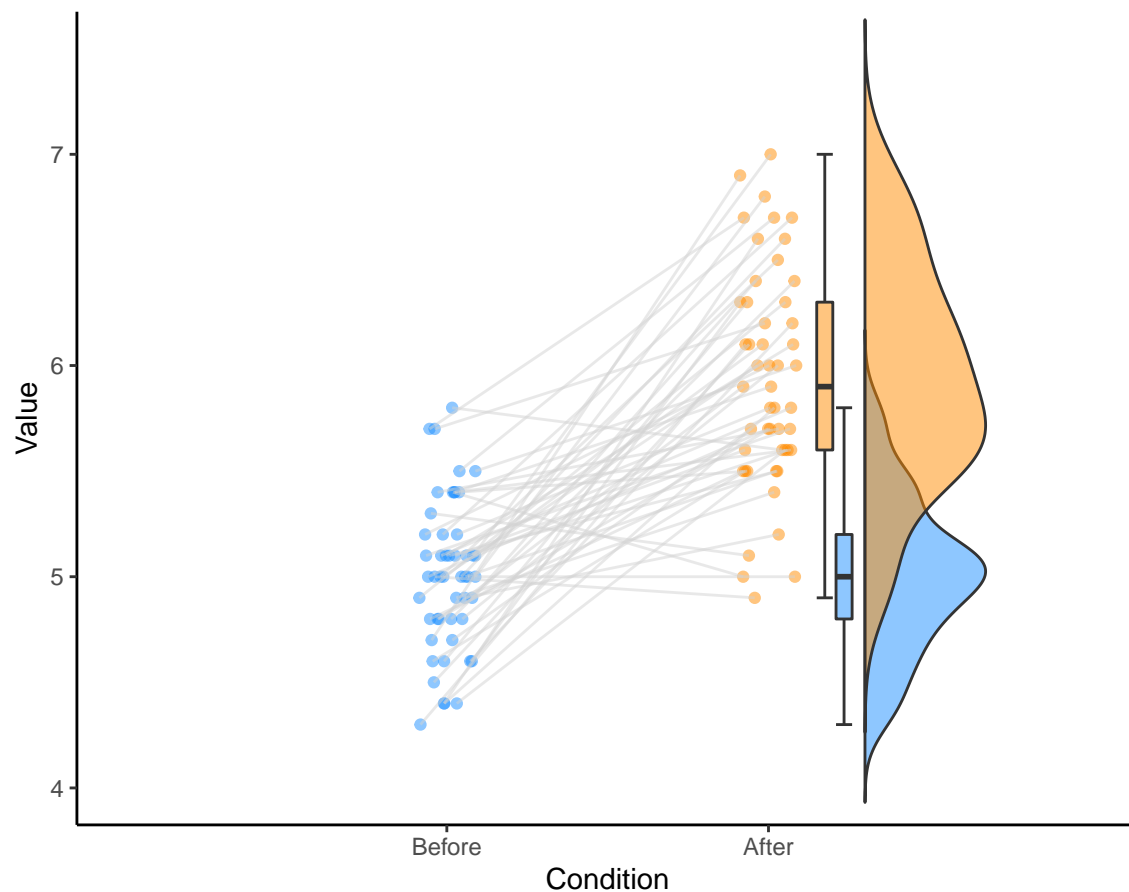
  geom_half_violin(
    data = d %>% filter(x=="1"), aes(x = x, y = y), position = position_nudge(x = 1.3),
    side = "r", fill = 'dodgerblue', alpha = .5, trim = FALSE) +

  geom_half_violin(
    data = d %>% filter(x=="2"), aes(x = x, y = y), position = position_nudge(x = .3),
    side = "r", fill = "darkorange", alpha = .5, trim = FALSE) +

  #Define additional settings
  scale_x_continuous(breaks=c(1,2), labels=c("Before", "After"), limits=c(0, 3)) +
  xlab("Condition") + ylab("Value") +
  ggtitle('Figure 5c: Repeated measures with box- and violin plots') +
  theme_classic()+
  coord_cartesian(ylim=c(y_lim_min, y_lim_max))
f5c

```

Figure 5c: Repeated measures with box- and violin plots



```
if (save_image == TRUE) {  
  ggsave('../tutorial_R/figs_repmes/figure5c.png', width = w, height = h)  
}
```

Note

A potential downside of the current approach is that it uses a lot of filtering and a lot of `geoms`.

Add descriptive statistics

- Create a dataframe including:
- Mean
- Median
- Standard deviation
- Standard error
- Confidence interval (95 %)

```
score_mean_1 <- mean(d$y[1:50])  
score_mean_2 <- mean(d$y[51:100])  
score_median1 <- median(d$y[1:50])
```

```

score_median2 <- median(d$y[51:100])
score_sd_1 <- sd(d$y[1:50])
score_sd_2 <- sd(d$y[51:100])
score_se_1 <- score_sd_1/sqrt(n) #-> adjust your n
score_se_2 <- score_sd_2/sqrt(n) #-> adjust your n
score_ci_1 <- CI(d$y[1:50], ci = 0.95)
score_ci_2 <- CI(d$y[51:100], ci = 0.95)
#Create data frame with 2 rows and 7 columns containing the descriptives
group <- c("x", "z")
N <- c(50, 50)
score_mean <- c(score_mean_1, score_mean_2)
score_median <- c(score_median1, score_median2)
sd <- c(score_sd_1, score_sd_2)
se <- c(score_se_1, score_se_2)
ci <- c((score_ci_1[1] - score_ci_1[3]), (score_ci_2[1] - score_ci_2[3]))
#Create the dataframe
summary_df <- data.frame(group, N, score_mean, score_median, sd, se, ci)

```

Figure 6

Let's add the items calculated in `summary_df` to the figure

```

f6 <- ggplot(data = d, aes(y = y)) +

  #Add geom() objects
  geom_point(data = d %>% filter(x == "1"), aes(x = xj), color = 'dodgerblue', size = 1.5,
    alpha = .6) +
  geom_point(data = d %>% filter(x == "2"), aes(x = xj), color = 'darkorange', size = 1.5,
    alpha = .6) +
  geom_line(aes(x = xj, group = id), color = 'lightgray', alpha = .3) +

  geom_half_boxplot(
    data = d %>% filter(x=="1"), aes(x=x, y = y), position = position_nudge(x = -.28),
    side = "r", outlier.shape = NA, center = TRUE, errorbar.draw = FALSE, width = .2,
    fill = 'dodgerblue') +

  geom_half_boxplot(
    data = d %>% filter(x=="2"), aes(x=x, y = y), position = position_nudge(x = .18),
    side = "r", outlier.shape = NA, center = TRUE, errorbar.draw = FALSE, width = .2,
    fill = 'darkorange') +

  geom_half_violin(
    data = d %>% filter(x=="1"), aes(x = x, y = y), position = position_nudge(x = -.3),
    side = "l", fill = 'dodgerblue') +

  geom_half_violin(
    data = d %>% filter(x=="2"), aes(x = x, y = y), position = position_nudge(x = .3),
    side = "r", fill = "darkorange") +

  geom_point(data = d %>% filter(x=="1"), aes(x = x, y = score_mean[1]),
    position = position_nudge(x = -.13), color = "dodgerblue", alpha = .6, size = 1.5) +

```

```

geom_errorbar(data = d %>% filter(x=="1"), aes(x = x, y = score_mean[1],
  ymin = score_ci_1[3], ymax = score_ci_1[1]),
  position = position_nudge(-.13),
  color = "dodgerblue", width = 0.05, size = 0.4, alpha = .5) +

geom_point(data = d %>% filter(x=="2"), aes(x = x, y = score_mean[2]),
  position = position_nudge(x = .13), color = "darkorange", alpha = .6, size = 1.5)+

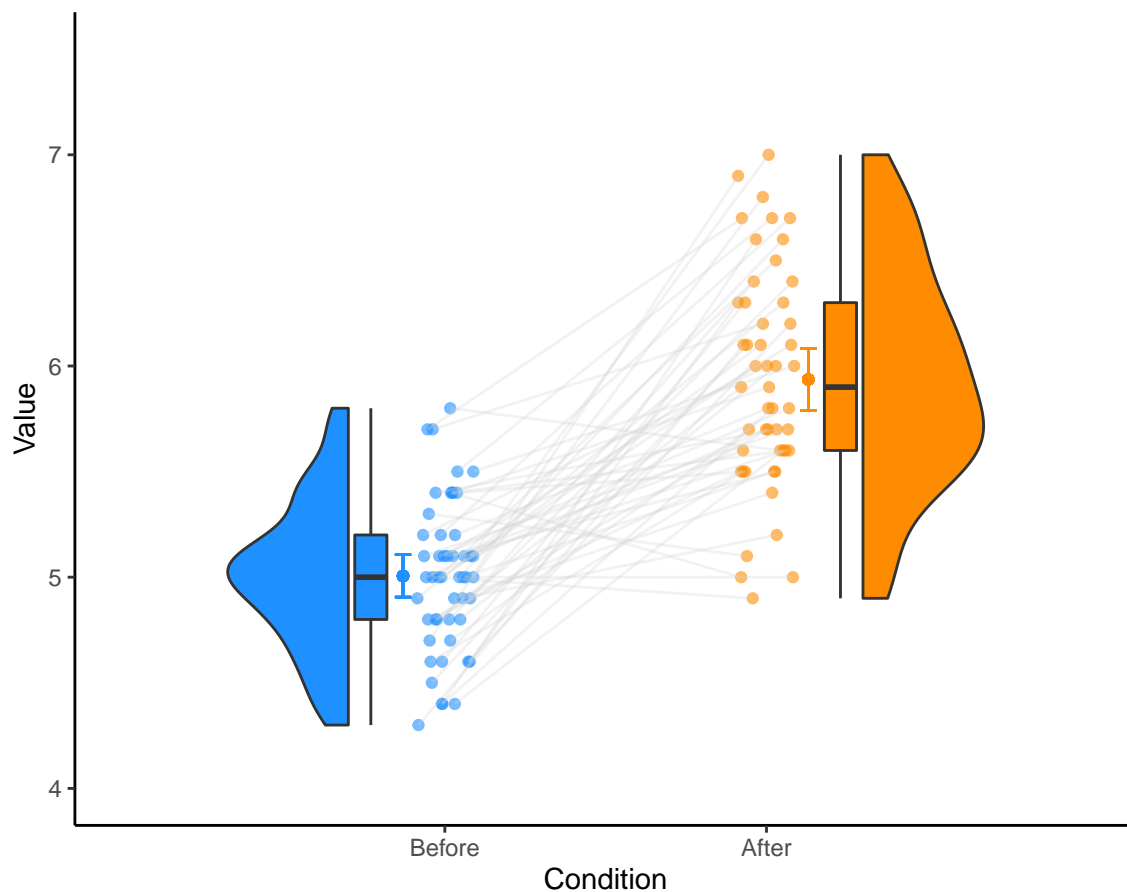
geom_errorbar(data = d %>% filter(x=="2"), aes(x = x, y = score_mean[2],
  ymin = score_ci_2[3],
  ymax = score_ci_2[1]), position = position_nudge(.13), color = "darkorange",
  width = 0.05, size = 0.4, alpha = .5) +

#Define additional settings
scale_x_continuous(breaks=c(1,2), labels=c("Before", "After"), limits=c(0, 3)) +
xlab("Condition") + ylab("Value") +
ggtitle('Figure 6: Repeated measures with box- and violin plots') +
theme_classic()+
coord_cartesian(ylim=c(y_lim_min, y_lim_max))

```

f6

Figure 6: Repeated measures with box- and violin plots



```

if (save_image == TRUE) {
  ggsave('../tutorial_R/figs_repmes/figure6.png', width = w, height = h)
}

```

Figure 7

Optionally you could add a line between the two means. Define the x-coordinates where the line needs to be drawn. Note these coordinates can be calculated as $1 - \text{position_nudge}()$ for the first variable and $2 + \text{position_nudge}()$ for the second variable, which in our case is $1 - .13 = .87$ and $2 + .13 = 2.13$.

```

x_tick_means <- c(.87, 2.13)
f7 <- ggplot(data = d, aes(y = y)) +

  #Add geom_() objects
  geom_point(data = d %>% filter(x == "1"), aes(x = xj), color = 'dodgerblue', size = 1.5,
    alpha = .6) +
  geom_point(data = d %>% filter(x == "2"), aes(x = xj), color = 'darkorange', size = 1.5,
    alpha = .6) +
  geom_line(aes(x = xj, group = id), color = 'lightgray', alpha = .3) +

  geom_half_boxplot(
    data = d %>% filter(x=="1"), aes(x=x, y = y), position = position_nudge(x = -.28),
    side = "r", outlier.shape = NA, center = TRUE, errorbar.draw = FALSE, width = .2,
    fill = 'dodgerblue') +

  geom_half_boxplot(
    data = d %>% filter(x=="2"), aes(x=x, y = y), position = position_nudge(x = .18),
    side = "r", outlier.shape = NA, center = TRUE, errorbar.draw = FALSE, width = .2,
    fill = 'darkorange') +

  geom_half_violin(
    data = d %>% filter(x=="1"), aes(x = x, y = y), position = position_nudge(x = -.3),
    side = "l", fill = 'dodgerblue') +

  geom_half_violin(
    data = d %>% filter(x=="2"), aes(x = x, y = y), position = position_nudge(x = .3),
    side = "r", fill = "darkorange") +

  geom_point(data = d %>% filter(x=="1"), aes(x = x, y = score_mean[1]),
    position = position_nudge(x = -.13), color = "dodgerblue", alpha = .6, size = 1.5) +

  geom_errorbar(data = d %>% filter(x=="1"), aes(x = x, y = score_mean[1],
    ymin = score_ci_1[3], ymax = score_ci_1[1]),
    position = position_nudge(-.13),
    color = "dodgerblue", width = 0.05, size = 0.4, alpha = .6) +

  geom_point(data = d %>% filter(x=="2"), aes(x = x, y = score_mean[2]),
    position = position_nudge(x = .13), color = "darkorange", alpha = .6, size = 1.5)+

  geom_errorbar(data = d %>% filter(x=="2"), aes(x = x, y = score_mean[2],
    ymin = score_ci_2[3],
    ymax = score_ci_2[1]), position = position_nudge(.13), color = "darkorange",

```

```

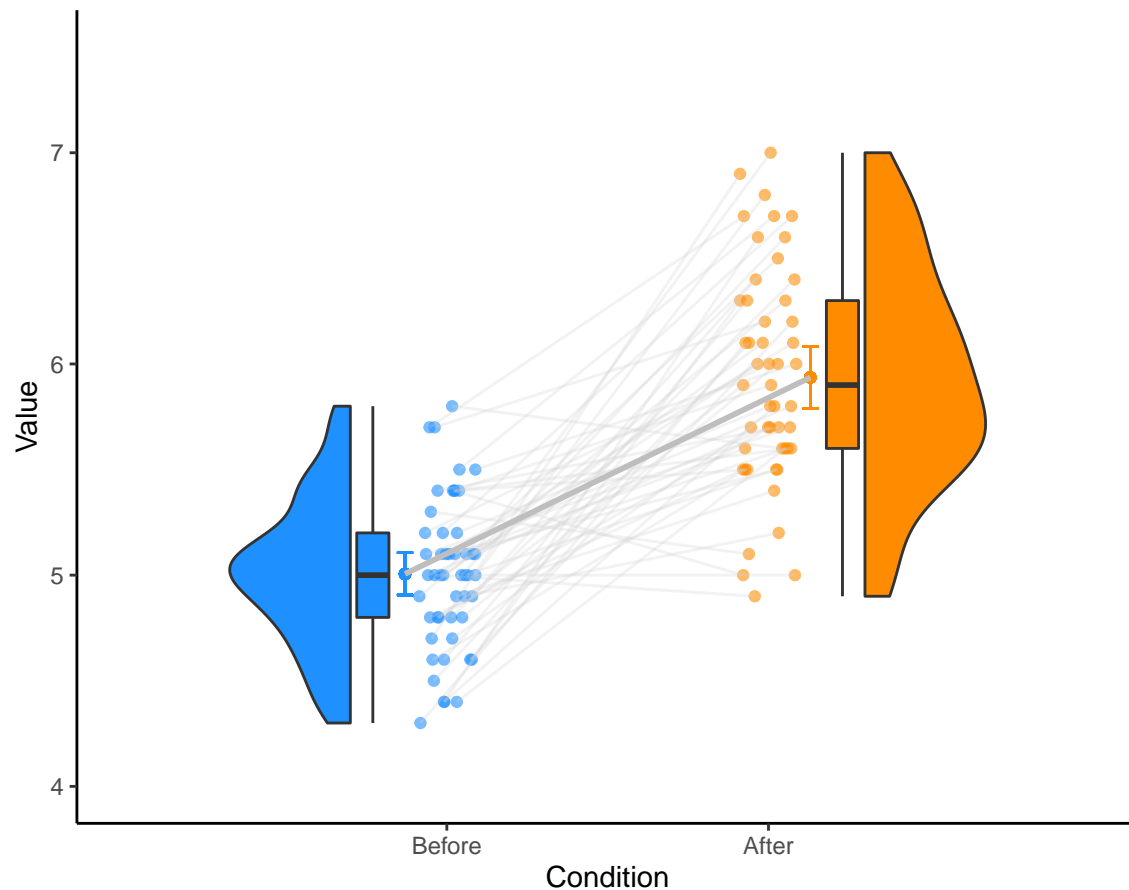
width = 0.05, size = 0.4, alpha = .6) +

#Add a line connecting the two means
geom_line(data = summary_df, aes(x = x_tick_means, y = score_mean), color = 'gray',
size = 1) +

#Define additional settings
scale_x_continuous(breaks=c(1,2), labels=c("Before", "After"), limits=c(0, 3)) +
xlab("Condition") + ylab("Value") +
ggtitle('Figure 7: Repeated measures with box- and violin plots and means + ci ') +
theme_classic()+
coord_cartesian(ylim=c(y_lim_min, y_lim_max))
f7

```

Figure 7: Repeated measures with box- and violin plots and means + ci



```

if (save_image == TRUE) {
ggsave('../tutorial_R/figs_repmes/figure7.png', width = w, height = h)
}

```

2 x 2 repeated measures rainclouds in a #butterfly fashion

As a last step, let's create these figures for a 2 x 2 repeated measures study.

Define an additional variable `z` which has two categories 3 and 4 and create a second jittered variable.

```
before = iris$Sepal.Length[1:50]
after = iris$Sepal.Length[51:100]
n <- length(before)
d <- data.frame(y = c(before, after),
                x = rep(c(1,2), each=n),
                z = rep(c(3,4), each=n),
                id = factor(rep(1:n,2)))
set.seed(321)
d$xj <- jitter(d$x, amount = .09)
d$xj_2 <- jitter(d$z, amount = .09)

f8 <- ggplot(data = d, aes(y = y)) +

  #Add geom_() objects
  geom_point(data = d %>% filter(x == "1"), aes(x = xj), color = 'dodgerblue', size = 1.5,
            alpha = .6) +
  geom_point(data = d %>% filter(x == "2"), aes(x = xj), color = 'darkorange', size = 1.5,
            alpha = .6) +
  geom_point(data = d %>% filter(z == "3"), aes(x = xj_2), color = 'dodgerblue', size = 1.5,
            alpha = .6) +
  geom_point(data = d %>% filter(z == "4"), aes(x = xj_2), color = 'darkorange', size = 1.5,
            alpha = .6) +
  geom_line(aes(x = xj, group = id), color = 'lightgray', alpha = .3) +
  geom_line(aes(x = xj_2, group = id), color = 'lightgray', alpha = .3) +

  geom_half_boxplot(
    data = d %>% filter(x == "1"), aes(x=x, y = y), position = position_nudge(x = -.35),
    side = "r", outlier.shape = NA, center = TRUE, errorbar.draw = FALSE, width = .2,
    fill = 'dodgerblue', alpha = .6) +

  geom_half_boxplot(
    data = d %>% filter(x == "2"), aes(x=x, y = y), position = position_nudge(x = -1.16),
    side = "l", outlier.shape = NA, center = TRUE, errorbar.draw = FALSE, width = .2,
    fill = 'darkorange', alpha = .6) +

  geom_half_boxplot(
    data = d %>% filter(z == "3"), aes(x=z, y = y), position = position_nudge(x = 1.3),
    side = "r", outlier.shape = NA, center = TRUE, errorbar.draw = FALSE, width = .2,
    fill = 'dodgerblue', alpha = .6) +

  geom_half_boxplot(
    data = d %>% filter(z == "4"), aes(x=z, y = y), position = position_nudge(x = .2),
    side = "r", outlier.shape = NA, center = TRUE, errorbar.draw = FALSE, width = .2,
    fill = 'darkorange', alpha = .6) +

  geom_half_violin(
    data = d %>% filter(x == "1"), aes(x = x, y = y), position = position_nudge(x = -.40),
    side = "l", fill = 'dodgerblue', alpha = .6) +

  geom_half_violin(
    data = d %>% filter(x == "2"), aes(x = x, y = y), position = position_nudge(x = -1.40),
    side = "l", fill = 'darkorange', alpha = .6) +
```

```

geom_half_violin(
  data = d %>% filter(z=="3"), aes(x = z, y = y), position = position_nudge(x = 1.45),
  side = "r", fill = 'dodgerblue', alpha = .6) +

geom_half_violin(
  data = d %>% filter(z=="4"), aes(x = z, y = y), position = position_nudge(x = .45),
  side = "r", fill = "darkorange", alpha = .6) +

geom_point(data = d %>% filter(x=="1"), aes(x = x, y = score_mean[1]),
  position = position_nudge(x = -.13), color = "dodgerblue", alpha = .6, size = 1.5) +

geom_errorbar(data = d %>% filter(x=="1"), aes(x = x, y = score_mean[1],
  ymin = score_ci_1[3], ymax = score_ci_1[1]),
  position = position_nudge(-.13),
  color = "dodgerblue", width = 0.05, size = 0.4, alpha = .6) +

geom_point(data = d %>% filter(x=="2"), aes(x = x, y = score_mean[2]),
  position = position_nudge(x = -1.1), color = "darkorange", alpha = .6, size = 1.5)+

geom_errorbar(data = d %>% filter(x=="2"), aes(x = x, y = score_mean[2],
  ymin = score_ci_2[3],
  ymax = score_ci_2[1]), position = position_nudge(x = -1.1), color = "darkorange",
  width = 0.05, size = 0.4, alpha = .6) +
geom_point(data = d %>% filter(z=="3"), aes(x = z, y = score_mean[1]),
  position = position_nudge(x = 1.15), color = "dodgerblue", alpha = .5) +

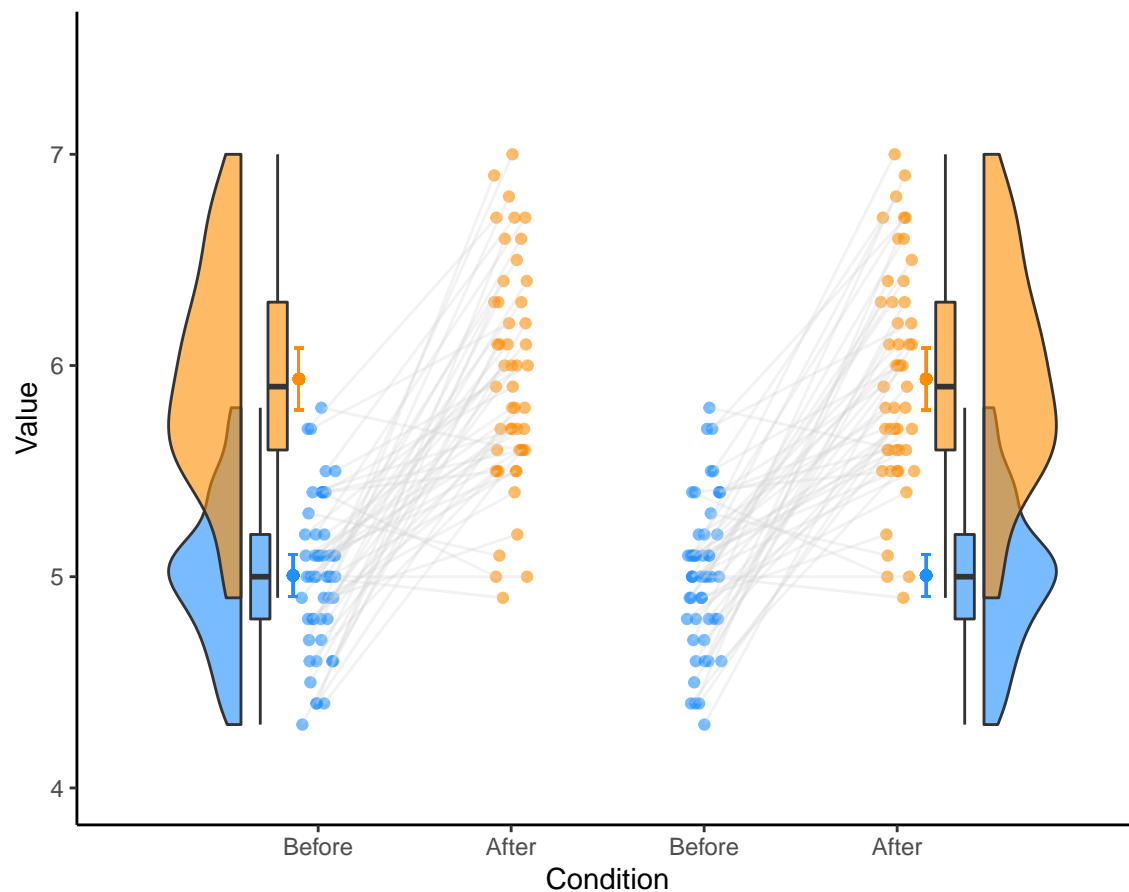
geom_errorbar(data = d %>% filter(z=="3"), aes(x = z, y = score_mean[1],
  ymin = score_ci_1[3],
  ymax = score_ci_1[1]), position = position_nudge(1.15),
  color = "dodgerblue", width = 0.05, size = 0.4, alpha = .5)+
geom_point(data = d %>% filter(z=="4"), aes(x = z, y = score_mean[2]),
  position = position_nudge(x = .15), color = "darkorange", alpha = .5)+
geom_errorbar(data = d %>% filter(z=="4"), aes(x = z, y = score_mean[2],
  ymin = score_ci_2[3], ymax = score_ci_2[1]), position = position_nudge(.15),
  color = "darkorange", width = 0.05, size = 0.4, alpha = .5)+

#Define additional settings
scale_x_continuous(breaks=c(1,2,3,4), labels=c("Before", "After", "Before", "After"),
  limits=c(0, 5))+
xlab("Condition") + ylab("Value") +
ggtitle('Figure 8: 2 x 2 Repeated measures with box- and violin plots') +
theme_classic()+
coord_cartesian(ylim=c(y_lim_min, y_lim_max))

```

f8

Figure 8: 2 x 2 Repeated measures with box- and violin plots



```
if (save_image == TRUE) {
  ggsave('../tutorial_R/figs_repmes/figure8.png', width = w, height = h)
}
```

Figure 9

Finally, let's add lines that connect the means of each group.

```
#First we must again define the x-coordinates of the means.
x_tick_means_x <- c(.87, 2.13) #same as above
x_tick_means_z <- c(2.87, 4.13) #just add 2 for each tick
f9 <- ggplot(data = d, aes(y = y)) +

  #Add geom_() objects
  geom_point(data = d %>% filter(x == "1"), aes(x = xj), color = 'dodgerblue', size = 1.5,
    alpha = .6) +
  geom_point(data = d %>% filter(x == "2"), aes(x = xj), color = 'darkorange', size = 1.5,
    alpha = .6) +
  geom_point(data = d %>% filter(z == "3"), aes(x = xj_2), color = 'dodgerblue', size = 1.5,
    alpha = .6) +
  geom_point(data = d %>% filter(z == "4"), aes(x = xj_2), color = 'darkorange', size = 1.5,
    alpha = .6) +
```

```

geom_line(aes(x = xj, group = id), color = 'lightgray', alpha = .3) +
geom_line(aes(x = xj_2, group = id), color = 'lightgray', alpha = .3) +

geom_half_boxplot(
  data = d %>% filter(x=="1"), aes(x=x, y = y), position = position_nudge(x = -.35),
  side = "r", outlier.shape = NA, center = TRUE, errorbar.draw = FALSE, width = .2,
  fill = 'dodgerblue', alpha = .6) +

geom_half_boxplot(
  data = d %>% filter(x=="2"), aes(x=x, y = y), position = position_nudge(x = -1.16),
  side = "l", outlier.shape = NA, center = TRUE, errorbar.draw = FALSE, width = .2,
  fill = 'darkorange', alpha = .6) +

geom_half_boxplot(
  data = d %>% filter(z=="3"), aes(x=z, y = y), position = position_nudge(x = 1.3),
  side = "r", outlier.shape = NA, center = TRUE, errorbar.draw = FALSE, width = .2,
  fill = 'dodgerblue', alpha = .6) +

geom_half_boxplot(
  data = d %>% filter(z=="4"), aes(x=z, y = y), position = position_nudge(x = .2),
  side = "r", outlier.shape = NA, center = TRUE, errorbar.draw = FALSE, width = .2,
  fill = 'darkorange', alpha = .6) +

geom_half_violin(
  data = d %>% filter(x=="1"), aes(x = x, y = y), position = position_nudge(x = -.40),
  side = "l", fill = 'dodgerblue', alpha = .6) +

geom_half_violin(
  data = d %>% filter(x=="2"), aes(x = x, y = y), position = position_nudge(x = -1.40),
  side = "l", fill = "darkorange", alpha = .6) +

geom_half_violin(
  data = d %>% filter(z=="3"), aes(x = z, y = y), position = position_nudge(x = 1.45),
  side = "r", fill = 'dodgerblue', alpha = .6) +

geom_half_violin(
  data = d %>% filter(z=="4"), aes(x = z, y = y), position = position_nudge(x = .45),
  side = "r", fill = "darkorange", alpha = .6) +

geom_point(data = d %>% filter(x=="1"), aes(x = x, y = score_mean[1]),
  position = position_nudge(x = -.13), color = "dodgerblue", alpha = .6, size = 1.5) +

geom_errorbar(data = d %>% filter(x=="1"), aes(x = x, y = score_mean[1],
  ymin = score_ci_1[3], ymax = score_ci_1[1]),
  position = position_nudge(-.13),
  color = "dodgerblue", width = 0.05, size = 0.4, alpha = .6) +

geom_point(data = d %>% filter(x=="2"), aes(x = x, y = score_mean[2]),
  position = position_nudge(x = .13), color = "darkorange", alpha = .6, size = 1.5) +

geom_errorbar(data = d %>% filter(x=="2"), aes(x = x, y = score_mean[2],
  ymin = score_ci_2[3],
  ymax = score_ci_2[1]), position = position_nudge(x = .13), color = "darkorange",

```

```

width = 0.05, size = 0.4, alpha = .6) +
geom_point(data = d %>% filter(z=="3"), aes(x = z, y = score_mean[1]),
position = position_nudge(x = -.13), color = "dodgerblue", alpha = .5) +

geom_errorbar(data = d %>% filter(z=="3"), aes(x = z, y = score_mean[1],
ymin = score_ci_1[3],
ymax = score_ci_1[1]), position = position_nudge(-.13),
color = "dodgerblue", width = 0.05, size = 0.4, alpha = .5)+
geom_point(data = d %>% filter(z=="4"), aes(x = z, y = score_mean[2]),
position = position_nudge(x = .13), color = "darkorange", alpha = .5)+
geom_errorbar(data = d %>% filter(z=="4"), aes(x = z, y = score_mean[2],
ymin = score_ci_2[3], ymax = score_ci_2[1]),
position = position_nudge(.13),
color = "darkorange", width = 0.05, size = 0.4, alpha = .5)+

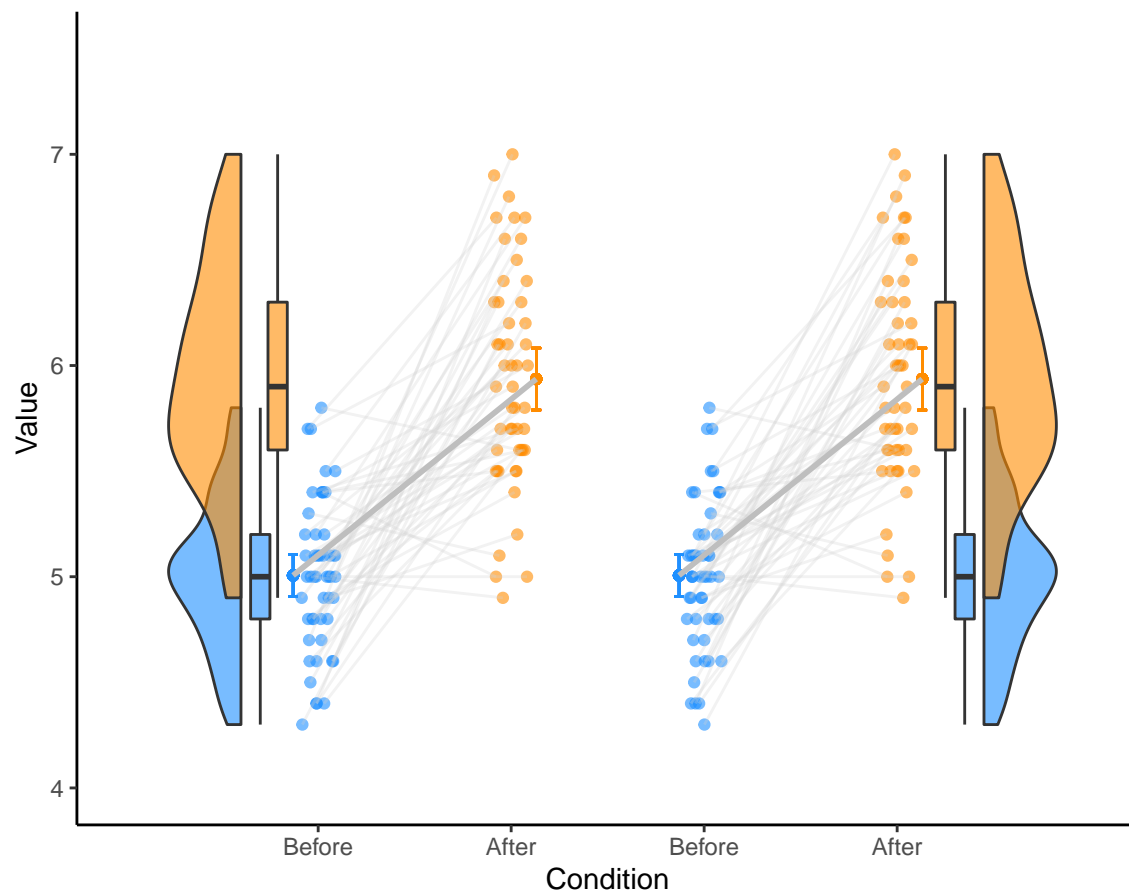
#Add lines connecting the two means
geom_line(data = summary_df, aes(x = x_tick_means_x, y = score_mean),
color = 'gray', size = 1) +
geom_line(data = summary_df, aes(x = x_tick_means_z, y = score_mean),
color = 'gray', size = 1) +

#Define additional settings
scale_x_continuous(breaks=c(1,2,3,4), labels=c("Before", "After","Before", "After"),
limits=c(0, 5))+
xlab("Condition") + ylab("Value") +
ggtitle('Figure 9: 2 x 2 Repeated measures with box- and violin plots') +
theme_classic()+
coord_cartesian(ylim=c(y_lim_min, y_lim_max))

```

f9

Figure 9: 2 x 2 Repeated measures with box- and violin plots



```
if (save_image == TRUE) {
  ggsave('../tutorial_R/figs_repmes/figure9.png', width = w, height = h)
}
```

Figure 10

Here, we add an additional variable 'during' if you want to show the effect measured over 3 timepoints.

```
before = iris$Sepal.Length[1:50]
during = iris$Sepal.Length[51:100]
after = iris$Sepal.Length[1:50]
n <- length(before)
d <- data.frame(y = c(before, during, after),
               x = rep(c(1,2,3), each=n),
               id = factor(rep(1:n,3)))
set.seed(321)
d$xj <- jitter(d$x, amount = .09)
f10 <- ggplot(data=d, aes(y=y)) +
```

```

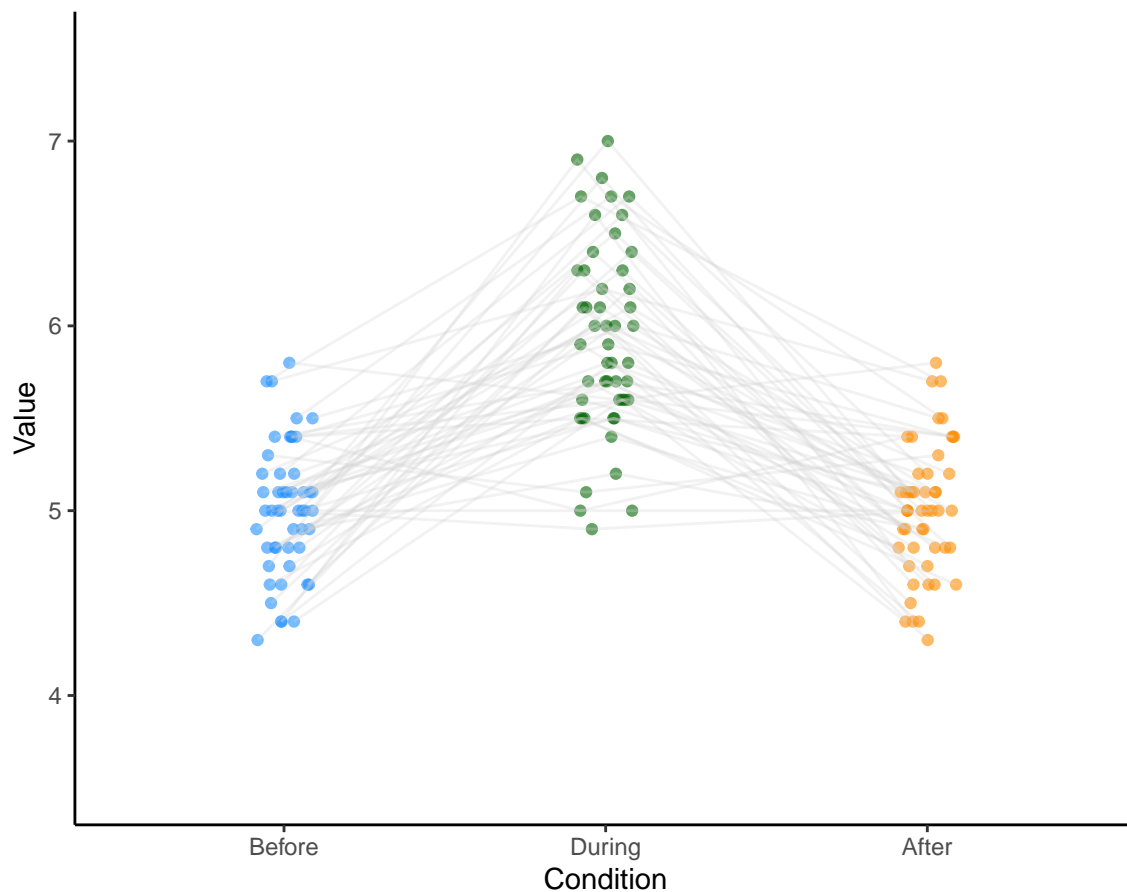
#Add geom_() objects
geom_point(data = d %>% filter(x=="1"), aes(x=xj), color = 'dodgerblue', size = 1.5,
  alpha = .6) +
geom_point(data = d %>% filter(x=="2"), aes(x=xj), color = 'darkgreen', size = 1.5,
  alpha = .6) +
geom_point(data = d %>% filter(x=="3"), aes(x=xj), color = 'darkorange', size = 1.5,
  alpha = .6) +

geom_line(aes(x=xj, group=id), color = 'lightgray', alpha = .3) +

#Define additional settings
scale_x_continuous(breaks=c(1,2,3), labels=c("Before", "During", "After"), limits=c(0.5, 3.5)) +
xlab("Condition") + ylab("Value") +
ggtitle('Figure 10: Repeated measures with jittered datapoints and connections') +
theme_classic()+
coord_cartesian(ylim=c(3.5, 7.5))
f10

```

Figure 10: Repeated measures with jittered datapoints and connection



```

if (save_image == TRUE) {
  ggsave('../tutorial_R/figs_repmes/figure10.png', width = w, height = h)
}

```

```

before = iris$Sepal.Width[1:50]
during = iris$Sepal.Length[51:100]
after = iris$Sepal.Length[1:50]
n <- length(before)
d <- data.frame(y = c(before, during, after),
               x = rep(c(1,2,3), each=n),
               id = factor(rep(1:n,3)))
set.seed(321)
d$xj <- jitter(d$x, amount = .09)
f11 <- ggplot(data=d, aes(y=y)) +

  #Add geom_() objects
  geom_point(data = d %>% filter(x=="1"), aes(x=xj), color = 'dodgerblue', size = 1.5,
            alpha = .6) +
  geom_point(data = d %>% filter(x=="2"), aes(x=xj), color = 'darkgreen', size = 1.5,
            alpha = .6) +
  geom_point(data = d %>% filter(x=="3"), aes(x=xj), color = 'darkorange', size = 1.5,
            alpha = .6) +

  geom_line(aes(x=xj, group=id), color = 'lightgray', alpha = .3) +

  geom_half_violin(
    data = d %>% filter(x=="1"), aes(x = x, y = y), position = position_nudge(x = 2.2),
    side = "r", fill = 'dodgerblue', alpha = .5, color = "dodgerblue", trim = TRUE) +

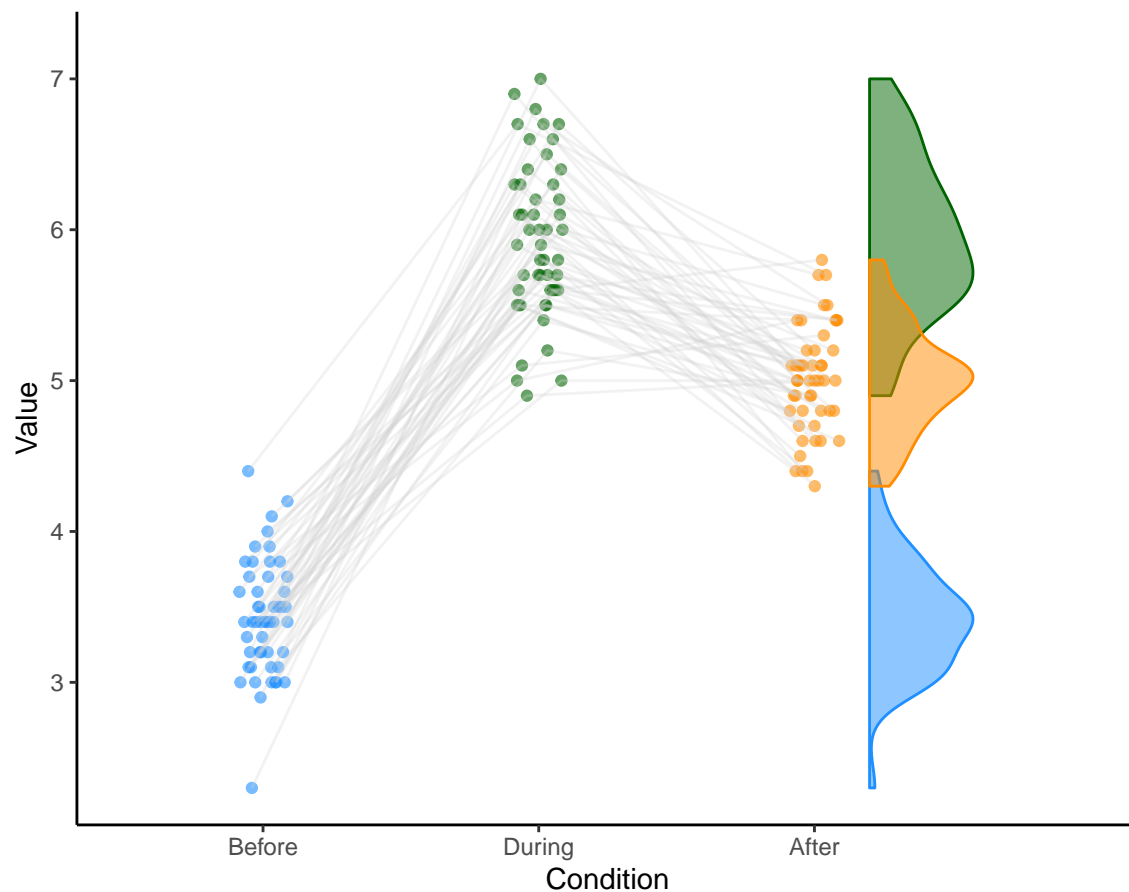
  geom_half_violin(
    data = d %>% filter(x=="2"), aes(x = x, y = y), position = position_nudge(x = 1.2),
    side = "r", fill = "darkgreen", alpha = .5, color = "darkgreen", trim = TRUE) +

  geom_half_violin(
    data = d %>% filter(x=="3"), aes(x = x, y = y), position = position_nudge(x = 0.2),
    side = "r", fill = "darkorange", alpha = .5, color = "darkorange", trim = TRUE) +

  #Define additional settings
  scale_x_continuous(breaks=c(1,2,3), labels=c("Before", "During", "After"), limits=c(0.5, 4)) +
  xlab("Condition") + ylab("Value") +
  ggtitle('Figure 11: Repeated measures with jittered datapoints and connections') +
  theme_classic()+
  coord_cartesian(ylim=c(2.3, 7.2))
f11

```


Figure 11: Repeated measures with jittered datapoints and connection



```
if (save_image == TRUE) {
  ggsave(' ../tutorial_R/figs_repmes/figure11.png', width = w, height = h)
}
```

```
f12 <- ggplot(data=d, aes(y=y)) +

  #Add geom_() objects
  geom_point(data = d %>% filter(x=="1"), aes(x=xj), color = 'dodgerblue', size = 1.5,
            alpha = .8) +
  geom_point(data = d %>% filter(x=="2"), aes(x=xj), color = 'darkgreen', size = 1.5,
            alpha = .8) +
  geom_point(data = d %>% filter(x=="3"), aes(x=xj), color = 'darkorange', size = 1.5,
            alpha = .8) +

  geom_line(aes(x=xj, group=id), color = 'lightgray', alpha = .3) +

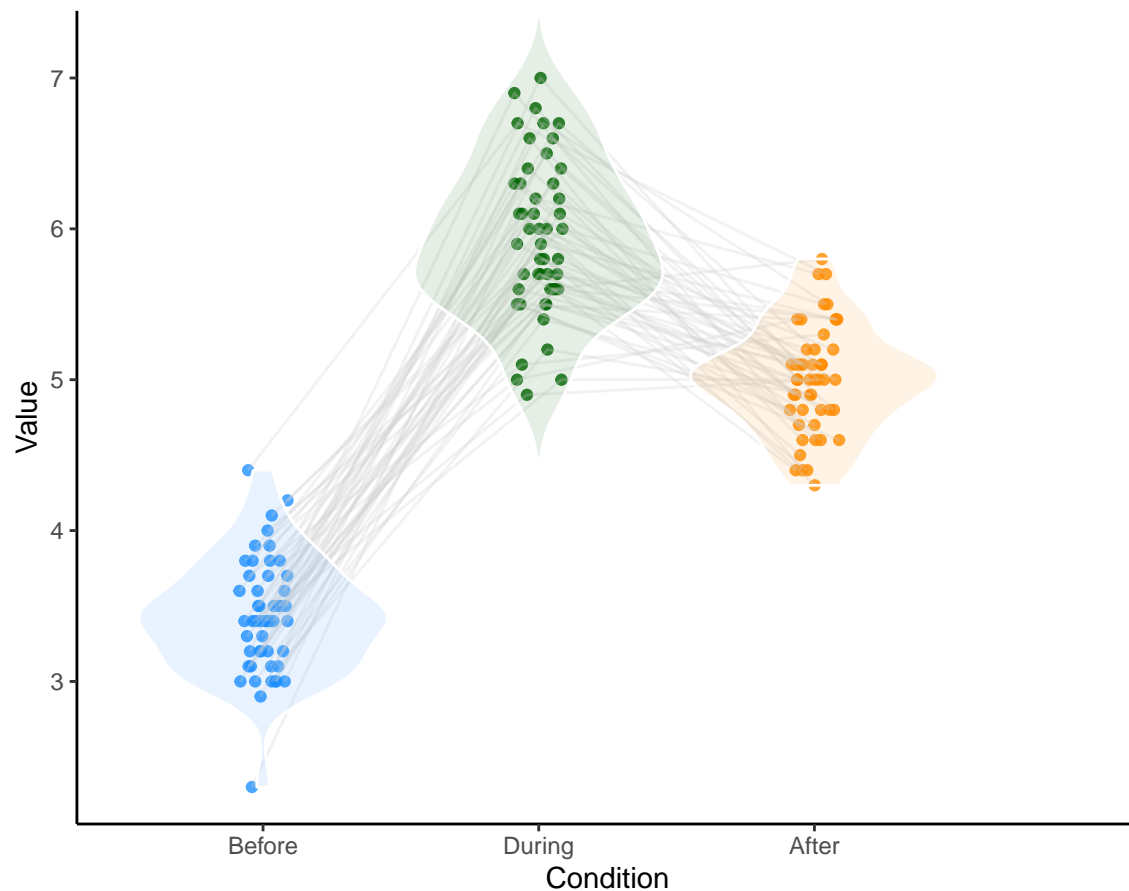
  geom_violin(
    data = d %>% filter(x=="1"), aes(x = x, y = y), position = position_nudge(x = 0),
    fill = 'dodgerblue', alpha = .1, color = "white", trim = TRUE) +

  geom_violin(
    data = d %>% filter(x=="2"), aes(x = x, y = y), position = position_nudge(x = 0),
    fill = "darkgreen", alpha = .1, color = "white", trim = FALSE) +
```

```
geom_violin(
  data = d %>% filter(x=="3"), aes(x = x, y = y), position = position_nudge(x = 0),
  fill = "darkorange", alpha = .1, color = "white", trim = TRUE) +

#Define additional settings
scale_x_continuous(breaks=c(1,2,3), labels=c("Before", "During", "After"), limits=c(0.5, 4)) +
xlab("Condition") + ylab("Value") +
ggtitle('Figure 12: Repeated measures with jittered datapoints and connections') +
theme_classic()+
coord_cartesian(ylim=c(2.3, 7.2))
f12
```

Figure 12: Repeated measures with jittered datapoints and connection



```
if (save_image == TRUE) {
  ggsave('../tutorial_R/figs_repmes/figure12.png', width = w, height = h)
}
```

```
before = iris$Sepal.Width[1:50]
during = iris$Sepal.Length[51:100]
after = iris$Sepal.Length[1:50]
n <- length(before)
d <- data.frame(y = c(before, during, after),
  x = rep(c(1,2,3), each=n),
```

```

      z = rep(c(4,5,6), each=n),
      id = factor(rep(1:n,3)))
set.seed(321)
d$xj <- jitter(d$x, amount = .09)
d$xj_2 <- jitter(d$z, amount = .09)
#d$xj_3 <- jitter(d$a, amount = .09)
f13 <- ggplot(data=d, aes(y=y)) +

  #Add geom_() objects
  geom_point(data = d %>% filter(x=="1"), aes(x=xj), color = 'dodgerblue', size = 1.5,
    alpha = .6) +
  geom_point(data = d %>% filter(x=="2"), aes(x=xj), color = 'darkgreen', size = 1.5,
    alpha = .6) +
  geom_point(data = d %>% filter(x=="3"), aes(x=xj), color = 'darkorange', size = 1.5,
    alpha = .6) +

  #Add geom_() objects
  geom_point(data = d %>% filter(z=="4"), aes(x=xj_2), color = 'dodgerblue', size = 1.5,
    alpha = .6) +
  geom_point(data = d %>% filter(z=="5"), aes(x=xj_2), color = 'darkgreen', size = 1.5,
    alpha = .6) +
  geom_point(data = d %>% filter(z=="6"), aes(x=xj_2), color = 'darkorange', size = 1.5,
    alpha = .6) +

  geom_line(aes(x=xj, group=id), color = 'lightgray', alpha = .3) +
  geom_line(aes(x=xj_2, group=id), color = 'lightgray', alpha = .3) +

  geom_half_violin(
    data = d %>% filter(x=="1"), aes(x = x, y = y), position = position_nudge(x = -0.2),
    side = "l", fill = 'dodgerblue', alpha = .5, color = "dodgerblue", trim = TRUE) +

  geom_half_violin(
    data = d %>% filter(x=="2"), aes(x = x, y = y), position = position_nudge(x = -1.2),
    side = "l", fill = "darkgreen", alpha = .5, color = "darkgreen", trim = TRUE) +

  geom_half_violin(
    data = d %>% filter(x=="3"), aes(x = x, y = y), position = position_nudge(x = -2.2),
    side = "l", fill = "darkorange", alpha = .5, color = "darkorange", trim = TRUE) +

  geom_half_violin(
    data = d %>% filter(z=="4"), aes(x = x, y = y), position = position_nudge(x = 5.2),
    side = "r", fill = 'dodgerblue', alpha = .5, color = "dodgerblue", trim = TRUE) +

  geom_half_violin(
    data = d %>% filter(z=="5"), aes(x = x, y = y), position = position_nudge(x = 4.2),
    side = "r", fill = "darkgreen", alpha = .5, color = "darkgreen", trim = TRUE) +

  geom_half_violin(
    data = d %>% filter(z=="6"), aes(x = x, y = y), position = position_nudge(x = 3.2),
    side = "r", fill = "darkorange", alpha = .5, color = "darkorange", trim = TRUE) +

  #Define additional settings
  scale_x_continuous(breaks=c(1,2,3,4,5,6), labels=c("Before", "During", "After", "Before", "During",

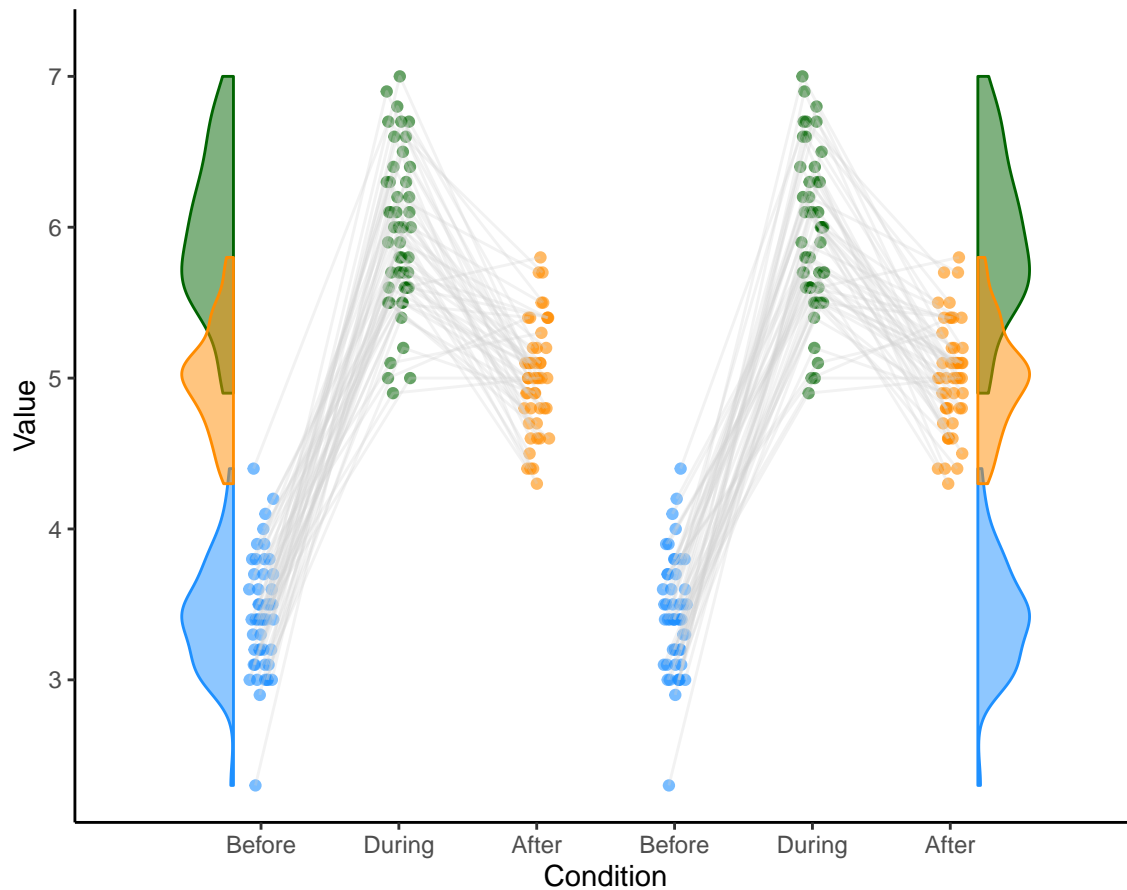
```

```

xlab("Condition") + ylab("Value") +
ggtitle('Figure 13: Repeated measures with jittered datapoints and connections') +
theme_classic()+
coord_cartesian(ylim=c(2.3, 7.2))
f13

```

Figure 13: Repeated measures with jittered datapoints and connection



```

if (save_image == TRUE) {
ggsave('..\\tutorial_R\\figs_repmes\\figure13.png', width = w, height = h)
}

```

```

f14 <- ggplot(data=d, aes(y=y)) +

  #Add geom_() objects
  geom_point(data = d %>% filter(x=="1"), aes(x=xj), color = 'dodgerblue', size = 1.5,
    alpha = .8) +
  geom_point(data = d %>% filter(x=="2"), aes(x=xj), color = 'darkgreen', size = 1.5,
    alpha = .8) +
  geom_point(data = d %>% filter(x=="3"), aes(x=xj), color = 'darkorange', size = 1.5,
    alpha = .8) +

  #Add geom_() objects
  geom_point(data = d %>% filter(z=="4"), aes(x=xj_2), color = 'dodgerblue', size = 1.5,

```

```

        alpha = .8) +
geom_point(data = d %>% filter(z=="5"), aes(x=xj_2), color = 'darkgreen', size = 1.5,
          alpha = .8) +
geom_point(data = d %>% filter(z=="6"), aes(x=xj_2), color = 'darkorange', size = 1.5,
          alpha = .8) +

geom_line(aes(x=xj, group=id), color = 'lightgray', alpha = .3) +
geom_line(aes(x=xj_2, group=id), color = 'lightgray', alpha = .3) +

geom_half_violin(
  data = d %>% filter(x=="1"),aes(x = x, y = y), position = position_nudge(x = 0),
  side = "r", fill = 'dodgerblue', alpha = .15, color = "lightgray", trim = TRUE) +

geom_half_violin(
  data = d %>% filter(x=="2"),aes(x = x, y = y), position = position_nudge(x = 0),
  side = "r", fill = "darkgreen", alpha = .15, color = "lightgray", trim = TRUE) +

geom_half_violin(
  data = d %>% filter(x=="3"),aes(x = x, y = y), position = position_nudge(x = 0),
  side = "r", fill = "darkorange", alpha = .15, color = "lightgray", trim = TRUE) +

geom_half_violin(
  data = d %>% filter(z=="4"),aes(x = x, y = y), position = position_nudge(x = 3),
  side = "r", fill = 'dodgerblue', alpha = .15, color = "lightgray", trim = TRUE) +

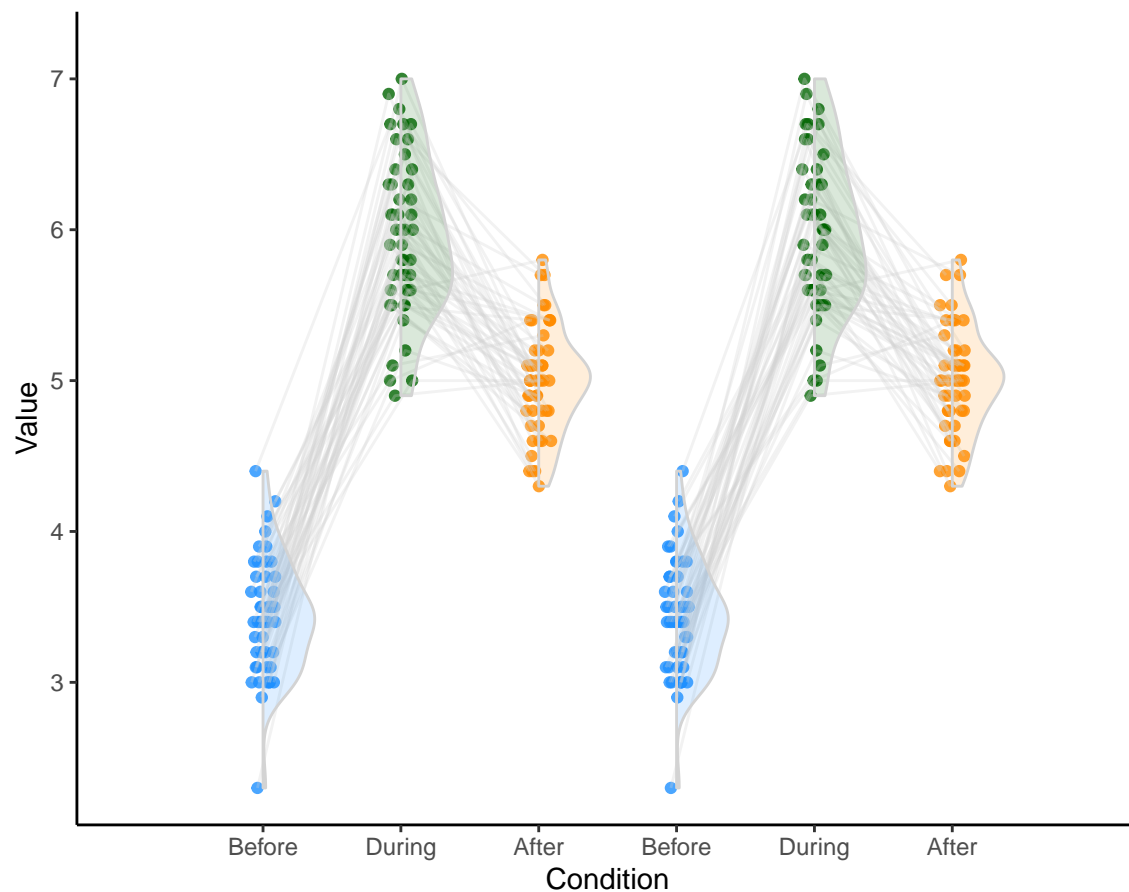
geom_half_violin(
  data = d %>% filter(z=="5"),aes(x = x, y = y), position = position_nudge(x = 3),
  side = "r", fill = "darkgreen", alpha = .15, color = "lightgray", trim = TRUE) +

geom_half_violin(
  data = d %>% filter(z=="6"),aes(x = x, y = y), position = position_nudge(x = 3),
  side = "r", fill = "darkorange", alpha = .15, color = "lightgray", trim = TRUE) +

#Define additional settings
scale_x_continuous(breaks=c(1,2,3,4,5,6), labels=c("Before", "During", "After", "Before", "During",
xlab("Condition") + ylab("Value") +
ggtitle('Figure 14: Repeated measures with jittered datapoints and connections') +
theme_classic()+
coord_cartesian(ylim=c(2.3, 7.2))
f14

```

Figure 14: Repeated measures with jittered datapoints and connection



```
if (save_image == TRUE) {
  ggsave('..tutorial_R/figs_repmes/figure14.png', width = w, height = h)
}
```

General remarks / tips

- To be more flexible in assigning labels to your figures, the **ggtext** package by [Wilke, 2020](#) might be worthwhile .
- If you would like to be flexible in plotting multiple figures next to each other, check-out the **patchwork** package by [Pedersen, 2020](#).
- If you want to save your figures in a high-quality manner (> GB) for e.g., publications, you could save your figure with a **.tiff** extension and add **dpi=** as used in the following line of code:

```
ggsave("figure.tiff", height=h, width=w, units='in', dpi=600)
```

- If for some reason your code does not work due to e.g., an update in a package, you could use the following line of code to unload and load that package again.

```
if("package_name" %in% (.packages())){
  detach('package:package_name', unload=TRUE)}
library("package_name")
```

You have reached the end of this document.

I hope you'll be able to use this tutorial to create more **open-visualizations** for your research!

If you use this tutorial, please cite it in your work.

[open-visualizations](#) for repeated measures in R by **Jordy van Langen**