

# Supplement 2

SPARS B (including NRS and SRS): Width of the pain threshold

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*06 Dec 2018*

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## Question

How wide is the pain threshold for participants taking part in the SPARS B trial?

To answer the question, we calculated the *Tukey Trimean* and bootstrapped 95% confidence interval (CI) for each individual, at each stimulus intensity. Next, we plotted these statistics to show the stimulus range over which each individual's CIs included zero on the SPARS (pain threshold).

To get an idea of the width of the stimulus range that included zero on the SPARS at the group level, we calculated the *Tukey trimean* for each individual, at each stimulus intensity, and then calculated the mean and bootstrapped 95% CI for the group at each stimulus intensity. These data were then plotted to show the stimulus range over which the group's CIs included zero (pain threshold).

The selection of the *tukey trimean* as the measure of central tendency at the individual level was based on the analysis of central tendency reported in the original description of the SPARS (Supplement\_3.pdf). The *Tukey trimean* is defined as the weighted average of the distribution's median and its two quartiles, and is a robust measure of central tendency that unlike a median, takes the spread of the data into account.

$$T_{mean} = \frac{1}{2}(Q_2 + \frac{Q_1 + Q_3}{2})$$

Where:

- $Q_1 = 25^{\text{th}}$  percentile
- $Q_2 = 50^{\text{th}}$  percentile (median)
- $Q_3 = 75^{\text{th}}$  percentile

```
# Define the tri_mean function
tri_mean <- function(x) {
  # Calculate quantiles
  q1 <- quantile(x, probs = 0.25, na.rm = TRUE)[[1]]
  q2 <- median(x, na.rm = TRUE)
  q3 <- quantile(x, probs = 0.75, na.rm = TRUE)[[1]]
  # Calculate trimean
  tri_mean <- (q2 + ((q1 + q3) / 2)) / 2
  # Round to a whole number
  tri_mean <- round(tri_mean)
  return(tri_mean)
}
```

**Note:** No inspection of block and stimulus order effects were undertaken because analysis of these factors in the original description of the SPARS revealed no order effects (Supplement\_4.pdf).

**Note:** The three scales measure were used in the SPARS B trial (Trial B). These were:

- pain NRS: 0 (no pain) to 100 (worst pain you can imagine)
- SRS: 0 (no sensation) to 100 (pain)
- SPARS: -50 (no sensation), 0 (pain threshold), +50 (worst pain you can imagine)

The stimulus range was centred on the pre-determined pain threshold of each participant (compared to the fixed range of intensities used in Trial A), all analyses use the rank order of the nine stimulus intensities each participant was exposed to rather than the absolute intensities of the stimuli used.

The experimental design involved exposing each participant to four successive experimental blocks of 27 trials (laser stimulations) each for each of the three measurement scales. The sequence of stimulus intensities used within each block was pre-determined, and differed between blocks. The order of in which the measurement scales were assessed was randomized, but for convenience of reporting, the plots are always shown in the order: pain NRS, SRS, and SPARS.

---

## Import and inspect data

```
# Import
data <- read_rds('data-cleaned/SPARS_B.rds')
```

```

# Rank stimulus intensity
data %<>%
  group_by(PID, scale) %>%
  arrange(intensity) %>%
  mutate(intensity_rank = dense_rank(intensity)) %>%
  select(-intensity) %>%
  rename(intensity = intensity_rank) %>%
  ungroup()

# Inspect
glimpse(data)

## Observations: 6,771
## Variables: 6
## $ PID          <chr> "ID06", "ID06", "ID06", "ID06", "ID06", "ID06", "...
## $ block_number <int> 1, 1, 1, 1, 1, 1, 1, 1, 1, 2, 2, 2, 2, 2, 2, 2...
## $ trial_number <dbl> 4, 4, 4, 6, 6, 6, 27, 27, 27, 9, 9, 9, 13, 13, 13...
## $ scale        <chr> "SPARS", "NRS", "SRS", "SPARS", "NRS", "SRS", "SP...
## $ rating       <dbl> -49, NA, NA, 2, NA, NA, -6, NA, NA, 3, NA, NA, -2...
## $ intensity    <int> 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1...

data %>%
  select(intensity, rating) %>%
  skim()

## Skim summary statistics
##   n obs: 6771
##   n variables: 2
##
## -- Variable type:integer -----
##   variable missing complete    n mean   sd p0 p25 p50 p75 p100   hist
##   intensity      0      6771 6771    5 2.58 1   3   5   7   9
##
## -- Variable type:numeric -----
##   variable missing complete    n  mean    sd  p0 p25 p50 p75 p100
##   rating      4622      2149 6771 -12.53 41.35 -100 -38   0   6   98
##   hist
##

```

---

## Data at the level of the individual

### Bootstrapping procedure for SPARS, NRS, and SRS

```

#####
#                                     #
#                                     SPARS                                     #
#                                     #
#                                     #
#####
# Extract SPARS data
data_spars <- data %>%
  filter(scale == 'SPARS') %>%
  filter(!is.na(rating))

```

```

# Nest data in preparation for bootstrapping at each stimulus intensity
spars_boot <- data_spars %>%
  group_by(PID, intensity) %>%
  nest()

# Define bootstrap function
boot_tri_mean <- function(d,i){
  tri_mean(d[i])
}

# Perform bootstrap
set.seed(123456789)
spars_boot %<>%
  mutate(boot = map(.x = data,
    ~ boot(data = .x$rating,
      statistic = boot_tri_mean,
      R = 10000, # For small sample size
      stype = 'i'))))

# Extract CI from boot object
spars_boot %<>%
  mutate(boot_ci = map(.x = boot,
    ~ boot.ci(.x,
      type = 'basic'))))

# Extract the data, giving original trimean and bootstrapped CI
spars_boot %<>%
  mutate(tri_mean = map_dbl(.x = boot_ci,
    ~ .x$t0),
    lower_ci = map_dbl(.x = boot_ci,
    ~ .x$basic[[4]]),
    upper_ci = map_dbl(.x = boot_ci,
    ~ .x$basic[[5]]))

# Delete unwanted columns
spars_boot %<>%
  select(-data, -boot, -boot_ci)

# Clip CI intervals (SPARS ranges from -50 to 50)
spars_boot %<>%
  mutate(upper_ci = ifelse(upper_ci > 50,
    yes = 50,
    no = upper_ci),
    lower_ci = ifelse(lower_ci < -50,
    yes = -50,
    no = lower_ci))

# Add fill column for plot
spars_boot %<>%
  mutate(fill = ifelse(upper_ci >= 0 & lower_ci <= 0,
    yes = 'inclusive',
    no = 'exclusive'),
    fill = factor(fill,

```

```

        levels = c('inclusive', 'exclusive'),
        ordered = TRUE))

#####
#                                                                 #
#                               NRS                               #
#                                                                 #
#####
# Extract NRS data
data_nrs <- data %>%
  filter(scale == 'NRS') %>%
  filter(!is.na(rating))

# Nest data in preparation for bootstrapping at each stimulus intensity
nrs_boot <- data_nrs %>%
  group_by(PID, intensity) %>%
  nest()

# Define bootstrap function
boot_tri_mean <- function(d,i){
  tri_mean(d[i])
}

# Perform bootstrap
set.seed(123456789)
nrs_boot %<>%
  mutate(boot = map(.x = data,
                    ~ boot(data = .x$rating,
                          statistic = boot_tri_mean,
                          R = 10000, # For small sample size
                          stype = 'i'))))

# Extract CI from boot object
nrs_boot %<>%
  mutate(boot_ci = map(.x = boot,
                      ~ boot.ci(.x,
                                type = 'basic'))))

# Remove problematic value ID01, rank intensity: 3 (no variation), row 14
nrs_boot <- nrs_boot[-14, ]

# Extract the data, giving original trimean and bootstrapped CI
nrs_boot %<>%
  mutate(tri_mean = map_dbl(.x = boot_ci,
                          ~ .x$t0),
         lower_ci = map_dbl(.x = boot_ci,
                          ~ .x$basic[[4]]),
         upper_ci = map_dbl(.x = boot_ci,
                          ~ .x$basic[[5]]))

# Delete unwanted columns
nrs_boot %<>%
  select(-data, -boot, -boot_ci)

```

```

# Clip CI intervals (NRS ranges from 0 to 100)
nrs_boot %<>%
  mutate(upper_ci = ifelse(upper_ci > 100,
                           yes = 100,
                           no = upper_ci),
         lower_ci = ifelse(lower_ci < 0,
                           yes = 0,
                           no = lower_ci))

# Add fill column for plot
nrs_boot %<>%
  mutate(fill = ifelse(lower_ci == 0,
                       yes = 'inclusive',
                       no = 'exclusive'),
         fill = factor(fill,
                       levels = c('inclusive', 'exclusive'),
                       ordered = TRUE))

#####
#                                                                 #
#                               SRS                               #
#                                                                 #
#####
# Extract SRS data
data_srs <- data %>%
  filter(scale == 'SRS') %>%
  filter(!is.na(rating)) %>%
  # Remove ID01 (didn't complete SRS)
  filter(PID != 'ID01')

# Nest data in preparation for bootstrapping at each stimulus intensity
srs_boot <- data_srs %>%
  group_by(PID, intensity) %>%
  nest()

# Define bootstrap function
boot_tri_mean <- function(d,i){
  tri_mean(d[i])
}

# Perform bootstrap
set.seed(123456789)
srs_boot %<>%
  mutate(boot = map(.x = data,
                    ~ boot(data = .x$rating,
                          statistic = boot_tri_mean,
                          R = 10000, # For small sample size
                          stype = 'i'))))

# Extract CI from boot object
srs_boot %<>%
  mutate(boot_ci = map(.x = boot,
                      ~ boot.ci(.x,
                                type = 'basic'))))

```

```

# Extract the data, giving original trimean and bootstrapped CI
srs_boot %<>%
  mutate(tri_mean = map_dbl(.x = boot_ci,
                            ~ .x$t0),
         lower_ci = map_dbl(.x = boot_ci,
                            ~ .x$basic[[4]]),
         upper_ci = map_dbl(.x = boot_ci,
                            ~ .x$basic[[5]]))

# Delete unwanted columns
srs_boot %<>%
  select(-data, -boot, -boot_ci)

# Clip CI intervals (SRS ranges from -100 to 0)
srs_boot %<>%
  mutate(upper_ci = ifelse(upper_ci > 0,
                          yes = 0,
                          no = upper_ci),
         lower_ci = ifelse(lower_ci < -100,
                          yes = -100,
                          no = lower_ci))

# Add fill column for plot
srs_boot %<>%
  mutate(fill = ifelse(upper_ci == 0,
                      yes = 'inclusive',
                      no = 'exclusive'),
         fill = factor(fill,
                      levels = c('inclusive', 'exclusive'),
                      ordered = TRUE))

```

## Plots

### Scatter plots

### SPARS

```

# Plot scatter plot of ratings for each individual at every intensity
ggplot(data = data_spars) +
  aes(x = intensity,
      y = rating,
      fill = intensity,
      colour = intensity) +
  geom_hline(yintercept = 0,
            size = 1) +
  geom_hline(yintercept = 25,
            linetype = 2) +
  geom_hline(yintercept = -25,
            linetype = 2) +
  geom_hline(yintercept = 50,
            linetype = 2) +
  geom_hline(yintercept = -50,
            linetype = 2) +

```

```

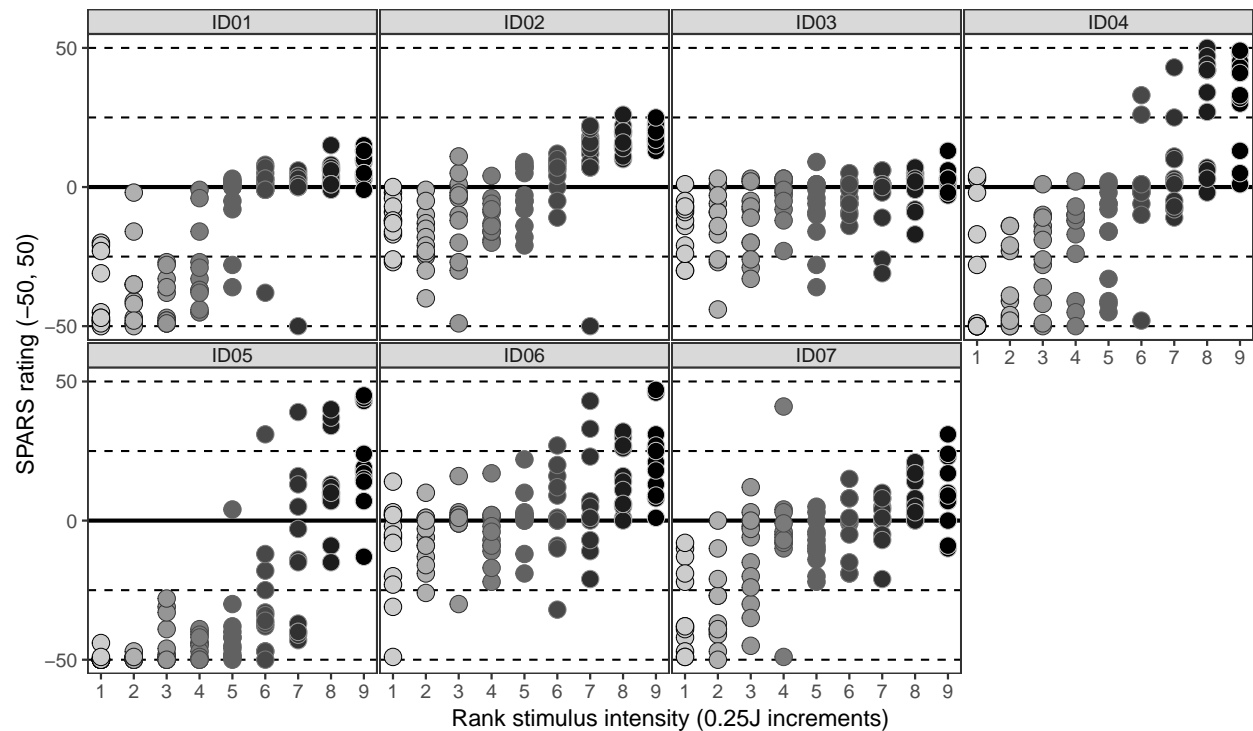
geom_point(shape = 21,
           size = 4,
           stroke = 0.3) +
scale_fill_gradient(low = '#CCCCCC', high = '#000000') +
scale_colour_gradient(low = '#000000', high = '#CCCCCC') +
scale_y_continuous(limits = c(-50, 50),
                   breaks = c(-50, 0, 50)) +
scale_x_continuous(breaks = seq(from = 1,
                                to = 9,
                                by = 1)) +

facet_wrap(~ PID, ncol = 4) +
labs(title = "SPARS individuals: Scatter plots of ratings at each stimulus intensity",
     subtitle = "- Dashed line: pain threshold\n- Colour gradient: stimulus intensity",
     x = 'Rank stimulus intensity (0.25J increments)',
     y = 'SPARS rating (-50, 50)') +
theme(legend.position = 'none',
      panel.grid = element_blank(),
      panel.spacing = unit(0.1, 'lines'),
      strip.text = element_text(margin = margin(t = 0.1,
                                                b = 0.1,
                                                r = 1,
                                                l = 1,
                                                'lines'))))

```

SPARS individuals: Scatter plots of ratings at each stimulus intensity

- Dashed line: pain threshold
- Colour gradient: stimulus intensity



NRS



```

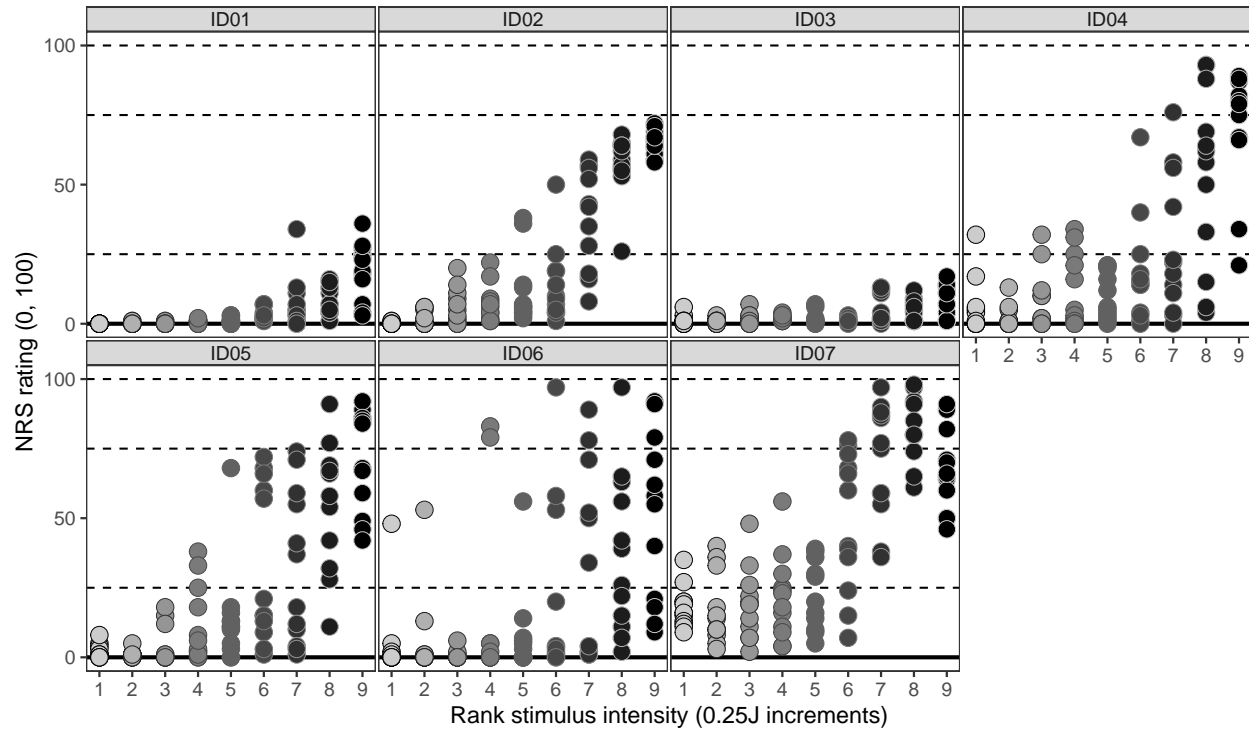
# Plot scatter plot of ratings for each individual at every intensity
ggplot(data = data_nrs) +
  aes(x = intensity,
       y = rating,
       fill = intensity,
       colour = intensity) +
  geom_hline(yintercept = 0,
             size = 1) +
  geom_hline(yintercept = 25,
             linetype = 2) +
  geom_hline(yintercept = 75,
             linetype = 2) +
  geom_hline(yintercept = 100,
             linetype = 2) +
  geom_point(shape = 21,
            size = 4,
            stroke = 0.3) +
  scale_fill_gradient(low = '#CCCCCC', high = '#000000') +
  scale_colour_gradient(low = '#000000', high = '#CCCCCC') +
  scale_y_continuous(limits = c(0, 100),
                    breaks = c(0, 50, 100)) +
  scale_x_continuous(breaks = seq(from = 1,
                                  to = 9,
                                  by = 1)) +

  facet_wrap(~ PID, ncol = 4) +
  labs(title = "NRS individuals: Scatter plots of ratings at each stimulus intensity",
       subtitle = "- Dashed line: pain threshold\n- Colour gradient: stimulus intensity",
       x = 'Rank stimulus intensity (0.25J increments)',
       y = 'NRS rating (0, 100)') +
  theme(legend.position = 'none',
        panel.grid = element_blank(),
        panel.spacing = unit(0.1, 'lines'),
        strip.text = element_text(margin = margin(t = 0.1,
                                                    b = 0.1,
                                                    r = 1,
                                                    l = 1,
                                                    'lines'))))

```

### NRS individuals: Scatter plots of ratings at each stimulus intensity

- Dashed line: pain threshold
- Colour gradient: stimulus intensity



### SRS

*# Plot scatter plot of ratings for each individual at every intensity*

```
ggplot(data = data_srs) +
  aes(x = intensity,
      y = rating,
      fill = intensity,
      colour = intensity) +
  geom_hline(yintercept = 0,
             size = 1) +
  geom_hline(yintercept = -25,
             linetype = 2) +
  geom_hline(yintercept = -75,
             linetype = 2) +
  geom_hline(yintercept = -100,
             linetype = 2) +
  geom_point(shape = 21,
             size = 4,
             stroke = 0.3) +
  scale_fill_gradient(low = '#CCCCCC', high = '#000000') +
  scale_colour_gradient(low = '#000000', high = '#CCCCCC') +
  scale_y_continuous(limits = c(-100, 0),
                    breaks = c(-100, -50, 0)) +
  scale_x_continuous(breaks = seq(from = 1,
                                  to = 9,
                                  by = 1)) +
  facet_wrap(~ PID, ncol = 4) +
```

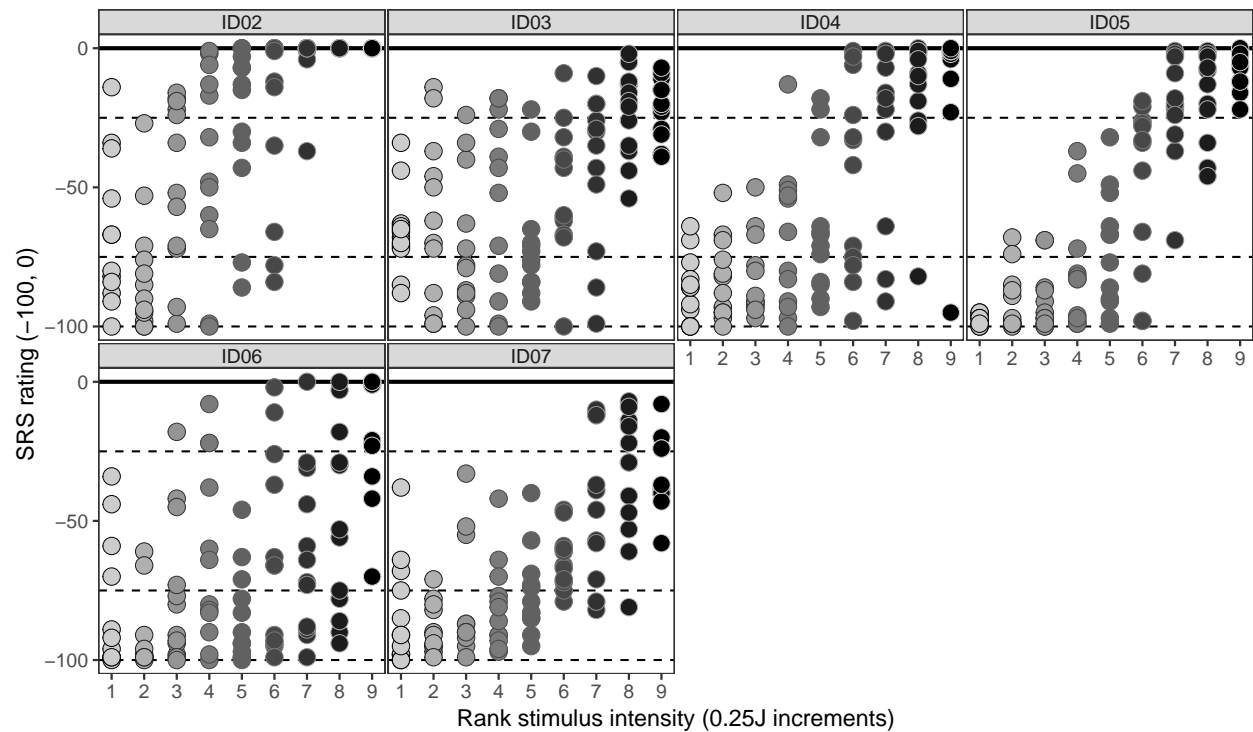
```

labs(title = "SRS individuals: Scatter plots of ratings at each stimulus intensity",
      subtitle = '- Dashed line: pain threshold\n- Colour gradient: stimulus intensity',
      x = 'Rank stimulus intensity (0.25J increments)',
      y = 'SRS rating (-100, 0)' +
theme(legend.position = 'none',
      panel.grid = element_blank(),
      panel.spacing = unit(0.1, 'lines'),
      strip.text = element_text(margin = margin(t = 0.1,
                                                b = 0.1,
                                                r = 1,
                                                l = 1,
                                                'lines'))))

```

### SRS individuals: Scatter plots of ratings at each stimulus intensity

- Dashed line: pain threshold
- Colour gradient: stimulus intensity



### Trimean confidence interval plots

#### SPARS

```

# Plot individual CIs at every intensity
ggplot(data = spars_boot) +
  aes(x = intensity,
      fill = fill,
      colour = fill) +
  geom_hline(yintercept = 0,
             size = 1) +
  geom_hline(yintercept = 25,
             linetype = 2) +

```

```

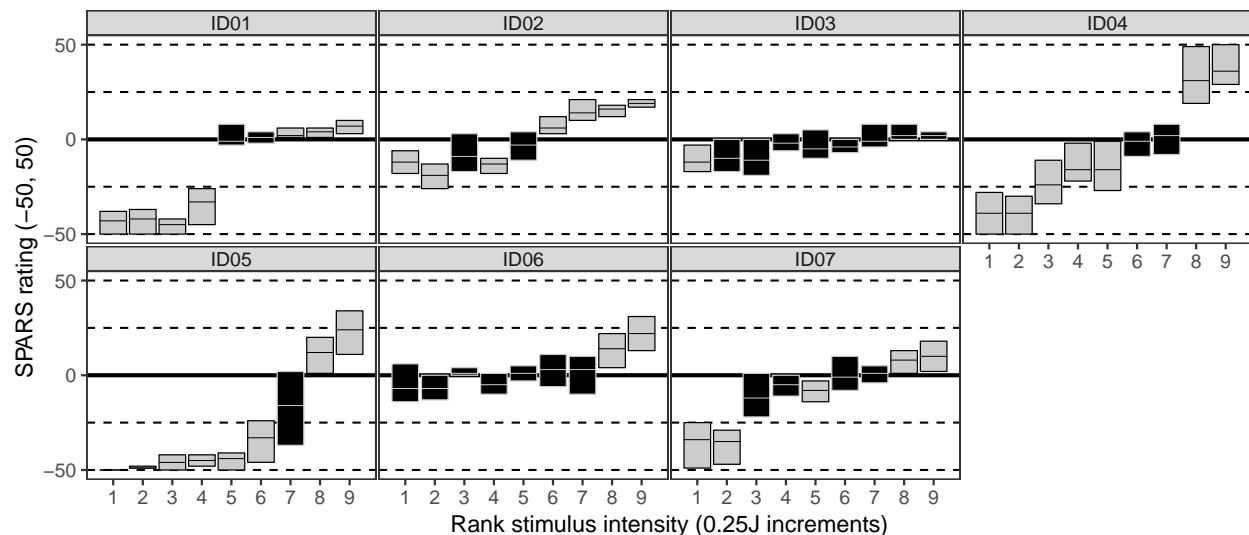
geom_hline(yintercept = -25,
           linetype = 2) +
geom_hline(yintercept = 50,
           linetype = 2) +
geom_hline(yintercept = -50,
           linetype = 2) +
geom_crossbar(aes(y = tri_mean,
                  ymin = lower_ci,
                  ymax = upper_ci),
              fatten = 0,
              size = 0.3) +
scale_fill_manual(values = c('#000000', '#CCCCCC')) +
scale_colour_manual(values = c('#CCCCCC', '#000000')) +
scale_y_continuous(limits = c(-50, 50),
                   breaks = c(-50, 0, 50)) +
scale_x_continuous(breaks = seq(from = 1,
                                to = 9,
                                by = 1)) +

facet_wrap(~ PID, ncol = 4) +
labs(title = "SPARS individuals: Crossbar plots of 95% CI of Tukey trimeans\nfor SPARS ratings at e",
     subtitle = "- Basic bootstrap 95% CI with 10,000 resamples\n- Dashed line: pain threshold | - 1",
     x = 'Rank stimulus intensity (0.25J increments)',
     y = 'SPARS rating (-50, 50)') +
theme(legend.position = 'none',
      panel.grid = element_blank(),
      panel.spacing = unit(0.1, 'lines'),
      strip.text = element_text(margin = margin(t = 0.1,
                                                b = 0.1,
                                                r = 1,
                                                l = 1,
                                                'lines'))))

```

SPARS individuals: Crossbar plots of 95% CI of Tukey trimeans  
for SPARS ratings at each stimulus intensity

- Basic bootstrap 95% CI with 10,000 resamples
- Dashed line: pain threshold | - Black fill: 95% CI includes zero



## NRS

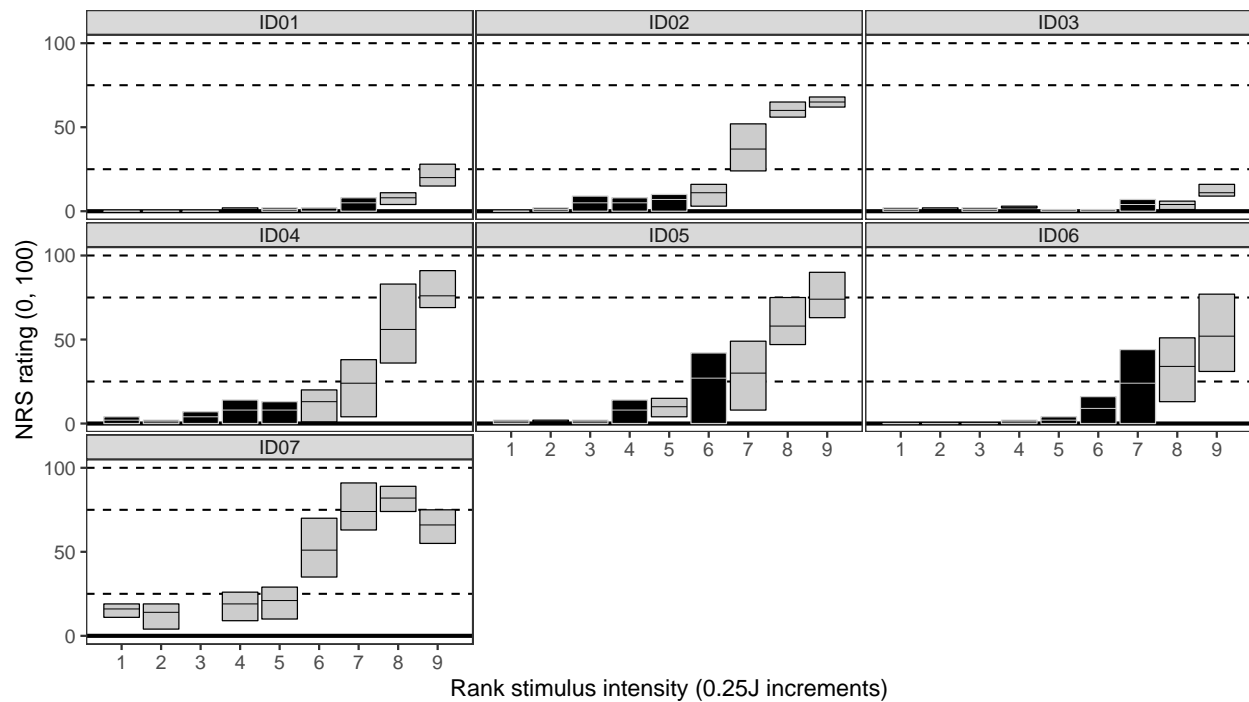
*# Plot individual CIs at every intensity*

```
ggplot(data = nrs_boot) +
  aes(x = intensity,
      fill = fill,
      colour = fill) +
  geom_hline(yintercept = 0,
             size = 1) +
  geom_hline(yintercept = 25,
             linetype = 2) +
  geom_hline(yintercept = 75,
             linetype = 2) +
  geom_hline(yintercept = 100,
             linetype = 2) +
  geom_crossbar(aes(y = tri_mean,
                   ymin = lower_ci,
                   ymax = upper_ci),
               fatten = 0,
               size = 0.3) +
  scale_fill_manual(values = c('#000000', '#CCCCCC')) +
  scale_colour_manual(values = c('#CCCCCC', '#000000')) +
  scale_y_continuous(limits = c(0, 100),
                    breaks = c(0, 50, 100)) +
  scale_x_continuous(breaks = seq(from = 1,
                                  to = 9,
                                  by = 1)) +

  facet_wrap(~ PID, ncol = 3) +
  labs(title = "NRS individuals: Crossbar plots of 95% CI of Tukey trimeans\nfor NRS ratings at each s",
       subtitle = "- Basic bootstrap 95% CI with 10,000 resamples\n- Dashed line: pain threshold | - L",
       x = 'Rank stimulus intensity (0.25J increments)',
       y = 'NRS rating (0, 100)') +
  theme(legend.position = 'none',
        panel.grid = element_blank(),
        panel.spacing = unit(0.1, 'lines'),
        strip.text = element_text(margin = margin(t = 0.1,
                                                  b = 0.1,
                                                  r = 1,
                                                  l = 1,
                                                  'lines'))))
```

NRS individuals: Crossbar plots of 95% CI of Tukey trimeans  
for NRS ratings at each stimulus intensity

- Basic bootstrap 95% CI with 10,000 resamples
- Dashed line: pain threshold | – Black fill: 95% CI includes zero



## SRS

*# Plot individual CIs at every intensity*

```
ggplot(data = srs_boot) +
  aes(x = intensity,
      fill = fill,
      colour = fill) +
  geom_hline(yintercept = 0,
             size = 1) +
  geom_hline(yintercept = -25,
             linetype = 2) +
  geom_hline(yintercept = -50,
             linetype = 2) +
  geom_hline(yintercept = -75,
             linetype = 2) +
  geom_hline(yintercept = -100,
             linetype = 2) +
  geom_crossbar(aes(y = tri_mean,
                    ymin = lower_ci,
                    ymax = upper_ci),
                fatten = 0,
                size = 0.3) +
  scale_fill_manual(values = c('#000000', '#CCCCCC')) +
  scale_colour_manual(values = c('#CCCCCC', '#000000')) +
  scale_y_continuous(limits = c(-100, 0),
                     breaks = c(-100, -50, 0)) +
  scale_x_continuous(breaks = seq(from = 1,
```

SRS individuals: Crossbar plots of 95% CI of Tukey trimeans for SRS ratings at each stimulus intensity

- Basic bootstrap 95% CI with 10,000 resamples
- Dashed line: pain threshold | – Grey fill: 95% CI includes zero

SRS rating (-100, 0)

Rank stimulus intensity (0.25J increments)

```

#
#####
# Calculate individual trimeans at each stimulus intensity
group_spars <- data_spars %>%
  group_by(PID, intensity) %>%
  summarise(tri_mean = tri_mean(rating)) %>%
  ungroup()

# Nest data in preparation for bootstrapping at each stimulus intensity
spars_boot_group <- group_spars %>%
  group_by(intensity) %>%
  nest()

# Perform bootstrap
set.seed(987654321)
spars_boot_group %<>% mutate(boot = map(.x = data,
  ~ boot(data = .x$tri_mean,
    statistic = boot_tri_mean,
    R = 10000, # For small sample size
    stype = 'i'))))

# Extract CI from boot object
spars_boot_group %<>% mutate(boot_ci = map(.x = boot,
  ~ boot.ci(.x,
    type = 'basic'))))

# Extract the data, giving original median and bootstrapped CI
spars_boot_group %<>% mutate(tri_mean = map(.x = boot_ci,
  ~ .x$t0),
  lower_ci = map(.x = boot_ci,
    ~ .x$basic[[4]]),
  upper_ci = map(.x = boot_ci,
    ~ .x$basic[[5]]))

# Delete unwanted columns
spars_boot_group %<>% select(-data, -boot, -boot_ci) %>%
  unnest()

# Clip CI intervals (SPARS ranges from -50 to 50)
spars_boot_group %<>%
  mutate(upper_ci = ifelse(upper_ci > 50,
    yes = 50,
    no = upper_ci),
    lower_ci = ifelse(lower_ci < -50,
    yes = -50,
    no = lower_ci))

# Add fill column for plot
spars_boot_group %<>%
  mutate(fill = ifelse(upper_ci >= 0 & lower_ci <= 0,
    yes = 'inclusive',
    no = 'exclusive'),
    fill = factor(fill,
    levels = c('inclusive', 'exclusive')),

```



```

        ordered = TRUE))

#####
#                                                                    #
#                                                                    #
#                                                                    #
#####
# Calculate individual trimeans at each stimulus intensity
group_nrs <- data_nrs %>%
  group_by(PID, intensity) %>%
  summarise(tri_mean = tri_mean(rating)) %>%
  ungroup()

# Nest data in preparation for bootstrapping at each stimulus intensity
nrs_boot_group <- group_nrs %>%
  group_by(intensity) %>%
  nest()

# Perform bootstrap
set.seed(987654321)
nrs_boot_group %<>% mutate(boot = map(.x = data,
  ~ boot(data = .x$tri_mean,
    statistic = boot_tri_mean,
    R = 10000, # For small sample size
    stype = 'i'))))

# Extract CI from boot object
nrs_boot_group %<>% mutate(boot_ci = map(.x = boot,
  ~ boot.ci(.x,
    type = 'basic'))))

# Extract the data, giving original median and bootstrapped CI
nrs_boot_group %<>% mutate(tri_mean = map(.x = boot_ci,
  ~ .x$t0),
  lower_ci = map(.x = boot_ci,
    ~ .x$basic[[4]]),
  upper_ci = map(.x = boot_ci,
    ~ .x$basic[[5]]))

# Delete unwanted columns
nrs_boot_group %<>% select(-data, -boot, -boot_ci) %>%
  unnest()

# Clip CI intervals (NRS ranges from 0 to 100)
nrs_boot_group %<>%
  mutate(upper_ci = ifelse(upper_ci > 100,
    yes = 100,
    no = upper_ci),
    lower_ci = ifelse(lower_ci < 0,
    yes = 0,
    no = lower_ci))

# Add fill column for plot
nrs_boot_group %<>%

```

```

mutate(fill = ifelse(lower_ci == 0,
                     yes = 'inclusive',
                     no = 'exclusive'),
       fill = factor(fill,
                     levels = c('inclusive', 'exclusive'),
                     ordered = TRUE))

#####
#                                                                    #
#                                                                    #
#                                                                    #
#####
# Calculate individual trimeans at each stimulus intensity
group_srs <- data_srs %>%
  group_by(PID, intensity) %>%
  summarise(tri_mean = tri_mean(rating)) %>%
  ungroup()

# Nest data in preparation for bootstrapping at each stimulus intensity
srs_boot_group <- group_srs %>%
  group_by(intensity) %>%
  nest()

# Perform bootstrap
set.seed(987654321)
srs_boot_group %<>% mutate(boot = map(.x = data,
                                     ~ boot(data = .x$tri_mean,
                                             statistic = boot_tri_mean,
                                             R = 10000, # For small sample size
                                             stype = 'i'))))

# Extract CI from boot object
srs_boot_group %<>% mutate(boot_ci = map(.x = boot,
                                         ~ boot.ci(.x,
                                                     type = 'basic'))))

# Extract the data, giving original median and bootstrapped CI
srs_boot_group %<>% mutate(tri_mean = map(.x = boot_ci,
                                         ~ .x$t0),
                          lower_ci = map(.x = boot_ci,
                                         ~ .x$basic[[4]]),
                          upper_ci = map(.x = boot_ci,
                                         ~ .x$basic[[5]]))

# Delete unwanted columns
srs_boot_group %<>% select(-data, -boot, -boot_ci) %>%
  unnest()

# Clip CI intervals (SRS ranges from -100 to 0)
srs_boot_group %<>%
  mutate(upper_ci = ifelse(upper_ci > 0,
                           yes = 0,
                           no = upper_ci),
         lower_ci = ifelse(lower_ci < -100,

```

```

        yes = -100,
        no = lower_ci))

# Add fill column for plot
srs_boot_group %<>%
  mutate(fill = ifelse(upper_ci == 0,
                        yes = 'inclusive',
                        no = 'exclusive'),
         fill = factor(fill,
                        levels = c('inclusive', 'exclusive'),
                        ordered = TRUE))

```

## Plots

### Scatter plot

#### SPARS

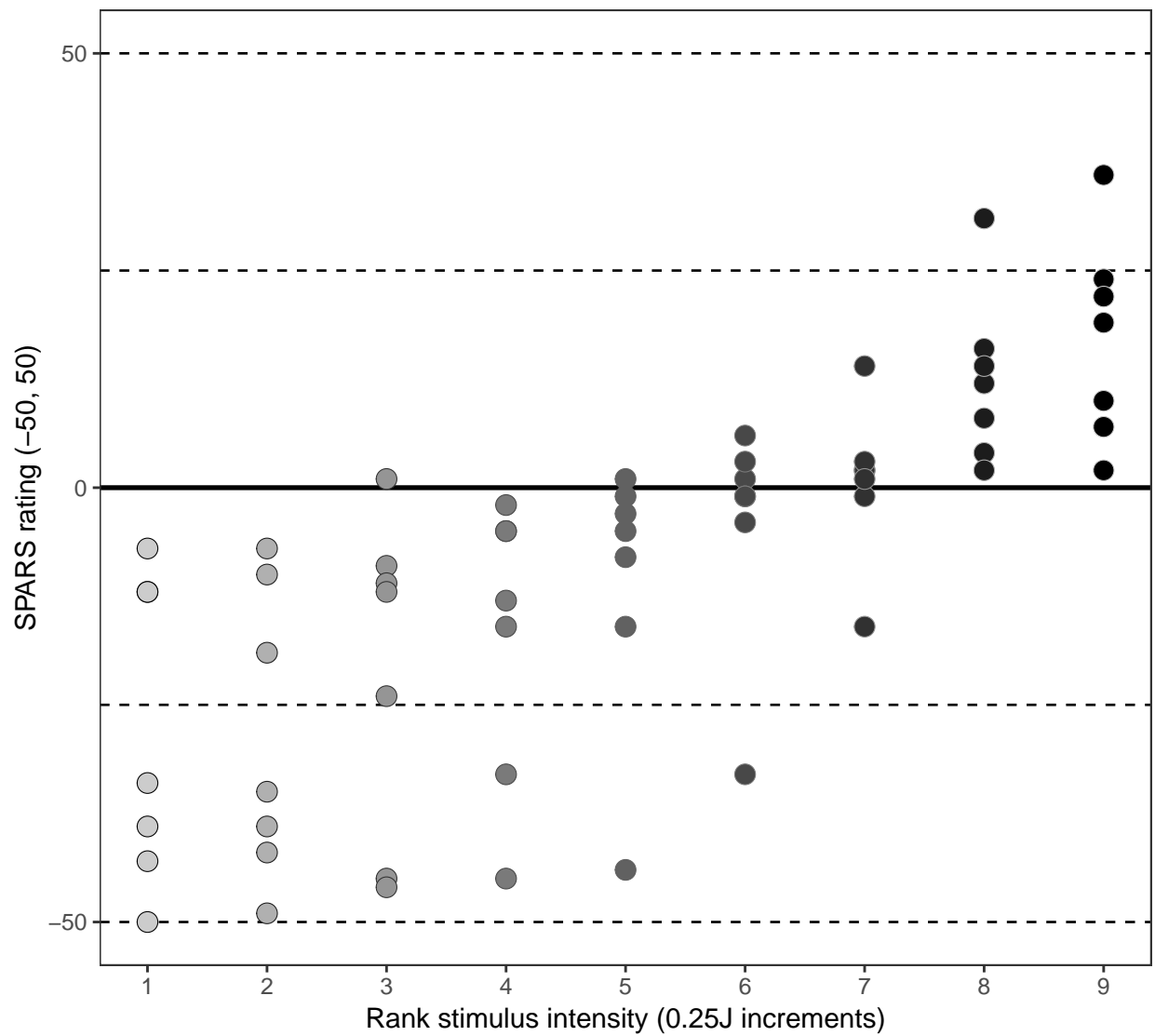
```

# Plot scatter plot of ratings for the group at every intensity
ggplot(data = group_spars) +
  aes(x = intensity,
      y = tri_mean,
      fill = intensity,
      colour = intensity) +
  geom_hline(yintercept = 0,
             size = 1) +
  geom_hline(yintercept = 25,
             linetype = 2) +
  geom_hline(yintercept = -25,
             linetype = 2) +
  geom_hline(yintercept = 50,
             linetype = 2) +
  geom_hline(yintercept = -50,
             linetype = 2) +
  geom_point(shape = 21,
             size = 4,
             stroke = 0.3) +
  scale_fill_gradient(low = '#CCCCCC', high = '#000000') +
  scale_colour_gradient(low = '#000000', high = '#CCCCCC') +
  scale_y_continuous(limits = c(-50, 50),
                     breaks = c(-50, 0, 50)) +
  scale_x_continuous(breaks = seq(from = 1,
                                   to = 9,
                                   by = 1)) +
  labs(title = "SPARS group: Scatter plots of Tukey trimean ratings at each stimulus intensity",
       subtitle = "- Dashed line: pain threshold\n- Colour gradient: stimulus intensity",
       x = 'Rank stimulus intensity (0.25J increments)',
       y = 'SPARS rating (-50, 50)') +
  theme(legend.position = 'none',
        panel.grid = element_blank())

```

## SPARS group: Scatter plots of Tukey trimean ratings at each stimulus inten

- Dashed line: pain threshold
- Colour gradient: stimulus intensity



## NRS

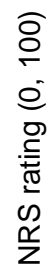
```
# Plot scatter plot of ratings for the group at every intensity
ggplot(data = group_nrs) +
  aes(x = intensity,
      y = tri_mean,
      fill = intensity,
      colour = intensity) +
  geom_hline(yintercept = 0,
             size = 1) +
  geom_hline(yintercept = 25,
             linetype = 2) +
  geom_hline(yintercept = 75,
             linetype = 2) +
```

```

geom_hline(yintercept = 100,
           linetype = 2) +
geom_point(shape = 21,
           size = 4,
           stroke = 0.3) +
scale_fill_gradient(low = '#CCCCCC', high = '#000000') +
scale_colour_gradient(low = '#000000', high = '#CCCCCC') +
scale_y_continuous(limits = c(0, 100),
                   breaks = c(0, 50, 100)) +
scale_x_continuous(breaks = seq(from = 1,
                                to = 9,
                                by = 1)) +
labs(title = "NRS group: Scatter plots of Tukey trimean ratings at each stimulus intensity",
     subtitle = '- Dashed line: pain threshold\n- Colour gradient: stimulus intensity',
     x = 'Rank stimulus intensity (0.25J increments)',
     y = 'NRS rating (0, 100)') +
theme(legend.position = 'none',
      panel.grid = element_blank())

```

- Dashed line: pain threshold
- Colour gradient: stimulus intensity



**SRS**

```
# Plot scatter plot of ratings for the group at every intensity
ggplot(data = group_srs) +
  aes(x = intensity,
      y = tri_mean,
      fill = intensity,
      colour = intensity) +
  geom_hline(yintercept = 0,
             size = 1) +
  geom_hline(yintercept = -25,
             linetype = 2) +
  geom_hline(yintercept = -75,
             linetype = 2) +
```

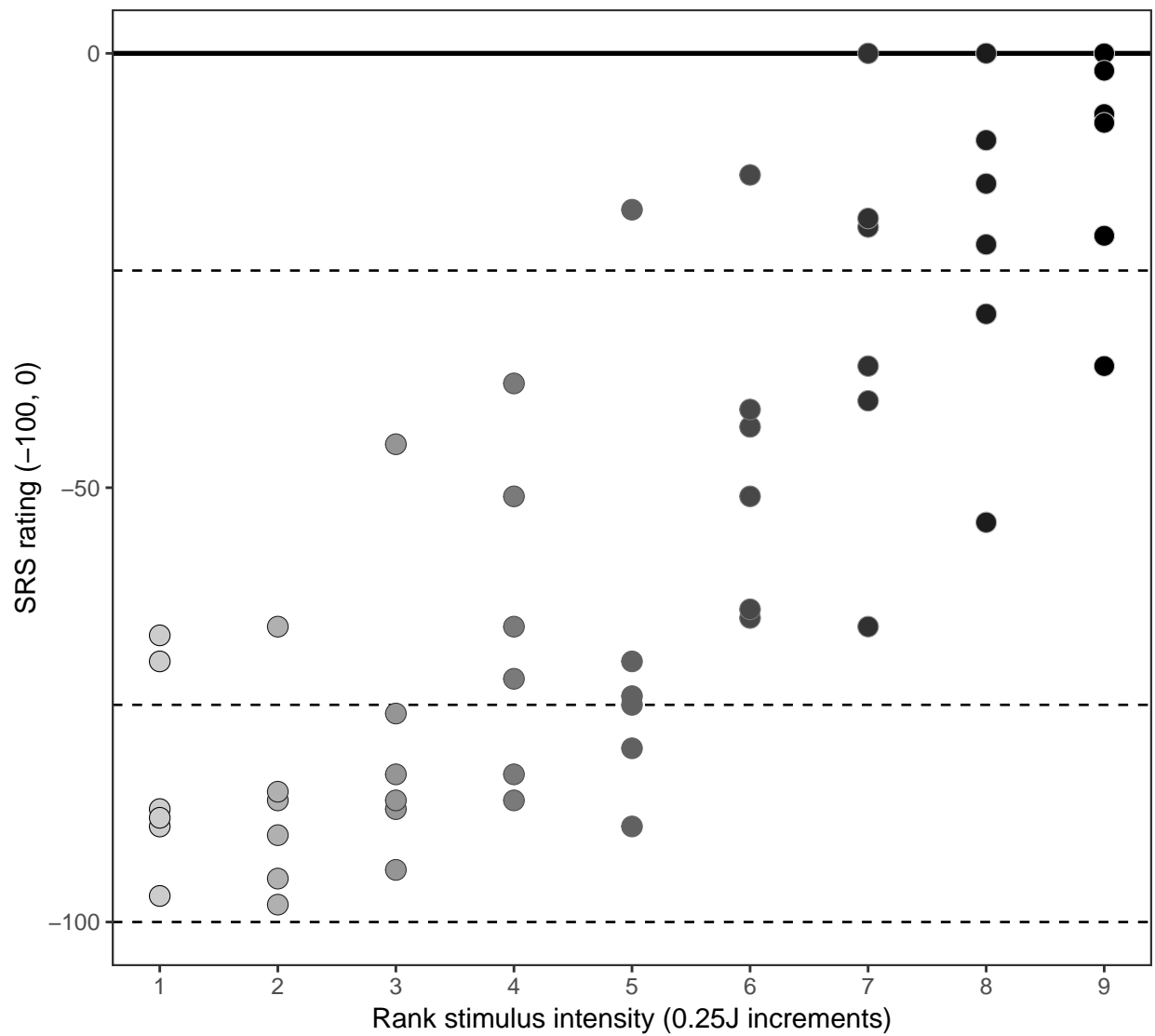
```

geom_hline(yintercept = -100,
           linetype = 2) +
geom_point(shape = 21,
           size = 4,
           stroke = 0.3) +
scale_fill_gradient(low = '#CCCCCC', high = '#000000') +
scale_colour_gradient(low = '#000000', high = '#CCCCCC') +
scale_y_continuous(limits = c(-100, 0),
                   breaks = c(-100, -50, 0)) +
scale_x_continuous(breaks = seq(from = 1,
                                to = 9,
                                by = 1)) +
labs(title = "SRS group: Scatter plots of Tukey trimean ratings at each stimulus intensity",
     subtitle = '- Dashed line: pain threshold\n- Colour gradient: stimulus intensity',
     x = 'Rank stimulus intensity (0.25J increments)',
     y = 'SRS rating (-100, 0)') +
theme(legend.position = 'none',
      panel.grid = element_blank())

```

SRS group: Scatter plots of Tukey trimean ratings at each stimulus intensity

- Dashed line: pain threshold
- Colour gradient: stimulus intensity



Trimean confidence interval plots

SPARS

```
# Plot group CIs at every intensity
ggplot(data = spars_boot_group) +
  aes(x = intensity) +
  geom_hline(yintercept = 0,
             size = 1) +
  geom_hline(yintercept = 25,
             linetype = 2) +
  geom_hline(yintercept = -25,
             linetype = 2) +
  geom_hline(yintercept = 50,
```



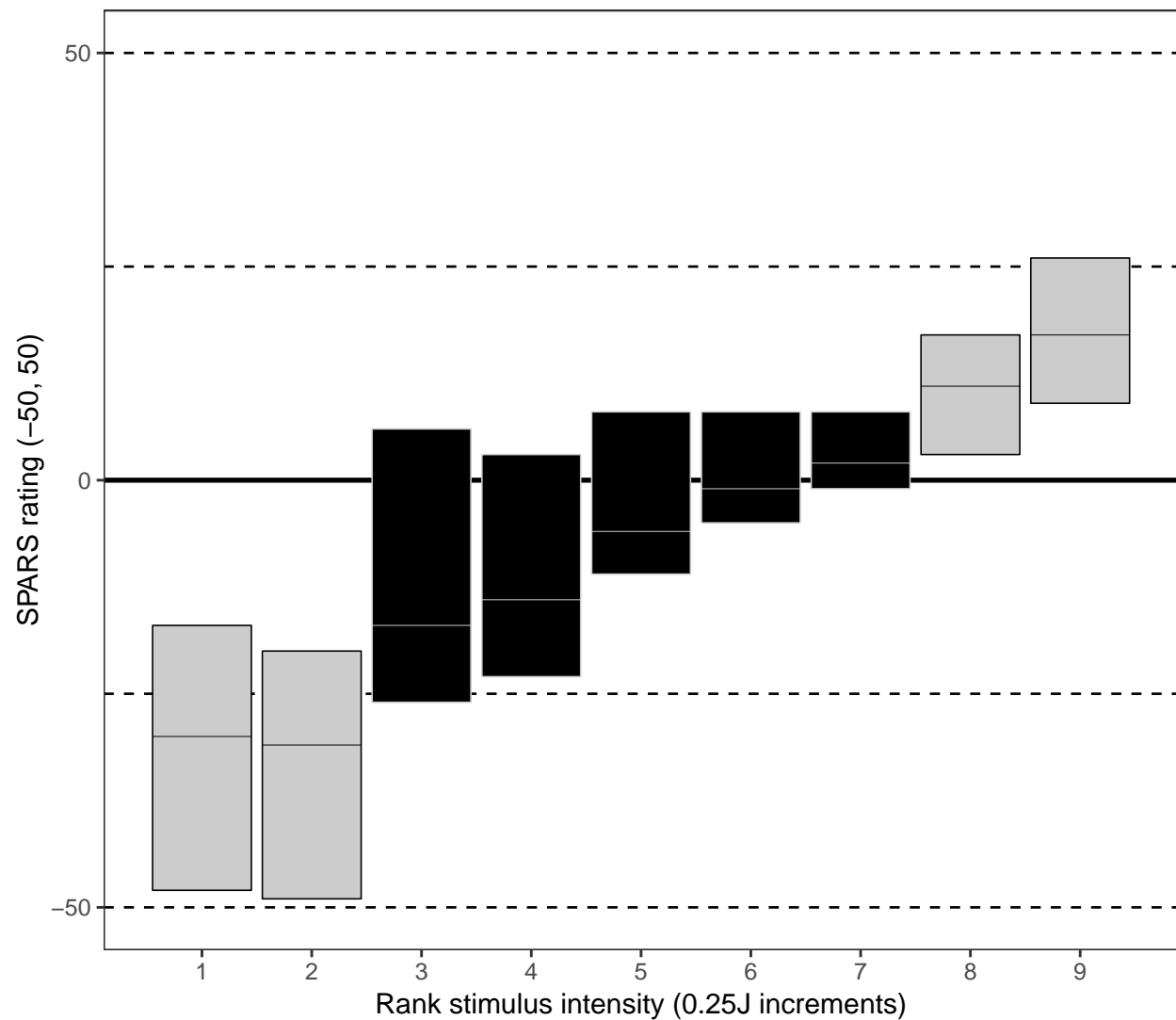
```

    linetype = 2) +
geom_hline(yintercept = -50,
    linetype = 2) +
geom_crossbar(aes(y = tri_mean,
    ymin = lower_ci,
    ymax = upper_ci,
    fill = fill,
    colour = fill),
    fatten = 0,
    size = 0.3) +
scale_fill_manual(values = c('#000000', '#CCCCCC')) +
scale_colour_manual(values = c('#CCCCCC', '#000000')) +
scale_y_continuous(limits = c(-50, 50),
    breaks = c(-50, 0, 50)) +
scale_x_continuous(breaks = seq(from = 1,
    to = 9,
    by = 1)) +
labs(title = "SPARS Group: Crossbar plots of 95% CI of Tukey trimeans\nfor ratings at each stimulus",
    subtitle = "- Basic bootstrap 95% CI with 10,000 resamples\n- Dashed line: pain threshold | - 1",
    x = 'Rank stimulus intensity (0.25J increments)',
    y = 'SPARS rating (-50, 50)') +
theme(legend.position = 'none',
    panel.grid = element_blank())

```

## SPARS Group: Crossbar plots of 95% CI of Tukey trimeans for ratings at each stimulus intensity

- Basic bootstrap 95% CI with 10,000 resamples
- Dashed line: pain threshold | – Black fill: 95% CI includes zero



## NRS

```
# Plot group CIs at every intensity
ggplot(data = nrs_boot_group) +
  aes(x = intensity) +
  geom_hline(yintercept = 0,
             size = 1) +
  geom_hline(yintercept = 25,
             linetype = 2) +
  geom_hline(yintercept = 50,
             linetype = 2) +
  geom_hline(yintercept = 75,
             linetype = 2) +
  geom_hline(yintercept = 100,
```

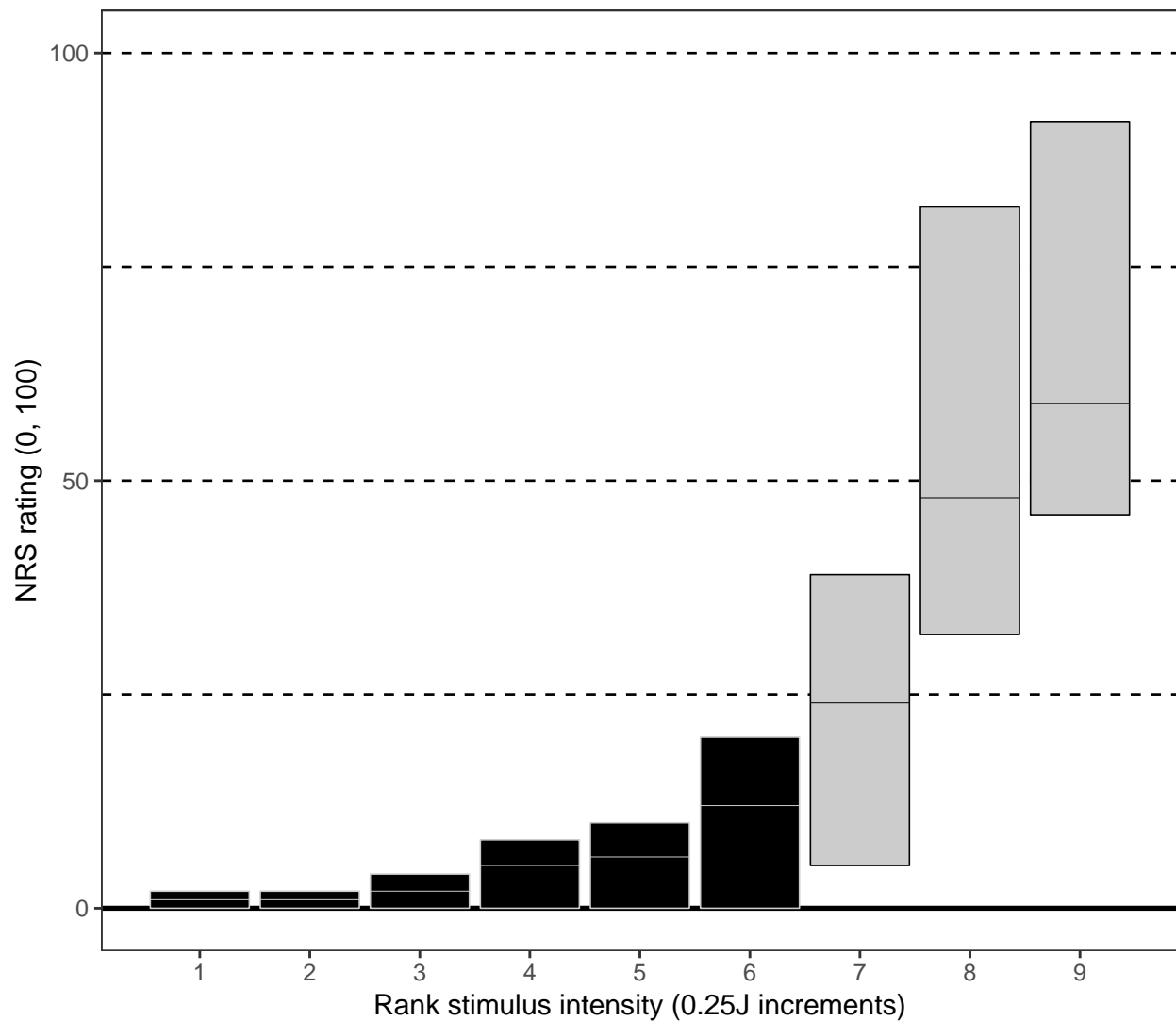
```

      linetype = 2) +
geom_crossbar(aes(y = tri_mean,
                  ymin = lower_ci,
                  ymax = upper_ci,
                  fill = fill,
                  colour = fill),
              fatten = 0,
              size = 0.3) +
scale_fill_manual(values = c('#000000', '#CCCCCC')) +
scale_colour_manual(values = c('#CCCCCC', '#000000')) +
scale_y_continuous(limits = c(0, 100),
                   breaks = c(0, 50, 100)) +
scale_x_continuous(breaks = seq(from = 1,
                                to = 9,
                                by = 1)) +
labs(title = "NRS Group: Crossbar plots of 95% CI of Tukey trimeans\nfor ratings at each stimulus i
      subtitle = '- Basic bootstrap 95% CI with 10,000 resamples\n- Dashed line: pain threshold | - (
      x = 'Rank stimulus intensity (0.25J increments)',
      y = 'NRS rating (0, 100)') +
theme(legend.position = 'none',
      panel.grid = element_blank())

```

### NRS Group: Crossbar plots of 95% CI of Tukey trimeans for ratings at each stimulus intensity

- Basic bootstrap 95% CI with 10,000 resamples
- Dashed line: pain threshold | – Grey fill: 95% CI includes zero



### SRS

```
# Plot group CIs at every intensity
ggplot(data = srs_boot_group) +
  aes(x = intensity) +
  geom_hline(yintercept = 0,
             size = 1) +
  geom_hline(yintercept = -25,
             linetype = 2) +
  geom_hline(yintercept = -50,
             linetype = 2) +
  geom_hline(yintercept = -75,
             linetype = 2) +
  geom_hline(yintercept = -100,
```

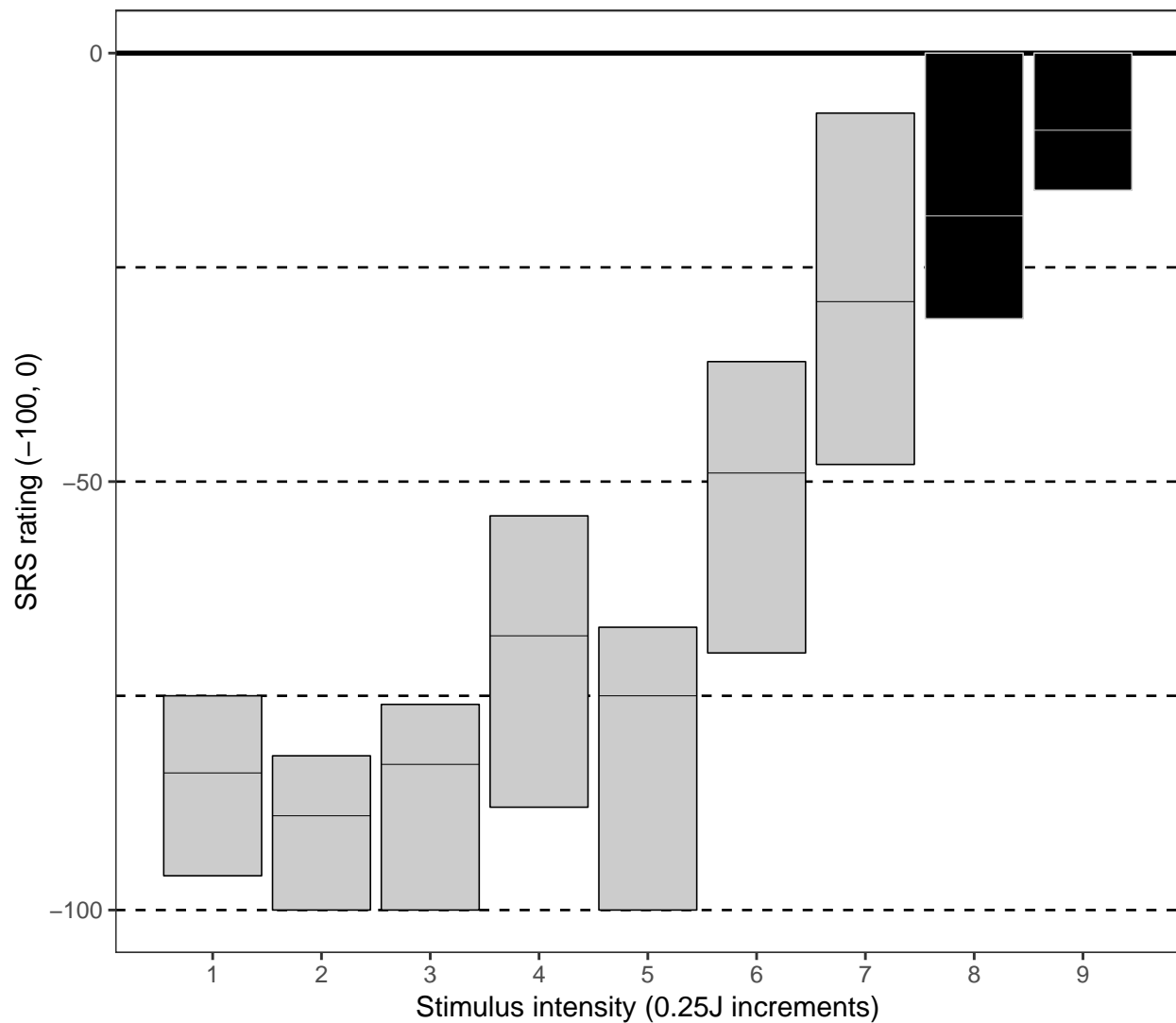
```

      linetype = 2) +
geom_crossbar(aes(y = tri_mean,
                  ymin = lower_ci,
                  ymax = upper_ci,
                  fill = fill,
                  colour = fill),
              fatten = 0,
              size = 0.3) +
scale_fill_manual(values = c('#000000', '#CCCCCC')) +
scale_colour_manual(values = c('#CCCCCC', '#000000')) +
scale_y_continuous(limits = c(-100, 0),
                   breaks = c(-100, -50, 0)) +
scale_x_continuous(breaks = seq(from = 1,
                                to = 9,
                                by = 1)) +
labs(title = "SRS Group: Crossbar plots of 95% CI of Tukey trimeans\nfor ratings at each stimulus i",
      subtitle = '- Basic bootstrap 95% CI with 10,000 resamples\n- Dashed line: pain threshold | - (',
      x = 'Stimulus intensity (0.25J increments)',
      y = 'SRS rating (-100, 0)') +
theme(legend.position = 'none',
      panel.grid = element_blank())

```

## SRS Group: Crossbar plots of 95% CI of Tukey trimeans for ratings at each stimulus intensity

- Basic bootstrap 95% CI with 10,000 resamples
- Dashed line: pain threshold | – Grey fill: 95% CI includes zero



## Session information

```
sessionInfo()

## R version 3.5.1 (2018-07-02)
## Platform: x86_64-apple-darwin15.6.0 (64-bit)
## Running under: macOS 10.14.1
##
## Matrix products: default
## BLAS: /Library/Frameworks/R.framework/Versions/3.5/Resources/lib/libRblas.0.dylib
## LAPACK: /Library/Frameworks/R.framework/Versions/3.5/Resources/lib/libRlapack.dylib
```

```
##
## locale:
## [1] en_GB.UTF-8/en_GB.UTF-8/en_GB.UTF-8/C/en_GB.UTF-8/en_GB.UTF-8
##
## attached base packages:
## [1] stats      graphics  grDevices  utils      datasets  methods    base
##
## other attached packages:
## [1] bindrcpp_0.2.2  skimr_1.0.3    boot_1.3-20    magrittr_1.5
## [5] forcats_0.3.0  stringr_1.3.1  dplyr_0.7.8    purrr_0.2.5
## [9] readr_1.2.1     tidyr_0.8.2    tibble_1.4.2   ggplot2_3.1.0
## [13] tidyverse_1.2.1
##
## loaded via a namespace (and not attached):
## [1] Rcpp_1.0.0      cellranger_1.1.0 pillar_1.3.0    compiler_3.5.1
## [5] plyr_1.8.4      bindr_0.1.1     tools_3.5.1     digest_0.6.18
## [9] lubridate_1.7.4 jsonlite_1.5    evaluate_0.12   nlme_3.1-137
## [13] gtable_0.2.0    lattice_0.20-38 pkgconfig_2.0.2 rlang_0.3.0.1
## [17] cli_1.0.1       rstudioapi_0.8  yaml_2.2.0      haven_2.0.0
## [21] withr_2.1.2.9000 xml2_1.2.0      httr_1.3.1      knitr_1.20
## [25] hms_0.4.2       rprojroot_1.3-2 grid_3.5.1      tidyselect_0.2.5
## [29] glue_1.3.0      R6_2.3.0        readxl_1.1.0    rmarkdown_1.10
## [33] modelr_0.1.2    backports_1.1.2 scales_1.0.0    htmltools_0.3.6
## [37] rvest_0.3.2     assertthat_0.2.0 colorspace_1.3-2 stringi_1.2.4
## [41] lazyeval_0.2.1  munsell_0.5.0   broom_0.5.0     crayon_1.3.4
```