

Supplement 3: Scenario 2

Mean pain intensity of 6.2 (SD 1.7) at 0.26, 0.37, and 0.51 inter-measurement correlation

Peter Kamerman

Last knitted: 01 July 2021

Contents

1	Introduction	2
1.1	Overview	2
1.2	Modelling specifics	2
1.2.1	Data simulation parameters	2
1.2.2	Data simulation and processing	3
1.2.3	Modelling the effect of baseline pain inclusion thresholds	3
2	Generate 2x2 covariance matrices	4
3	Scenario 2A: Inter-measurement correlation = 0.26	5
3.1	Generate and summarise data	5
3.1.1	Unconstrained data	5
3.1.2	Constrained data	6
3.2	Sample size after constraining data	8
3.3	Effect of having a threshold on mean pain intensity scores	8
3.3.1	Model the mean of V1 with increasing pain inclusion thresholds from 0 to 5	9
3.3.2	Model mean of V2 with increasing inclusion thresholds from 0 to 5	10
3.4	Distributional shifts caused by having a threshold	12
3.4.1	Threshold: 0	12
3.4.1.1	Points lost by cutoff	14
3.4.2	Threshold: 3	14
3.4.2.1	Points lost by cutoff	16
3.4.3	Threshold: 4	17
3.4.3.1	Points lost by cutoff	18
3.4.4	Threshold: 5	19
3.4.4.1	Points lost by cutoff	21
3.5	Summary plots	21
4	Scenario 2B: Inter-measurement correlation = 0.37	24
4.1	Generate and summarise data	24
4.1.1	Unconstrained data	24
4.1.2	Constrained data	25
4.2	Sample size after constraining data	27
4.3	Effect of having a threshold on mean pain intensity scores	27
4.3.1	Model mean of V1 with increasing pain inclusion thresholds from 0 to 5	28
4.3.2	Model mean of V2 with increasing inclusion thresholds from 0 to 5	29
4.4	Distributional shifts caused by having a threshold	31
4.4.1	Threshold: 0	31
4.4.1.1	Points lost by cutoff	34
4.4.2	Threshold: 3	34
4.4.2.1	Points lost by cutoff	37
4.4.3	Threshold: 4	37
4.4.3.1	Points lost by cutoff	40
4.4.4	Threshold: 5	40

4.4.4.1	Points lost by cutoff	43
4.5	Summary plots	43
5	Scenario 2C: Inter-measurement correlation = 0.51	46
5.1	Generate and summarise data	46
5.1.1	Unconstrained data	46
5.1.2	Constrained data	47
5.2	Sample size after constraining data	49
5.3	Effect of having a threshold on mean pain intensity scores	49
5.3.1	Model mean of V1 with increasing pain inclusion thresholds from 0 to 5	50
5.3.2	Model mean of V2 with increasing V1 thresholds from 0 to 5	51
5.4	Distributional shifts caused by having a threshold	53
5.4.1	Threshold: 0	53
5.4.1.1	Points lost by cutoff	55
5.4.2	Threshold: 3	55
5.4.2.1	Points lost by cutoff	57
5.4.3	Threshold: 4	58
5.4.3.1	Points lost by cutoff	59
5.4.4	Threshold: 5	60
5.4.4.1	Points lost by cutoff	62
5.5	Summary plots	62
6	Publication plots	65
7	Session information	68

1 Introduction

1.1 Overview

The use of pain intensity cut-offs for study inclusion in clinical trials has two consequences. Firstly, the cut-off artificially raises the baseline mean pain score of the cohort being studied compared to the population the cohort was sampled from. Secondly, unless the correlation between two sequential measurements is 1, there should be a “flattening” of the relationship between the first and subsequent measurements. This “flattening” means that the cut-off has a disproportionate effect on the mean baseline pain intensity compared to subsequent measurements.

This script demonstrates the effect of this “flattening” of the relationship between two sequential pain measurements in a hypothetical placebo group in a clinical trial for the management of pain in the presence of various pain intensity cut-off values for trial inclusion.

1.2 Modelling specifics

1.2.1 Data simulation parameters

Baseline pain scores were extracted from papers listed in the supplementary materials of a systematic review of pharmacological treatments for neuropathic pain¹ and that did not include baseline pain threshold inclusion criteria. Using this information, the pooled mean pain intensity at baseline was calculated to be 6.2 on an 11-point numerical pain rating scale (NRS), and the pooled SD of pain intensity at baseline was 1.7. The correlation between measurements 1 (V1) and 2 (V2) was set at 0.51 and 0.37 based on aggregated data across five clinical trials from 788 patients with rheumatoid arthritis for baseline vs week 4 and week 12 of the trial, respectively², and 0.26 based on aggregated data across nine

¹Finnerup NB, Attal N, Haroutounian S, McNicol E, Baron R, Dworkin RH, Gilron I, Haanpää M, Hansson P, Jensen TS, Kamerman PR, Lund K, Moore A, Raja SN, Rice ASC, Rowbotham M, Sena E, Siddall P, Smith BH, Wallace M. Pharmacotherapy for neuropathic pain in adults: a systematic review and meta-analysis. *Lancet Neurol* 2015;14:162–173. doi:10.1016/S1474-4422(14)70251-0

²Vollert J, Cook NR, Kaptchuk TJ, Sehra ST, Bowen EX, Yong F, Zhang L, Tobias DK, Hall KT. Favorable placebo responses in objective and subjective outcome measures in rheumatoid arthritis clinical trials – implications on new drug development. *[Unpublished data]*

clinical trials from 2017 patients with knee or hip arthritis or chronic low back pain for baseline vs week 12 of the trial³.

1.2.2 Data simulation and processing

Covariance matrices were generated for each of the three combinations of correlation ($r = 0.26, 0.37$, or 0.51) and the SD (1.7) using the `cor2cov` function from the `MBESS` package⁴. Then, each of the three covariance matrices was used to generate random sample from a bivariate normal distribution ($n = 1000$ per sample) with a mean of 6.2. The samples were generated using the `mvrnorm` function from the `MASS` package⁵.

To check the data once they had been generated, measurement 1 (V1) and measurement 2 (V2) were plotted against each other using scatterplots with marginal density plots, and the sample means and SDs were calculated, as was the correlation between the two samples (*unconstrained data*). Thereafter, values were filtered (constrained) such that the minimum V1 value was 1 and the minimum V2 value was 0 on an 11-point NRS, and the maximum V1 and V2 values were 10 on an 11-point NRS. The minimum value of V1 was set to 1 because volunteers eligible to enter a placebo-controlled clinical trial can be expected to have at least some pain. In comparison, V2 values were unconstrained and could take any value from 0 to 10 because pain intensity may take values across the full range of the scale on follow-up. Maximum pain rating were limited to values of 10, the upper limit of the rating scale. To check for changes in centrality, spread, and correlation after filtering the data, the data were once again assessed using plots and numeric summaries.

1.2.3 Modelling the effect of baseline pain inclusion thresholds

A baseline inclusion threshold of 0 on an 11-point NRS (i.e., no inclusion threshold) was used as a “control”. In addition to the control threshold, three baseline pain intensity inclusion thresholds were selected based on the data listed in the supplementary materials of Finnerup and colleagues¹. The three thresholds were: pain intensity ≥ 4 (71% of listed studies), pain intensity ≥ 3 (12% of listed studies), and pain intensity ≥ 5 (11% of listed studies). Data from the three simulated datasets (mean = 6.2, SD = 1.7, correlation = 0.26, 0.37, 0.51) were each modelled under each of the three baseline pain intensity inclusion thresholds, and when there was no threshold.

Modelling the effect of the thresholds involved removing all pairs of V1 and V2 data where V1 was less than the threshold value, yielding new datasets V1' and V2'. To assess the effect of removing data pairs on the group means, we calculated the difference in group means between V1 and V1', and V2 and V2'. To assess the magnitude of the effect, we calculated the mean difference in pain intensity scores between V1' and V2' (point estimate), and generated bias-corrected and accelerated 95% bootstrapped confidence intervals of the difference (2000 resamples, generated using the `groupwiseMean` function from the `rcompanion` package⁶).

For reproducibility, I set the random seed to “2019” for all random sampling.

Note: Because of random sampling the mean (SD) of the samples differ slightly from the population mean (SD).

³Vase L, Vollert J, Finnerup NB, Miao X, Atkinson G, Marshall S, Nemeth R, Lange B, Liss C, Price DD, Maier C, Jensen TS, Segerdahl M. Predictors of the placebo analgesia response in randomized controlled trials of chronic pain: a meta-analysis of the individual data from nine industrially sponsored trials. *Pain* 2015;156:1795–1802. doi:10.1097/j.pain.0000000000000217.

⁴Kelley K. MBESS: The MBESS R package. 2019. Available: <https://CRAN.R-project.org/package=MBESS>

⁵Venables WN, Ripley BD. Modern Applied Statistics with S. Fourth. New York: Springer, 2002. Available: <http://www.stats.ox.ac.uk/pub/MASS4>

⁶Mangiafico S. rcompanion: functions to support extension education program evaluation. 2018. Available: <https://CRAN.R-project.org/package=rcompanion>.

2 Generate 2x2 covariance matrices

Generate a covariance matrix using an SD of 1.7 and correlation of:

- $r = 0.26$ (Scenario 2A)
- $r = 0.37$ (Scenario 2B)
- $r = 0.51$ (Scenario 2C)

```
# Generate 2*2 correlation matrices
cor_026 <- matrix(c(1, 0.26, 0.26, 1), ncol = 2)
cor_037 <- matrix(c(1, 0.37, 0.37, 1), ncol = 2)
cor_051 <- matrix(c(1, 0.51, 0.51, 1), ncol = 2)

# Set the standard deviation
std <- c(1.7, 1.7)

# Generate a 2*2 covariance matrices
cov_026 <- cor2cov(cor.mat = cor_026,
                  sd = std)
cov_037 <- cor2cov(cor.mat = cor_037,
                  sd = std)
cov_051 <- cor2cov(cor.mat = cor_051,
                  sd = std)
```

3 Scenario 2A: Inter-measurement correlation = 0.26

3.1 Generate and summarise data

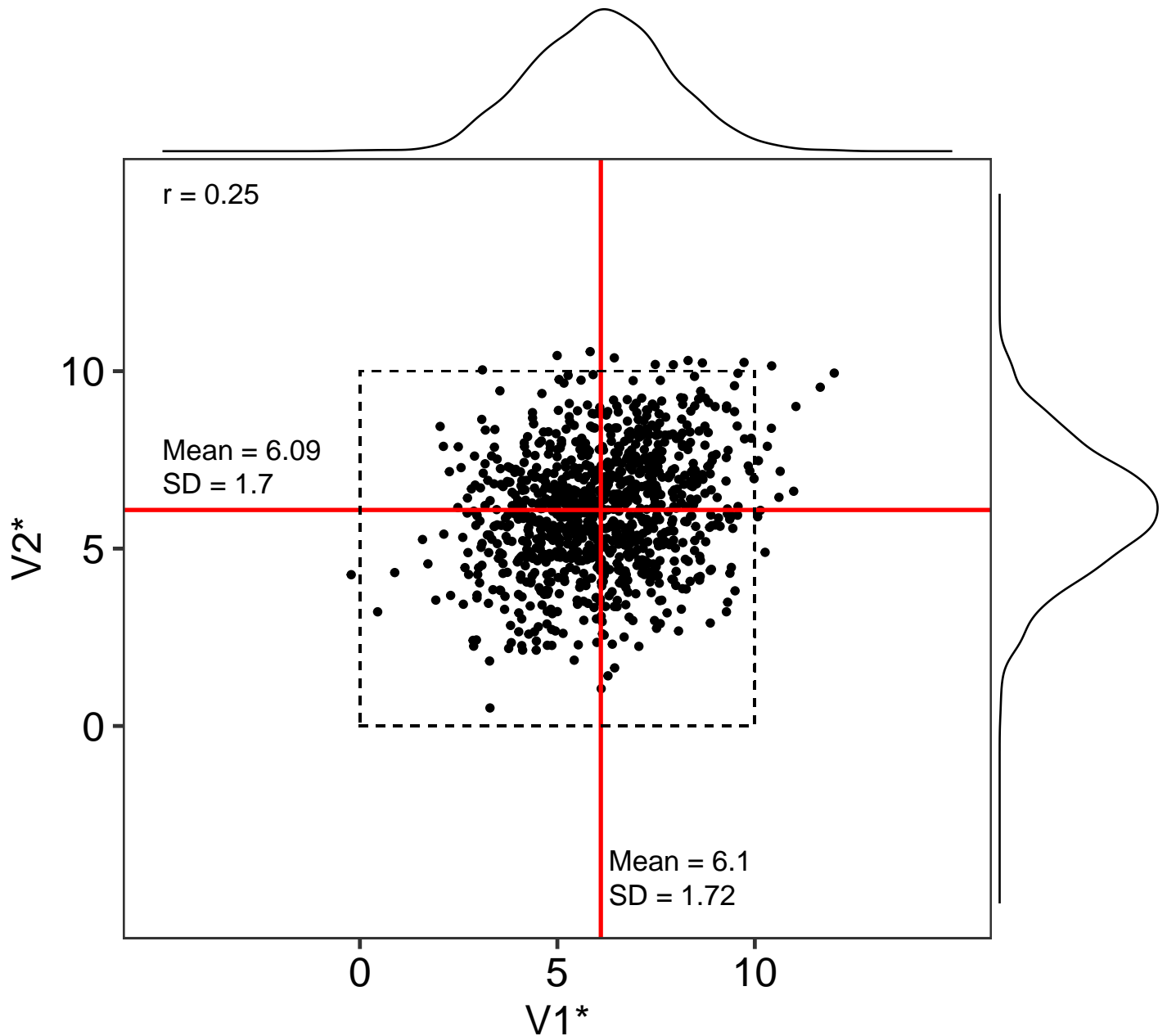
3.1.1 Unconstrained data

```
# Set the random seed for reproducibility
set.seed(2019)

# Generate the data
cor_026.base <- as.data.frame(mvrnorm(n = 1000, mu = c(6.2, 6.2), Sigma = cov_026))

# Plot unconstrained data
ggMarginal(ggplot(data = cor_026.base) +
  aes(x = V1, y = V2) +
  geom_point() +
  geom_hline(yintercept = mean(cor_026.base$V2),
    colour = 'red', size = 1) +
  geom_vline(xintercept = mean(cor_026.base$V1),
    colour = 'red', size = 1) +
  geom_rect(ymin = 0, ymax = 10,
    xmin = 0, xmax = 10,
    colour = '#000000',
    alpha = 0,
    linetype = 2) +
  annotate(geom = 'text', x = -5, y = 15, hjust = 0, size = 5,
    label = str_glue("r = {round(cor(cor_026.base$V1,
      cor_026.base$V2), 2)}")) +
  annotate(geom = 'text', x = -5, y = mean(cor_026.base$V2) + 1.7,
    hjust = 0, size = 5,
    label = str_glue("Mean = {round(mean(cor_026.base$V2), 2)}")) +
  annotate(geom = 'text', x = -5, y = mean(cor_026.base$V2) + 0.75,
    hjust = 0, size = 5,
    label = str_glue("SD = {round(sd(cor_026.base$V2), 2)}")) +
  annotate(geom = 'text', x = mean(cor_026.base$V1) + 0.2, y = -3.8,
    hjust = 0, size = 5,
    label = str_glue("Mean = {round(mean(cor_026.base$V1), 2)}")) +
  annotate(geom = 'text', x = mean(cor_026.base$V1) + 0.2, y = -4.75,
    hjust = 0, size = 5,
    label = str_glue("SD = {round(sd(cor_026.base$V1), 2)}")) +
  labs(title = 'Scenario 2A: Unconstained',
    caption = '*Pain rated on a 0 to 10 numerical pain rating scale',
    x = 'V1*',
    y = 'V2*') +
  scale_y_continuous(limits = c(-5, 15),
    breaks = c(0, 5, 10)) +
  scale_x_continuous(limits = c(-5, 15),
    breaks = c(0, 5, 10)))
```

Scenario 2A: Unconstrained



*Pain rated on a 0 to 10 numerical pain rating scale

3.1.2 Constrained data

```
# Constrain data
cor_026 <- cor_026.base %>%
  filter(V1 >= 1 & V1 <= 10) %>%
  filter(V2 >= 0 & V2 <= 10) %>%
  mutate(group = 'No threshold')

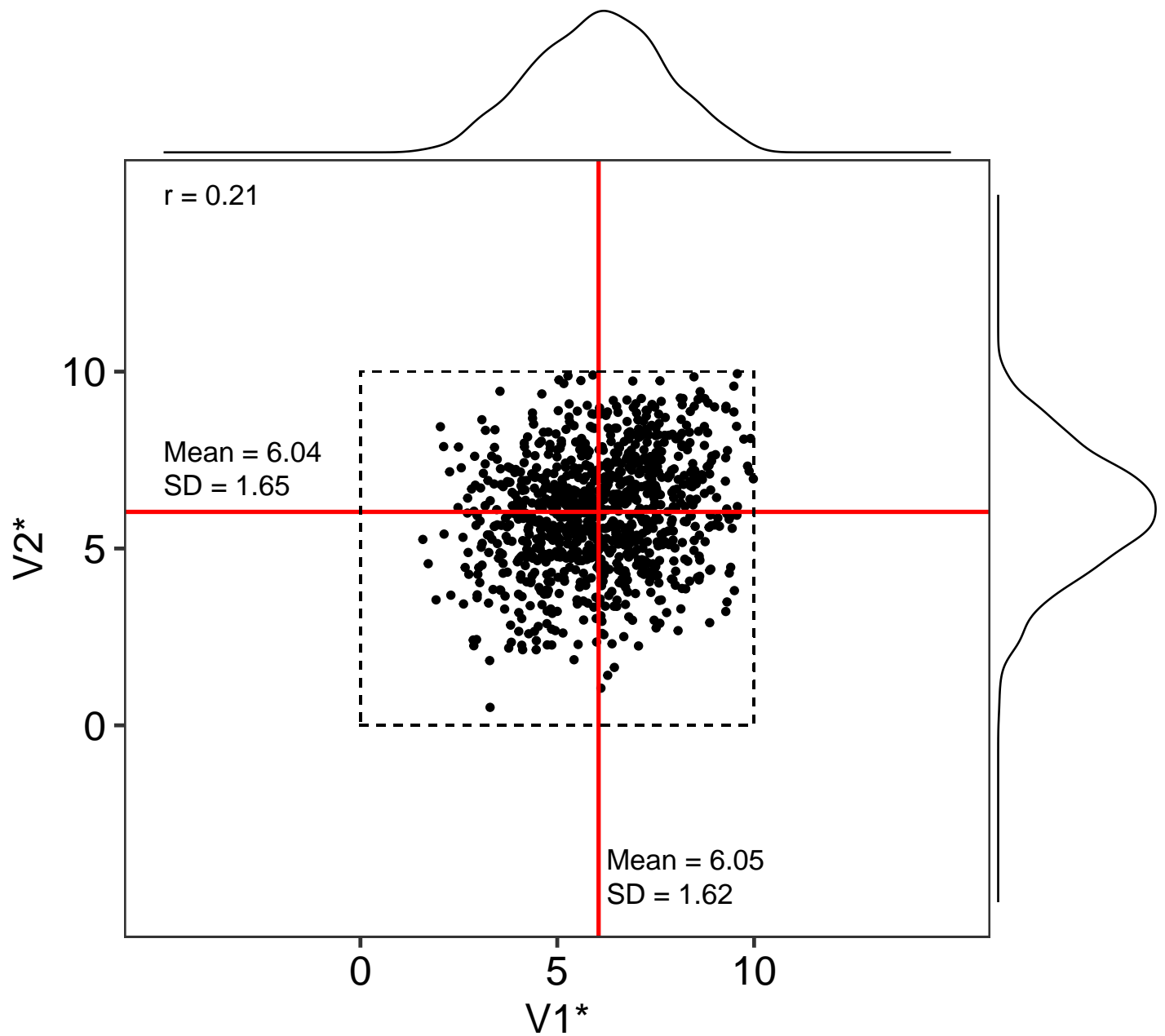
# Plot constrained data
ggMarginal(ggplot(data = cor_026) +
  aes(x = V1, y = V2) +
  geom_point() +
```

```

geom_hline(yintercept = mean(cor_026$V2),
           colour = 'red', size = 1) +
geom_vline(xintercept = mean(cor_026$V1),
           colour = 'red', size = 1) +
geom_rect(ymin = 0, ymax = 10,
          xmin = 0, xmax = 10,
          colour = '#000000',
          alpha = 0,
          linetype = 2) +
annotate(geom = 'text', x = -5, y = 15, hjust = 0, size = 5,
         label = str_glue("r = {round(cor(cor_026$V1,
                                   cor_026$V2), 2)}")) +
annotate(geom = 'text', x = -5, y = mean(cor_026$V2) + 1.7,
         hjust = 0, size = 5,
         label = str_glue("Mean = {round(mean(cor_026$V2), 2)}")) +
annotate(geom = 'text', x = -5, y = mean(cor_026$V2) + 0.75,
         hjust = 0, size = 5,
         label = str_glue("SD = {round(sd(cor_026$V2), 2)}")) +
annotate(geom = 'text', x = mean(cor_026$V1) + 0.2, y = -3.8,
         hjust = 0, size = 5,
         label = str_glue("Mean = {round(mean(cor_026$V1), 2)}")) +
annotate(geom = 'text', x = mean(cor_026$V1) + 0.2, y = -4.75,
         hjust = 0, size = 5,
         label = str_glue("SD = {round(sd(cor_026$V1), 2)}")) +
labs(title = 'Scenario 2A: Constrained',
     caption = '*Pain rated on a 0 to 10 numerical pain rating scale',
     x = 'V1*',
     y = 'V2*') +
scale_y_continuous(limits = c(-5, 15),
                   breaks = c(0, 5, 10)) +
scale_x_continuous(limits = c(-5, 15),
                   breaks = c(0, 5, 10)))

```

Scenario 2A: Constrained



*Pain rated on a 0 to 10 numerical pain rating scale

3.2 Sample size after constraining data

```
nrow(cor_026)
```

```
## [1] 975
```

3.3 Effect of having a threshold on mean pain intensity scores

Constrained data only

3.3.1 Model the mean of V1 with increasing pain inclusion thresholds from 0 to 5

```
# Extract visit 1 data
cor_026V1 <- cor_026$V1

# Generate a vector of threshold values to iterate over
cutoff <- 0:5

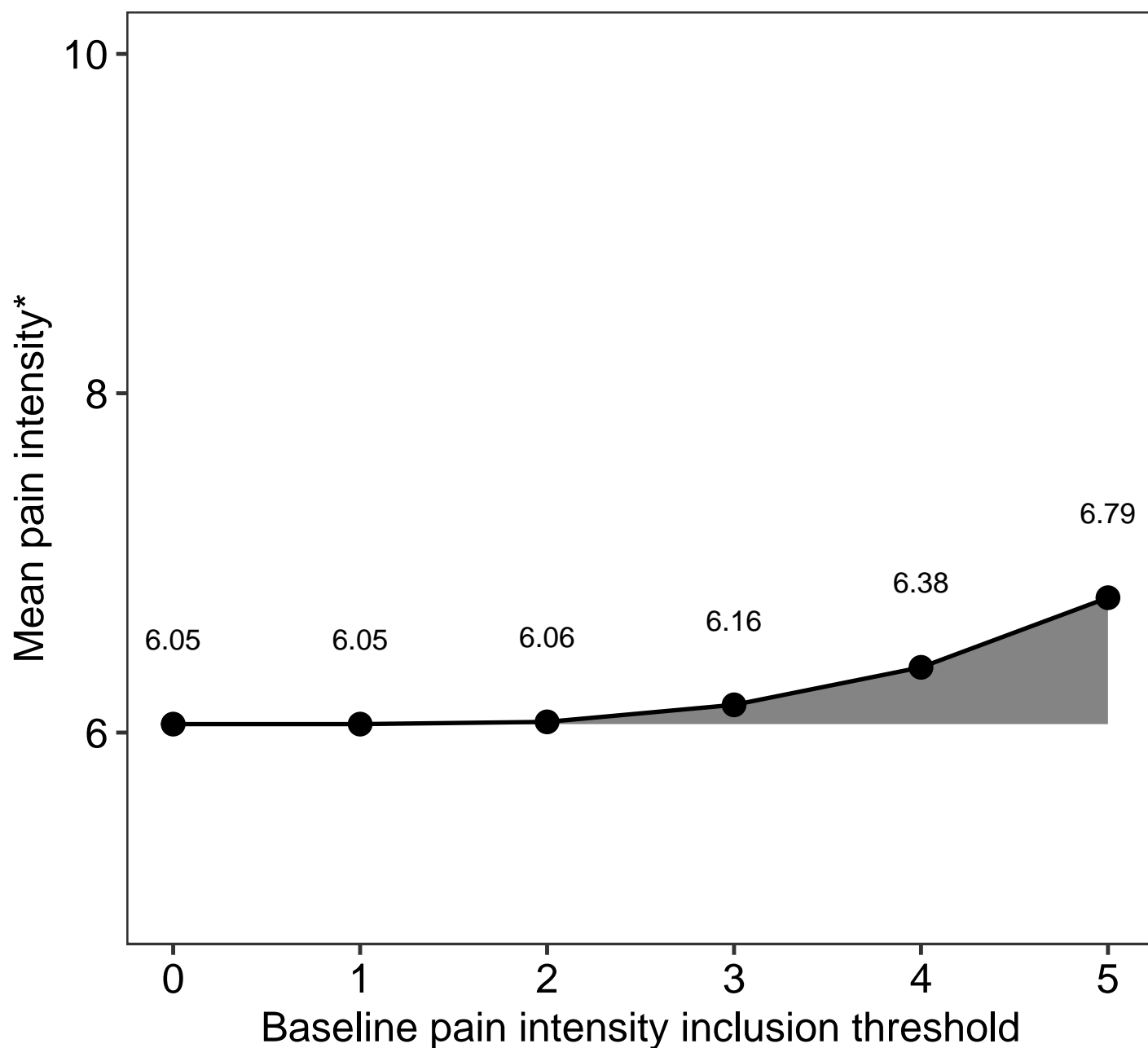
# Generate a vector of V1 means at each V1 threshold
cor_026V1.shift <- sapply(cutoff, function(x){mean(cor_026V1[cor_026V1 > x])})

# Calculate deviation
(cor_026V1.df <- data.frame(time = 'V1',
                             cutoff = cutoff,
                             cutoff2 = cutoff - 0.15, # Offset for plotting purposes
                             mean = cor_026V1.shift) %>%
  mutate(deviation = mean - mean(cor_026V1),
         time = as.character(time)))

##   time cutoff cutoff2    mean deviation
## 1   V1      0   -0.15 6.049875 0.00000000
## 2   V1      1    0.85 6.049875 0.00000000
## 3   V1      2    1.85 6.063167 0.01329184
## 4   V1      3    2.85 6.163357 0.11348182
## 5   V1      4    3.85 6.384584 0.33470941
## 6   V1      5    4.85 6.794978 0.74510347

# Plot data
ggplot(data = cor_026V1.df) +
  aes(x = cutoff, y = mean, ymin = mean(cor_026V1), ymax = mean) +
  geom_ribbon(alpha = 0.6) +
  geom_point(size = 5) +
  geom_line(size = 1) +
  geom_text(aes(label = round(mean, 2)),
            nudge_y = 0.5, size = 5) +
  scale_y_continuous(limits = c(5, 10),
                     breaks = c(0, 2, 4, 6, 8, 10)) +
  labs(title = 'Scenario 2A: Shift in V1 mean pain intensity',
       caption = '*Pain rated on a 0 to 10 numerical pain rating scale',
       x = 'Baseline pain intensity inclusion threshold',
       y = 'Mean pain intensity*')
```

Scenario 2A: Shift in V1 mean pain intensity



*Pain rated on a 0 to 10 numerical pain rating scale

3.3.2 Model mean of V2 with increasing inclusion thresholds from 0 to 5

```
# Extract visit 2 data
cor_026V2 <- cor_026$V2

# Generate a vector of threshold values to iterate over
cutoff <- 0:5

# Generate a vector of V2 means at each V1 threshold
cor_026V2.shift <- map_dbl(.x = cutoff,
  ~ cor_026 %>%
    filter(V1 > .x) %>%
```

```

        .$V2 %>%
        mean(.))

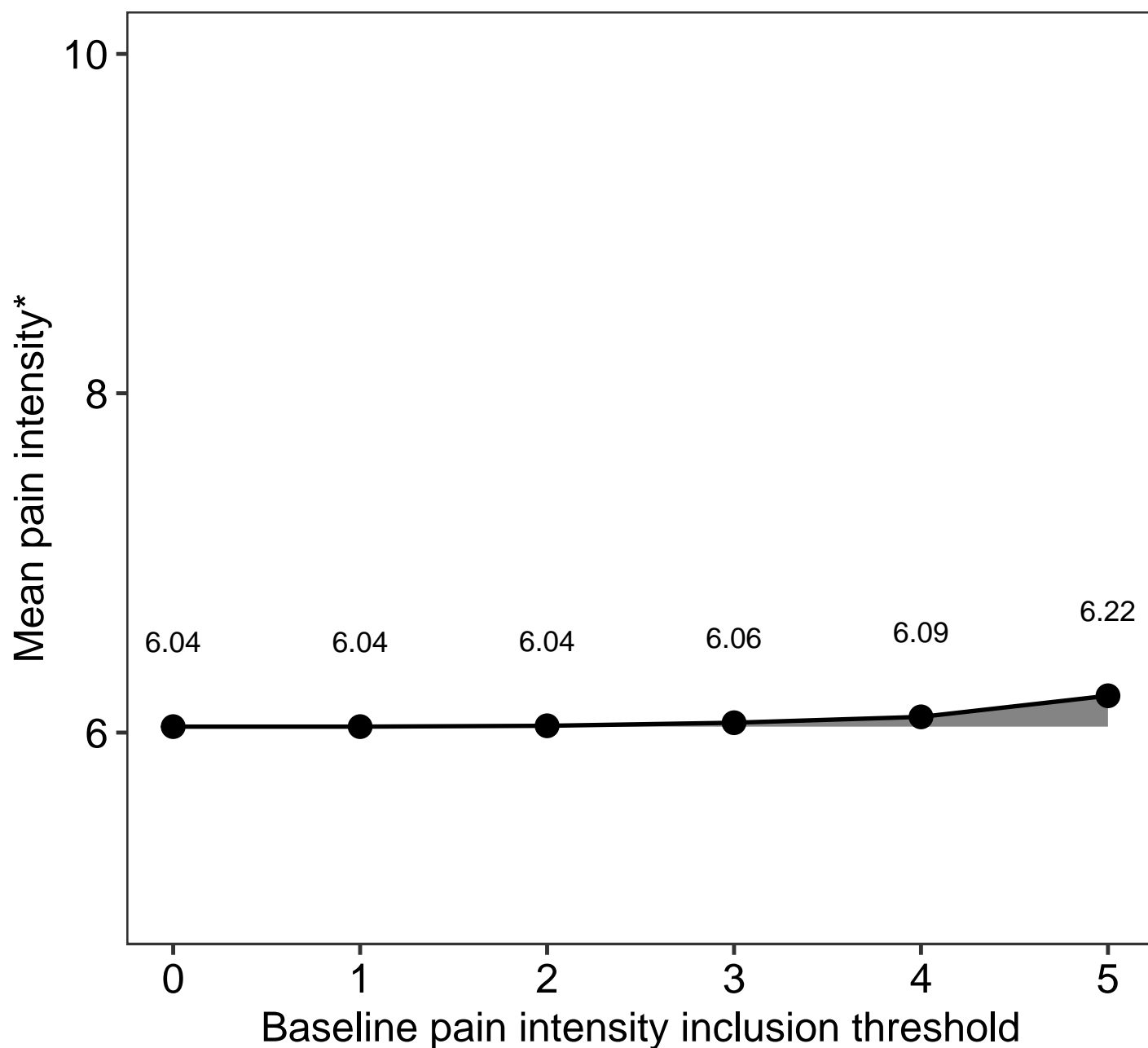
# Calculate deviation
(cor_026V2.df <- data.frame(time = 'V2',
                             cutoff = cutoff,
                             cutoff2 = cutoff + 0.15, # Offset for plotting purposes
                             mean = cor_026V2.shift) %>%
mutate(deviation = mean - mean(cor_026V2),
       time = as.character(time)))

##   time cutoff cutoff2    mean  deviation
## 1   V2      0    0.15 6.035110 0.000000000
## 2   V2      1    1.15 6.035110 0.000000000
## 3   V2      2    2.15 6.039978 0.004868239
## 4   V2      3    3.15 6.058107 0.022997730
## 5   V2      4    4.15 6.092630 0.057520908
## 6   V2      5    5.15 6.216998 0.181888400

# Plot data
ggplot(data = cor_026V2.df) +
  aes(x = cutoff, y = mean, ymin = mean(cor_026V2), ymax = mean) +
  geom_ribbon(alpha = 0.6) +
  geom_point(size = 5) +
  geom_line(size = 1) +
  geom_text(aes(label = round(mean, 2)),
            nudge_y = 0.5, size = 5) +
  scale_y_continuous(limits = c(5, 10),
                     breaks = c(0, 2, 4, 6, 8, 10)) +
  labs(title = 'Scenario 2A: Shift in V2 mean pain intensity',
       caption = '*Pain rated on a 0 to 10 numerical pain rating scale',
       x = 'Baseline pain intensity inclusion threshold',
       y = 'Mean pain intensity*')

```

Scenario 2A: Shift in V2 mean pain intensity



*Pain rated on a 0 to 10 numerical pain rating scale

3.4 Distributional shifts caused by having a threshold

3.4.1 Threshold: 0

```
# Process data
placebo_1.0 <- cor_026 %>%
  filter(V1 >= 0) %>%
  mutate(difference = V1 - V2) %>%
  mutate(group = 'Threshold')

# Set seed
set.seed(2019)
```

```
# Calculate the mean (95%CI) difference between V1 and V2
```

```
diff_1.0 <- groupwiseMean(difference ~ 1,
  data = placebo_1.0,
  R = 2000,
  traditional = FALSE,
  bca = TRUE)
```

```
diff_1.0$.id <- 0
```

```
kable(diff_1.0)
```

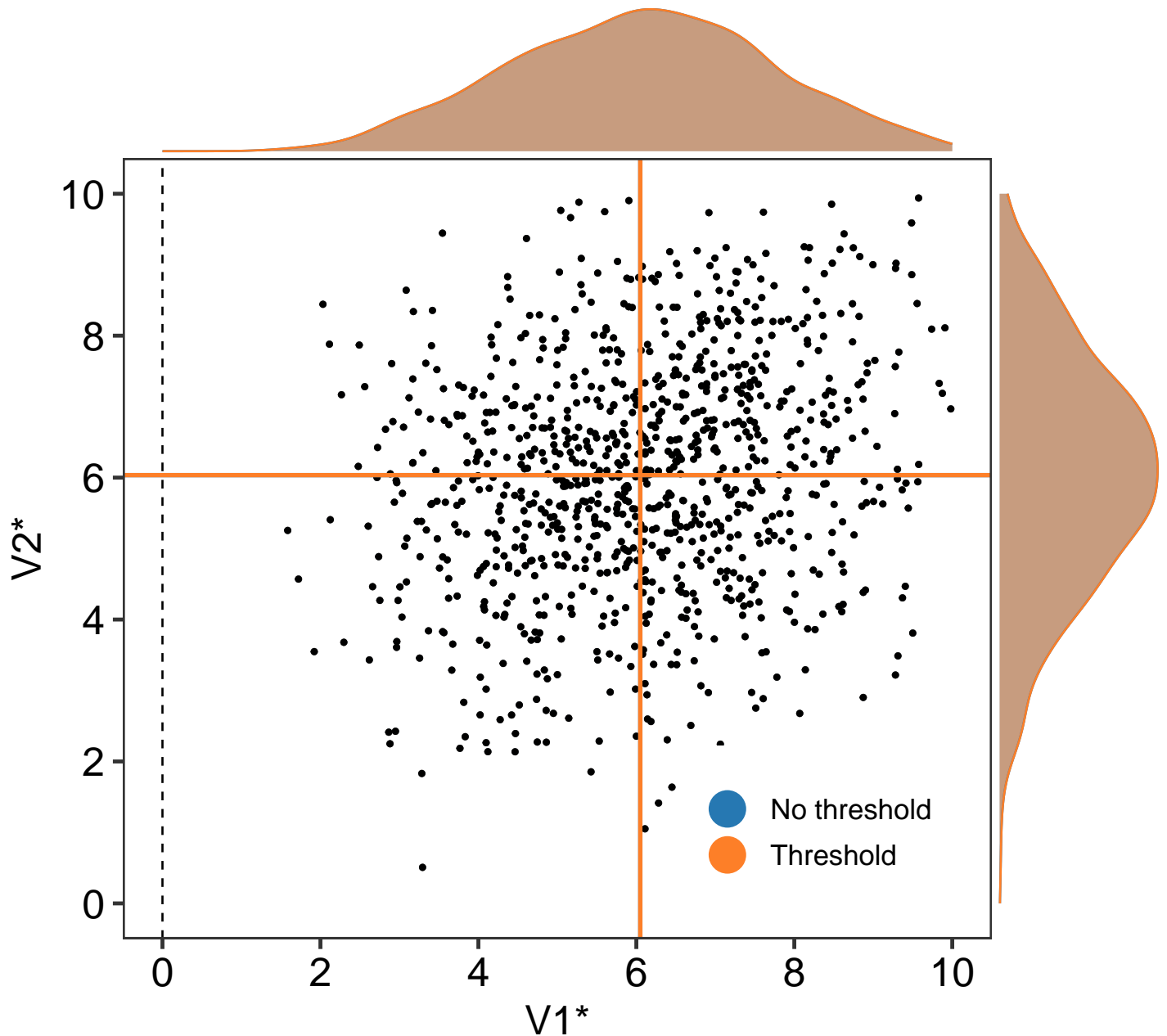
.id	n	Mean	Conf.level	Bca.lower	Bca.upper
0	975	0.0148	0.95	-0.116	0.142

```
# Plot the data
```

```
ggMarginal(placebo_1.0[, 1:3] %>%
  bind_rows(cor_026) %>%
  mutate(group = factor(group,
    levels = c('No threshold', 'Threshold'),
    ordered = TRUE)) %>%

  ggplot(data = .) +
  aes(x = V1, y = V2) +
  geom_point(aes(colour = group, fill = group),
    size = 1) +
  guides(colour = guide_legend(override.aes = list(size = 8))) +
  geom_point(data = cor_026,
    colour = '#999999',
    size = 1) +
  geom_point(data = placebo_1.0,
    size = 1,
    colour = '#000000') +
  geom_vline(xintercept = mean(cor_026$V1),
    colour = pal[1], size = 1) +
  geom_vline(xintercept = mean(placebo_1.0$V1),
    colour = pal[2], size = 1) +
  geom_vline(xintercept = 0, linetype = 2) +
  geom_hline(yintercept = mean(cor_026$V2),
    colour = pal[1], size = 1) +
  geom_hline(yintercept = mean(placebo_1.0$V2),
    colour = pal[2], size = 1) +
  scale_y_continuous(limits = c(0, 10),
    breaks = c(0, 2, 4, 6, 8, 10)) +
  scale_x_continuous(limits = c(0, 10),
    breaks = c(0, 2, 4, 6, 8, 10)) +
  scale_fill_manual(values = pal) +
  scale_colour_manual(values = pal) +
  labs(title = 'Scenario 2A: Pain inclusion threshold = 0',
    caption = '*Pain rated on a 0 to 10 numerical pain rating scale',
    x = 'V1*',
    y = 'V2*') +
  theme(legend.title = element_blank(),
    legend.position = c(0.8, 0.15)),
groupColour = TRUE,
groupFill = TRUE)
```

Scenario 2A: Pain inclusion threshold = 0



*Pain rated on a 0 to 10 numerical pain rating scale

```
nrow(cor_026) - nrow(placebo_1.0)
```

3.4.1.1 Points lost by cutoff

```
## [1] 0
```

3.4.2 Threshold: 3

```
# Process data  
placebo_1.3 <- cor_026 %>%  
  filter(V1 >= 3) %>%
```

```

mutate(difference = V1 - V2) %>%
mutate(group = 'Threshold')

# Set seed
set.seed(2019)

# Calculate the mean (95%CI) difference between V1 and V2
diff_1.3 <- groupwiseMean(difference ~ 1,
                          data = placebo_1.3,
                          R = 2000,
                          traditional = FALSE,
                          bca = TRUE)

diff_1.3$.id <- 3

kable(diff_1.3)

```

.id	n	Mean	Conf.level	Bca.lower	Bca.upper
3	944	0.105	0.95	-0.0185	0.223

```

# Plot the data
ggMarginal(placebo_1.3[, 1:3] %>%
  bind_rows(cor_026) %>%
  mutate(group = factor(group,
                        levels = c('No threshold', 'Threshold'),
                        ordered = TRUE)) %>%

  ggplot(data = .) +
  aes(x = V1, y = V2) +
  geom_point(aes(colour = group, fill = group),
            size = 1) +
  guides(colour = guide_legend(override.aes = list(size = 8))) +
  geom_point(data = cor_026,
            colour = '#999999',
            size = 1) +
  geom_point(data = placebo_1.3,
            size = 1,
            colour = '#000000') +
  geom_vline(xintercept = mean(cor_026$V1),
            colour = pal[1], size = 1) +
  geom_vline(xintercept = mean(placebo_1.3$V1),
            colour = pal[2], size = 1) +
  geom_vline(xintercept = 3, linetype = 2) +
  geom_hline(yintercept = mean(cor_026$V2),
            colour = pal[1], size = 1) +
  geom_hline(yintercept = mean(placebo_1.3$V2),
            colour = pal[2], size = 1) +
  scale_y_continuous(limits = c(0, 10),
                    breaks = c(0, 2, 4, 6, 8, 10)) +
  scale_x_continuous(limits = c(0, 10),
                    breaks = c(0, 2, 4, 6, 8, 10)) +
  scale_fill_manual(values = pal) +
  scale_colour_manual(values = pal) +
  labs(title = 'Scenario 2A: Pain inclusion threshold = 3',
       caption = '*Pain rated on a 0 to 10 numerical pain rating scale',
       x = 'V1*',
       y = 'V2*') +
  theme(legend.title = element_blank(),

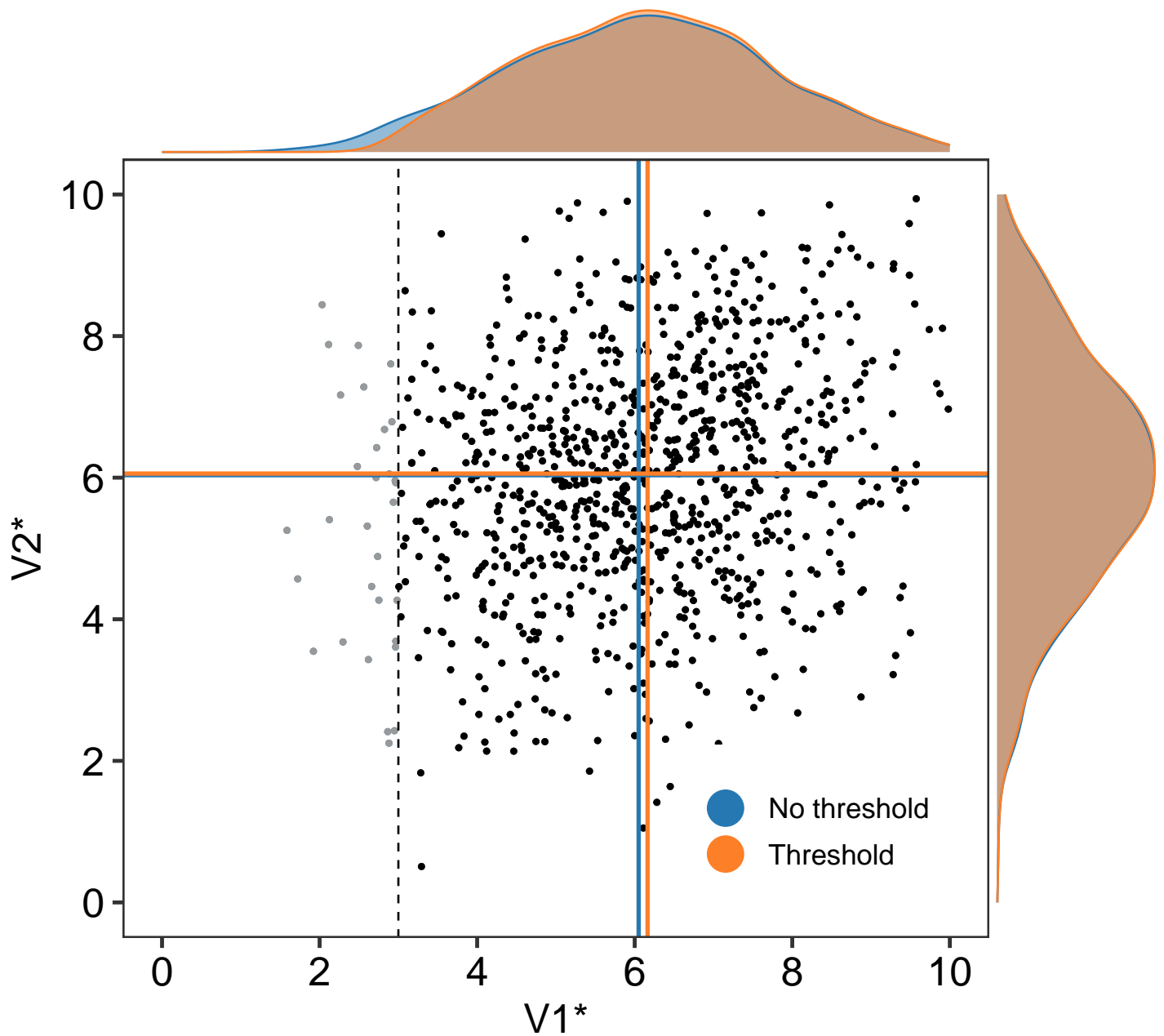
```

```

legend.position = c(0.8, 0.15)),
groupColour = TRUE,
groupFill = TRUE)

```

Scenario 2A: Pain inclusion threshold = 3



*Pain rated on a 0 to 10 numerical pain rating scale

```
nrow(cor_026) - nrow(placebo_1.3)
```

3.4.2.1 Points lost by cutoff

```
## [1] 31
```


3.4.3 Threshold: 4

```
# Process that data
placebo_1.4 <- cor_026 %>%
  filter(V1 >= 4) %>%
  mutate(difference = V1 - V2) %>%
  mutate(group = 'Threshold')

# Set seed
set.seed(2019)

# Calculate the mean (95%CI) difference between V1 and V2
diff_1.4 <- groupwiseMean(difference ~ 1,
  data = placebo_1.4,
  R = 2000,
  traditional = FALSE,
  bca = TRUE)

diff_1.4$.id <- 4

kable(diff_1.4)
```

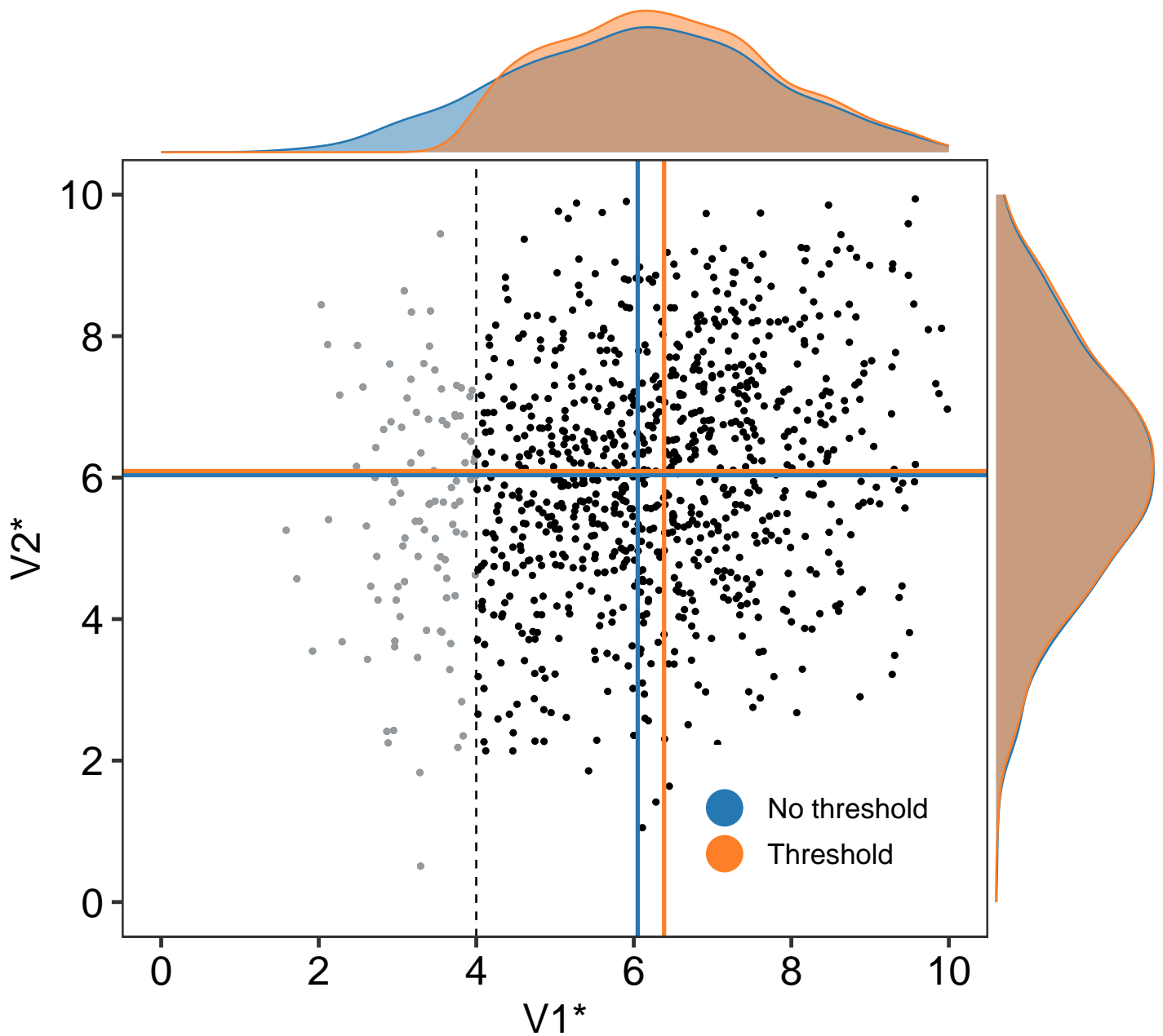
.id	n	Mean	Conf.level	Bca.lower	Bca.upper
4	871	0.292	0.95	0.169	0.428

```
# Plot the data
ggMarginal(placebo_1.4[, 1:3] %>%
  bind_rows(cor_026) %>%
  mutate(group = factor(group,
    levels = c('No threshold', 'Threshold'),
    ordered = TRUE)) %>%

  ggplot(data = .) +
  aes(x = V1, y = V2) +
  geom_point(aes(colour = group, fill = group),
    size = 1) +
  guides(colour = guide_legend(override.aes = list(size = 8))) +
  geom_point(data = cor_026,
    colour = '#999999',
    size = 1) +
  geom_point(data = placebo_1.4,
    size = 1,
    colour = '#000000') +
  geom_vline(xintercept = mean(cor_026$V1),
    colour = pal[1], size = 1) +
  geom_vline(xintercept = mean(placebo_1.4$V1),
    colour = pal[2], size = 1) +
  geom_vline(xintercept = 4, linetype = 2) +
  geom_hline(yintercept = mean(cor_026$V2),
    colour = pal[1], size = 1) +
  geom_hline(yintercept = mean(placebo_1.4$V2),
    colour = pal[2], size = 1) +
  scale_y_continuous(limits = c(0, 10),
    breaks = c(0, 2, 4, 6, 8, 10)) +
  scale_x_continuous(limits = c(0, 10),
    breaks = c(0, 2, 4, 6, 8, 10)) +
  scale_fill_manual(values = pal) +
  scale_colour_manual(values = pal) +
```

```
labs(title = 'Scenario 2A: Pain inclusion threshold = 4',
     caption = '*Pain rated on a 0 to 10 numerical pain rating scale',
     x = 'V1*',
     y = 'V2*') +
theme(legend.title = element_blank(),
     legend.position = c(0.8, 0.15)),
groupColour = TRUE,
groupFill = TRUE)
```

Scenario 2A: Pain inclusion threshold = 4



*Pain rated on a 0 to 10 numerical pain rating scale

```
nrow(cor_026) - nrow(placebo_1.4)
```

3.4.3.1 Points lost by cutoff

```
## [1] 104
```

3.4.4 Threshold: 5

```
# Process that data
placebo_1.5 <- cor_026 %>%
  filter(V1 >= 5) %>%
  mutate(difference = V1 - V2) %>%
  mutate(group = 'Threshold')

# Set seed
set.seed(2019)

# Calculate the mean (95%CI) difference between V1 and V2
diff_1.5 <- groupwiseMean(difference ~ 1,
  data = placebo_1.5,
  R = 2000,
  traditional = FALSE,
  bca = TRUE)

diff_1.5$.id <- 5

kable(diff_1.5)
```

.id	n	Mean	Conf.level	Bca.lower	Bca.upper
5	714	0.578	0.95	0.438	0.718

```
# Plot the data
ggMarginal(placebo_1.5[, 1:3] %>%
  bind_rows(cor_026) %>%
  mutate(group = factor(group,
    levels = c('No threshold', 'Threshold'),
    ordered = TRUE)) %>%

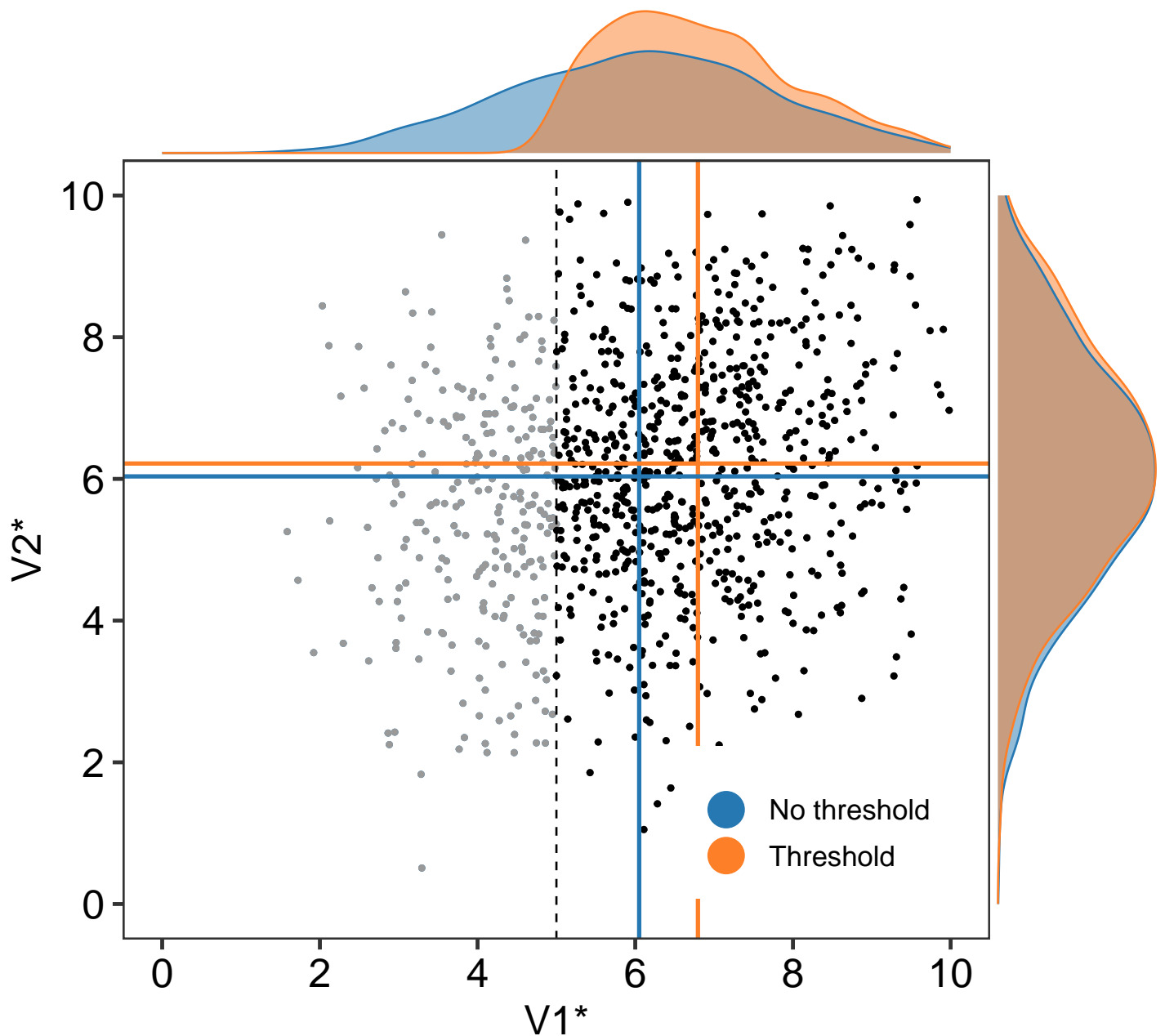
  ggplot(data = .) +
  aes(x = V1, y = V2) +
  geom_point(aes(colour = group, fill = group),
    size = 1) +
  guides(colour = guide_legend(override.aes = list(size = 8))) +
  geom_point(data = cor_026,
    colour = '#999999',
    size = 1) +
  geom_point(data = placebo_1.5,
    size = 1,
    colour = '#000000') +
  geom_vline(xintercept = mean(cor_026$V1),
    colour = pal[1], size = 1) +
  geom_vline(xintercept = mean(placebo_1.5$V1),
    colour = pal[2], size = 1) +
  geom_vline(xintercept = 5, linetype = 2) +
  geom_hline(yintercept = mean(cor_026$V2),
    colour = pal[1], size = 1) +
  geom_hline(yintercept = mean(placebo_1.5$V2),
    colour = pal[2], size = 1) +
  scale_y_continuous(limits = c(0, 10),
    breaks = c(0, 2, 4, 6, 8, 10)) +
  scale_x_continuous(limits = c(0, 10),
```

```

breaks = c(0, 2, 4, 6, 8, 10)) +
scale_fill_manual(values = pal) +
scale_colour_manual(values = pal) +
labs(title = 'Scenario 2A: Pain inclusion threshold = 5',
caption = '*Pain rated on a 0 to 10 numerical pain rating scale',
x = 'V1*',
y = 'V2*') +
theme(legend.title = element_blank(),
legend.position = c(0.8, 0.15)),
groupColour = TRUE,
groupFill = TRUE)

```

Scenario 2A: Pain inclusion threshold = 5



*Pain rated on a 0 to 10 numerical pain rating scale

```
nrow(cor_026) - nrow(placebo_1.5)
```

3.4.4.1 Points lost by cutoff

```
## [1] 261
```

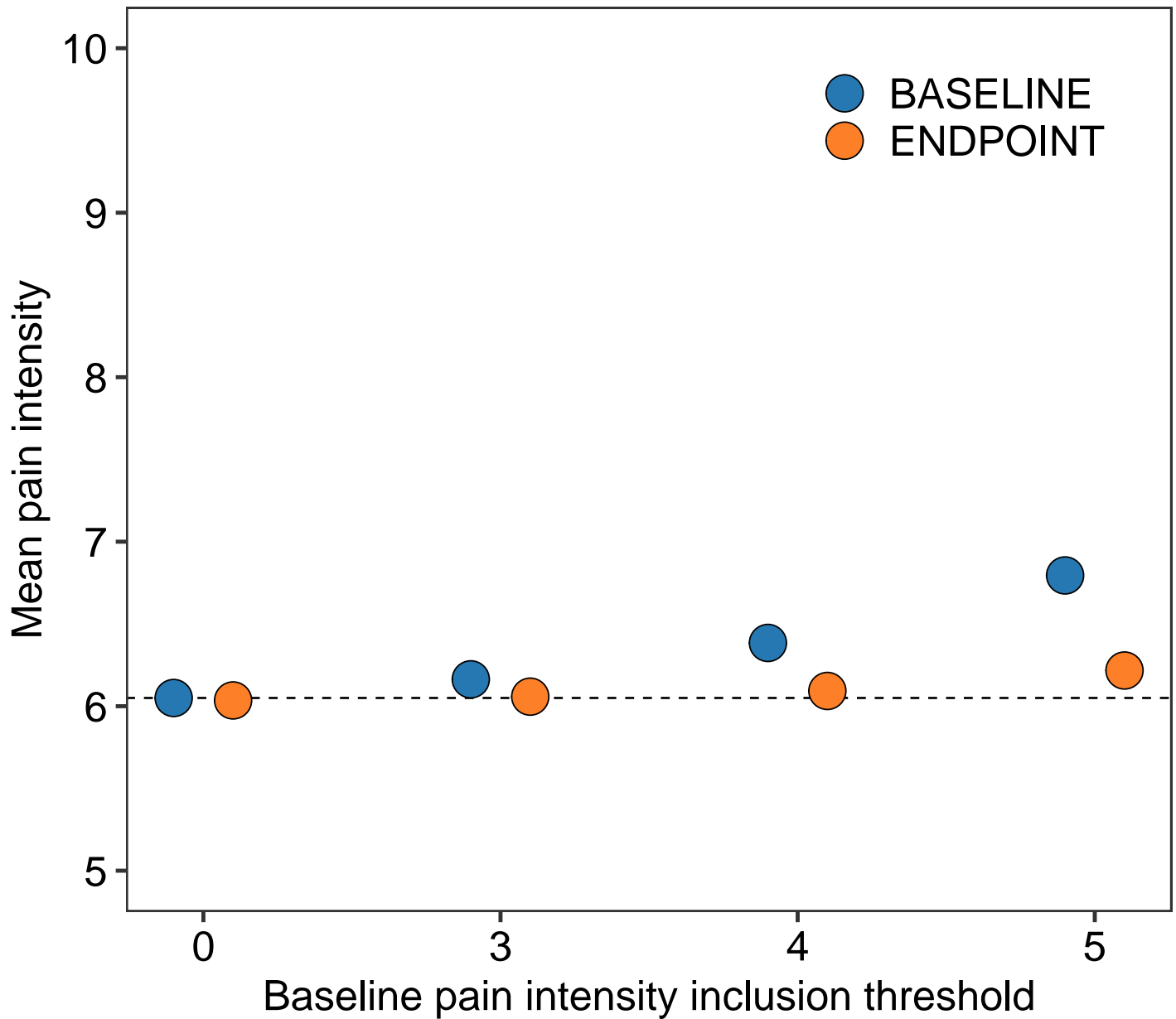
3.5 Summary plots

```
# Plot 1
shift_A <- cor_026V1.df %>%
  bind_rows(cor_026V2.df) %>%
  filter(cutoff != 1 & cutoff != 2) %>%
  mutate(cutoff2 = c(-0.1, 0.9, 1.9, 2.9, 0.1, 1.1, 2.1, 3.1)) %>%
  ggplot(data = .) +
  aes(y = mean,
      x = cutoff2,
      fill = time) +
  geom_hline(yintercept = 6.05,
            linetype = 2) +
  geom_point(shape = 21,
            size = 8) +
  labs(title = 'Scenario 2A',
      x = 'Baseline pain intensity inclusion threshold',
      y = 'Mean pain intensity',
      subtitle = 'Threshold 0:\nBASELINE = 6.1 (1.6), ENDPOINT = 6.0 (1.7), r = 0.21') +
  scale_x_continuous(breaks = c(0, 1, 2, 3),
                    labels = c(0, 3, 4, 5)) +
  scale_y_continuous(limits = c(5, 10)) +
  scale_fill_manual(labels = c('BASELINE', 'ENDPOINT'),
                    values = pal) +
  theme(legend.title = element_blank(),
      legend.position = c(0.8, 0.89),
      legend.text = element_text(size = 20)); shift_A
```

Scenario 2A

Threshold 0:

BASELINE = 6.1 (1.6), ENDPOINT = 6.0 (1.7), $r = 0.21$



```
# Plot 2
# Bind diff_*. dataframes
diff_all_1 <- diff_1.0 %>%
  bind_rows(diff_1.3, diff_1.4, diff_1.5)

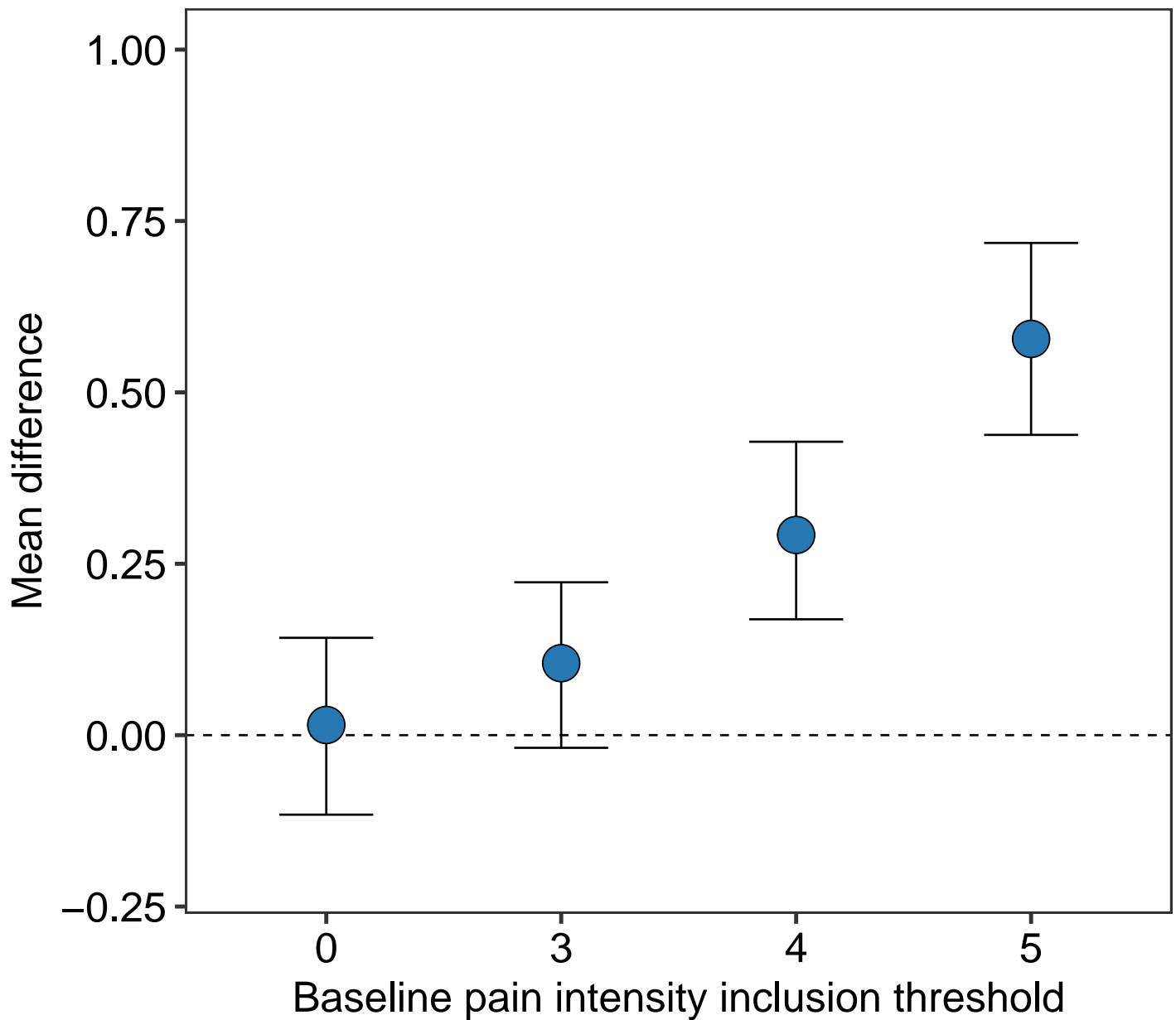
diff_A <- diff_all_1 %>%
  mutate(Threshold = factor(.id)) %>%
  ggplot(data = .) +
  aes(x = Threshold,
      y = Mean,
      ymin = Bca.lower,
      ymax = Bca.upper) +
  geom_hline(yintercept = 0,
             linetype = 2) +
```

```
geom_errorbar(width = 0.4) +
geom_point(shape = 21,
           fill = pal[[1]],
           size = 8) +
labs(title = 'Scenario 2A',
     subtitle = 'Threshold 0:\nBASELINE = 6.1 (1.6), ENDPOINT = 6.0 (1.7), r = 0.21',
     x = 'Baseline pain intensity inclusion threshold',
     y = 'Mean difference') +
scale_y_continuous(limits = c(-0.2, 1.0)); diff_A
```

Scenario 2A

Threshold 0:

BASELINE = 6.1 (1.6), ENDPOINT = 6.0 (1.7), $r = 0.21$



4 Scenario 2B: Inter-measurement correlation = 0.37

4.1 Generate and summarise data

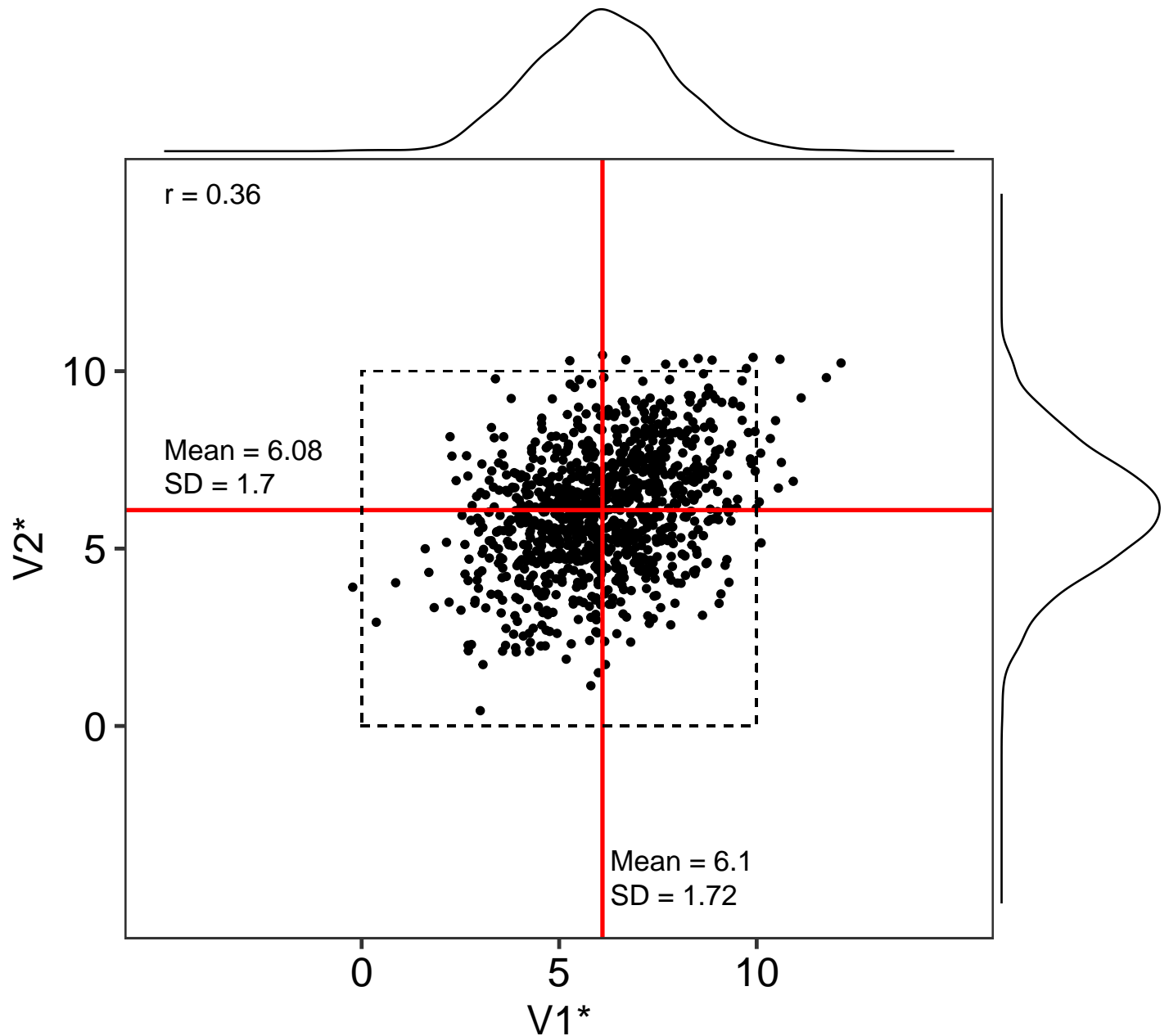
4.1.1 Unconstrained data

```
# Set the random seed for reproducibility
set.seed(2019)

# Generate the data
cor_037.base <- as.data.frame(mvrnorm(n = 1000, mu = c(6.2, 6.2), Sigma = cov_037))

# Plot unconstrained data
ggMarginal(ggplot(data = cor_037.base) +
  aes(x = V1, y = V2) +
  geom_point() +
  geom_hline(yintercept = mean(cor_037.base$V2),
    colour = 'red', size = 1) +
  geom_vline(xintercept = mean(cor_037.base$V1),
    colour = 'red', size = 1) +
  geom_rect(ymin = 0, ymax = 10,
    xmin = 0, xmax = 10,
    colour = '#000000',
    alpha = 0,
    linetype = 2) +
  annotate(geom = 'text', x = -5, y = 15, hjust = 0, size = 5,
    label = str_glue("r = {round(cor(cor_037.base$V1,
      cor_037.base$V2), 2)}")) +
  annotate(geom = 'text', x = -5, y = mean(cor_037.base$V2) + 1.7,
    hjust = 0, size = 5,
    label = str_glue("Mean = {round(mean(cor_037.base$V2), 2)}")) +
  annotate(geom = 'text', x = -5, y = mean(cor_037.base$V2) + 0.75,
    hjust = 0, size = 5,
    label = str_glue("SD = {round(sd(cor_037.base$V2), 2)}")) +
  annotate(geom = 'text', x = mean(cor_037.base$V1) + 0.2, y = -3.8,
    hjust = 0, size = 5,
    label = str_glue("Mean = {round(mean(cor_037.base$V1), 2)}")) +
  annotate(geom = 'text', x = mean(cor_037.base$V1) + 0.2, y = -4.75,
    hjust = 0, size = 5,
    label = str_glue("SD = {round(sd(cor_037.base$V1), 2)}")) +
  labs(title = 'Scenario 2B: Unconstained',
    caption = '*Pain rated on a 0 to 10 numerical pain rating scale',
    x = 'V1*',
    y = 'V2*') +
  scale_y_continuous(limits = c(-5, 15),
    breaks = c(0, 5, 10)) +
  scale_x_continuous(limits = c(-5, 15),
    breaks = c(0, 5, 10)))
```


Scenario 2B: Unconstrained



*Pain rated on a 0 to 10 numerical pain rating scale

4.1.2 Constrained data

```
# Constrain data
cor_037 <- cor_037.base %>%
  filter(V1 >= 1 & V1 <= 10) %>%
  filter(V2 >= 0 & V2 <= 10) %>%
  mutate(group = 'No threshold')

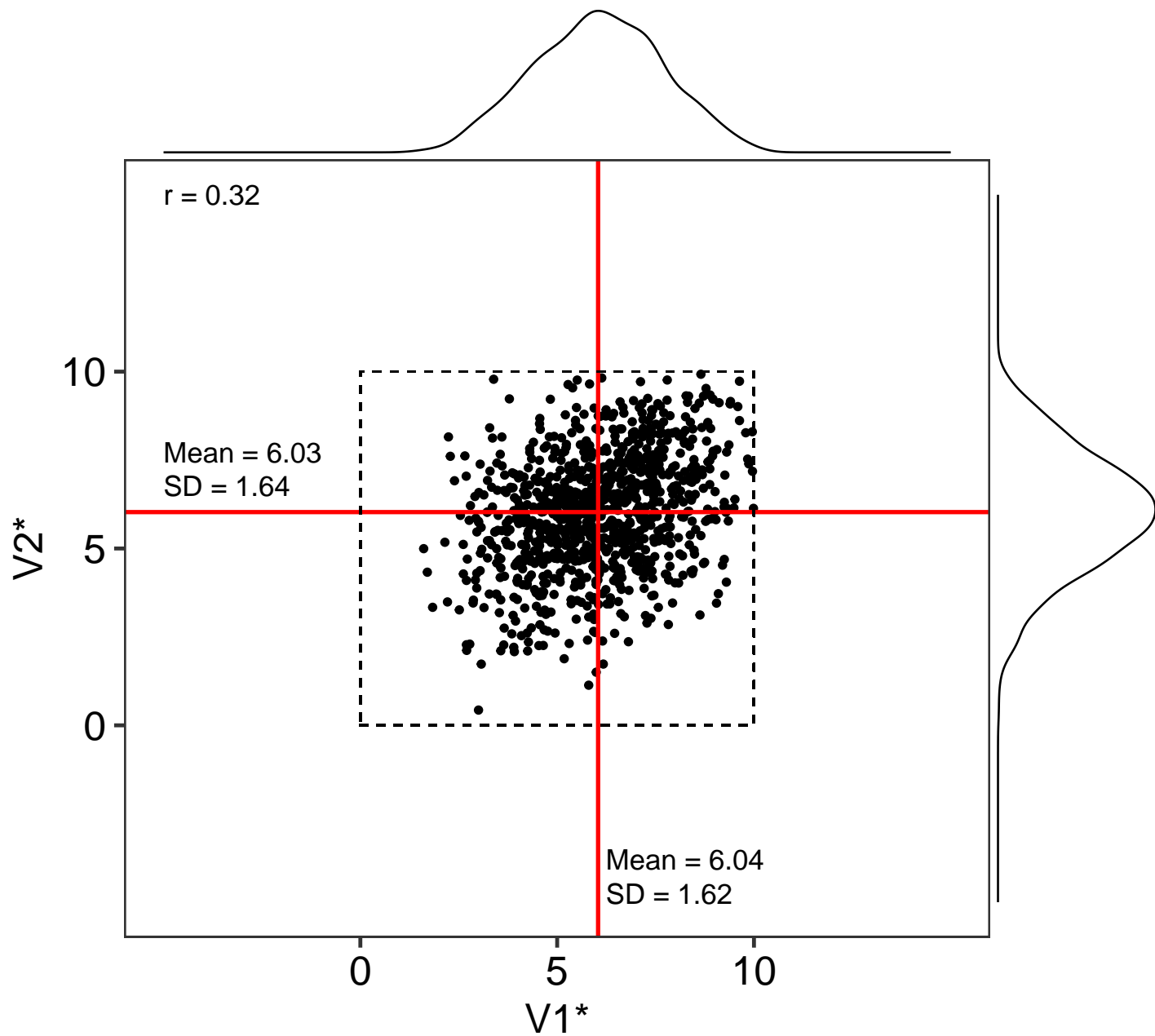
# Plot constrained data
ggMarginal(ggplot(data = cor_037) +
  aes(x = V1, y = V2) +
  geom_point() +
```

```

geom_hline(yintercept = mean(cor_037$V2),
           colour = 'red', size = 1) +
geom_vline(xintercept = mean(cor_037$V1),
           colour = 'red', size = 1) +
geom_rect(ymin = 0, ymax = 10,
          xmin = 0, xmax = 10,
          colour = '#000000',
          alpha = 0,
          linetype = 2) +
annotate(geom = 'text', x = -5, y = 15, hjust = 0, size = 5,
         label = str_glue("r = {round(cor(cor_037$V1,
          cor_037$V2), 2)}")) +
annotate(geom = 'text', x = -5, y = mean(cor_037$V2) + 1.7,
         hjust = 0, size = 5,
         label = str_glue("Mean = {round(mean(cor_037$V2), 2)}")) +
annotate(geom = 'text', x = -5, y = mean(cor_037$V2) + 0.75,
         hjust = 0, size = 5,
         label = str_glue("SD = {round(sd(cor_037$V2), 2)}")) +
annotate(geom = 'text', x = mean(cor_037$V1) + 0.2, y = -3.8,
         hjust = 0, size = 5,
         label = str_glue("Mean = {round(mean(cor_037$V1), 2)}")) +
annotate(geom = 'text', x = mean(cor_037$V1) + 0.2, y = -4.75,
         hjust = 0, size = 5,
         label = str_glue("SD = {round(sd(cor_037$V1), 2)}")) +
labs(title = 'Scenario 2B: Constrained',
     caption = '*Pain rated on a 0 to 10 numerical pain rating scale',
     x = 'V1*',
     y = 'V2*') +
scale_y_continuous(limits = c(-5, 15),
                  breaks = c(0, 5, 10)) +
scale_x_continuous(limits = c(-5, 15),
                  breaks = c(0, 5, 10)))

```

Scenario 2B: Constrained



*Pain rated on a 0 to 10 numerical pain rating scale

4.2 Sample size after constraining data

```
nrow(cor_037)
```

```
## [1] 976
```

4.3 Effect of having a threshold on mean pain intensity scores

Constrained data only

4.3.1 Model mean of V1 with increasing pain inclusion thresholds from 0 to 5

```
# Extract visit 1 data
cor_037V1 <- cor_037$V1

# Generate a vector of threshold values to iterate over
cutoff <- 0:5

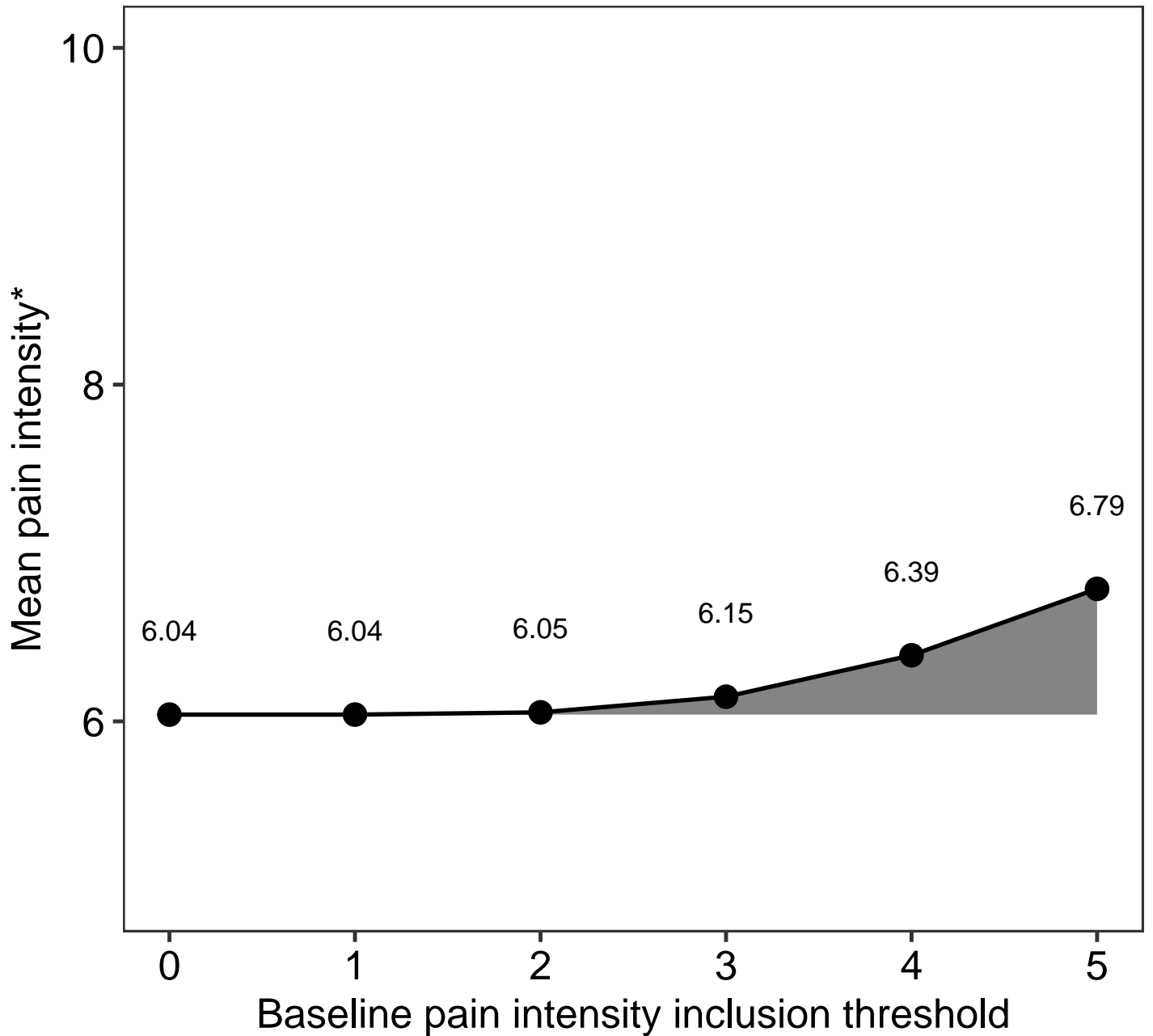
# Generate a vector of V1 means at each V1 threshold
cor_037V1.shift <- sapply(cutoff, function(x){mean(cor_037V1[cor_037V1 > x])})

# Calculate deviation
(cor_037V1.df <- data.frame(time = 'V1',
                             cutoff = cutoff,
                             cutoff2 = cutoff - 0.15, # Offset for plotting purposes
                             mean = cor_037V1.shift) %>%
  mutate(deviation = mean - mean(cor_037V1),
         time = as.character(time)))

##   time cutoff cutoff2    mean deviation
## 1   V1      0   -0.15 6.040105 0.00000000
## 2   V1      1    0.85 6.040105 0.00000000
## 3   V1      2    1.85 6.053438 0.01333294
## 4   V1      3    2.85 6.146302 0.10619707
## 5   V1      4    3.85 6.392649 0.35254408
## 6   V1      5    4.85 6.787107 0.74700201

# Plot data
ggplot(data = cor_037V1.df) +
  aes(x = cutoff, y = mean, ymin = mean(cor_037V1), ymax = mean) +
  geom_ribbon(alpha = 0.6) +
  geom_point(size = 5) +
  geom_line(size = 1) +
  geom_text(aes(label = round(mean, 2)),
            nudge_y = 0.5, size = 5) +
  scale_y_continuous(limits = c(5, 10),
                     breaks = c(0, 2, 4, 6, 8, 10)) +
  labs(title = 'Scenario 2B: Shift in V1 mean pain intensity',
       caption = '*Pain rated on a 0 to 10 numerical pain rating scale',
       x = 'Baseline pain intensity inclusion threshold',
       y = 'Mean pain intensity')
```

Scenario 2B: Shift in V1 mean pain intensity



*Pain rated on a 0 to 10 numerical pain rating scale

4.3.2 Model mean of V2 with increasing inclusion thresholds from 0 to 5

```
# Extract visit 2 data
cor_037V2 <- cor_037$V2

# Generate a vector of threshold values to iterate over
cutoff <- 0:5

# Generate a vector of V2 means at each V1 threshold
cor_037V2.shift <- map_dbl(.x = cutoff,
  ~ cor_037 %>%
    filter(V1 > .x) %>%
```

```

        .$V2 %>%
        mean(.))

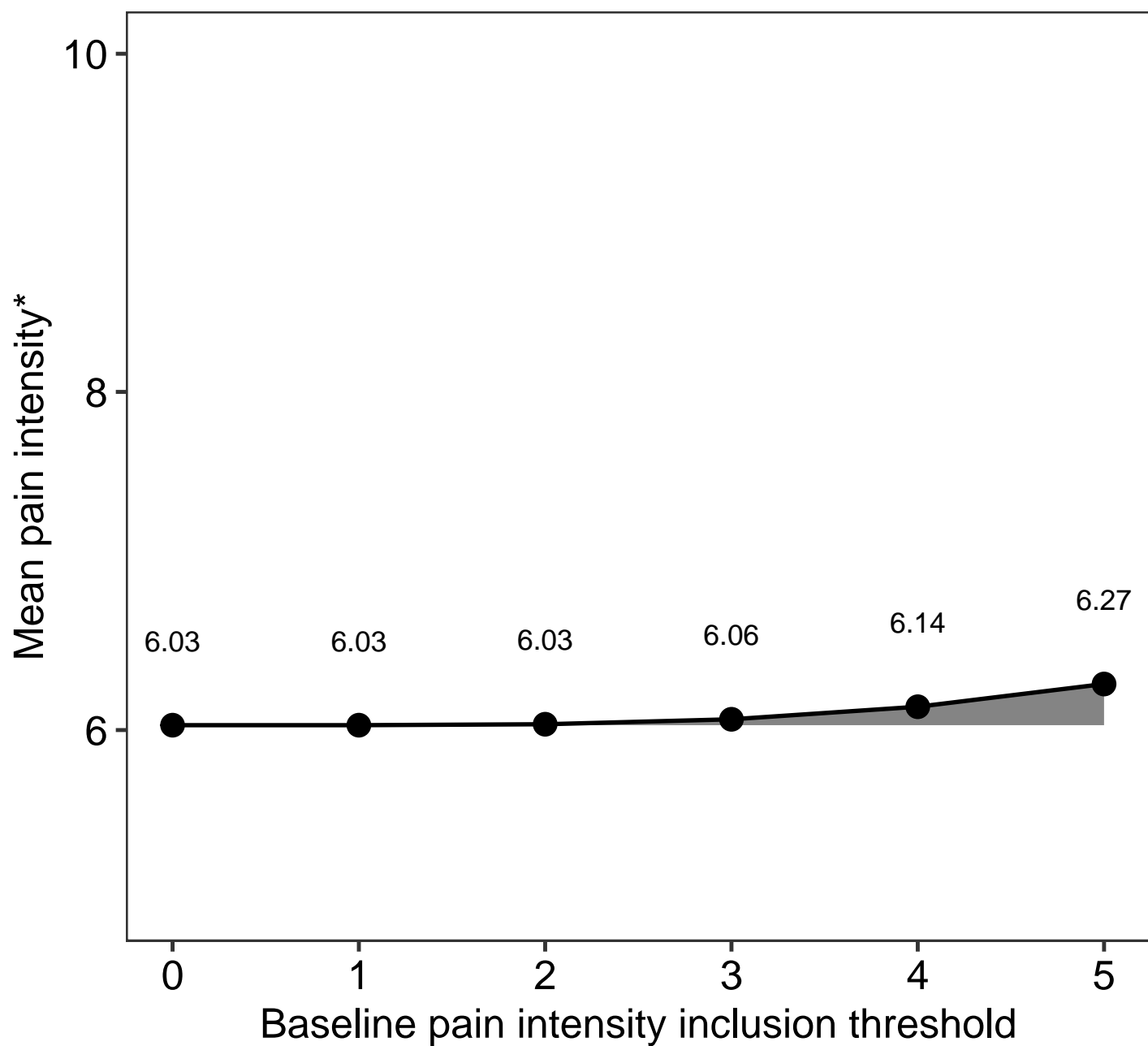
# Calculate deviation
(cor_037V2.df <- data.frame(time = 'V2',
                           cutoff = cutoff,
                           cutoff2 = cutoff + 0.15, # Offset for plotting purposes
                           mean = cor_037V2.shift) %>%
  mutate(deviation = mean - mean(cor_037V2),
         time = as.character(time)))

##   time cutoff cutoff2    mean  deviation
## 1   V2      0    0.15 6.028756 0.000000000
## 2   V2      1    1.15 6.028756 0.000000000
## 3   V2      2    2.15 6.034332 0.005575593
## 4   V2      3    3.15 6.063600 0.034844007
## 5   V2      4    4.15 6.137843 0.109086983
## 6   V2      5    5.15 6.272264 0.243508044

# Plot data
ggplot(data = cor_037V2.df) +
  aes(x = cutoff, y = mean, ymin = mean(cor_037V2), ymax = mean) +
  geom_ribbon(alpha = 0.6) +
  geom_point(size = 5) +
  geom_line(size = 1) +
  geom_text(aes(label = round(mean, 2)),
            nudge_y = 0.5, size = 5) +
  scale_y_continuous(limits = c(5, 10),
                     breaks = c(0, 2, 4, 6, 8, 10)) +
  labs(title = 'Scenario 2B: Shift in V2 mean pain intensity',
       caption = '*Pain rated on a 0 to 10 numerical pain rating scale',
       x = 'Baseline pain intensity inclusion threshold',
       y = 'Mean pain intensity*')

```

Scenario 2B: Shift in V2 mean pain intensity



*Pain rated on a 0 to 10 numerical pain rating scale

4.4 Distributional shifts caused by having a threshold

4.4.1 Threshold: 0

```
# Process data
placebo_2.0 <- cor_037 %>%
  filter(V1 >= 0) %>%
  mutate(difference = V1 - V2) %>%
  mutate(group = 'Threshold')

# Set seed
set.seed(2019)
```

```
# Calculate the mean (95%CI) difference between V1 and V2
```

```
diff_2.0 <- groupwiseMean(difference ~ 1,  
  data = placebo_2.0,  
  R = 2000,  
  traditional = FALSE,  
  bca = TRUE)
```

```
diff_2.0$.id <- 0
```

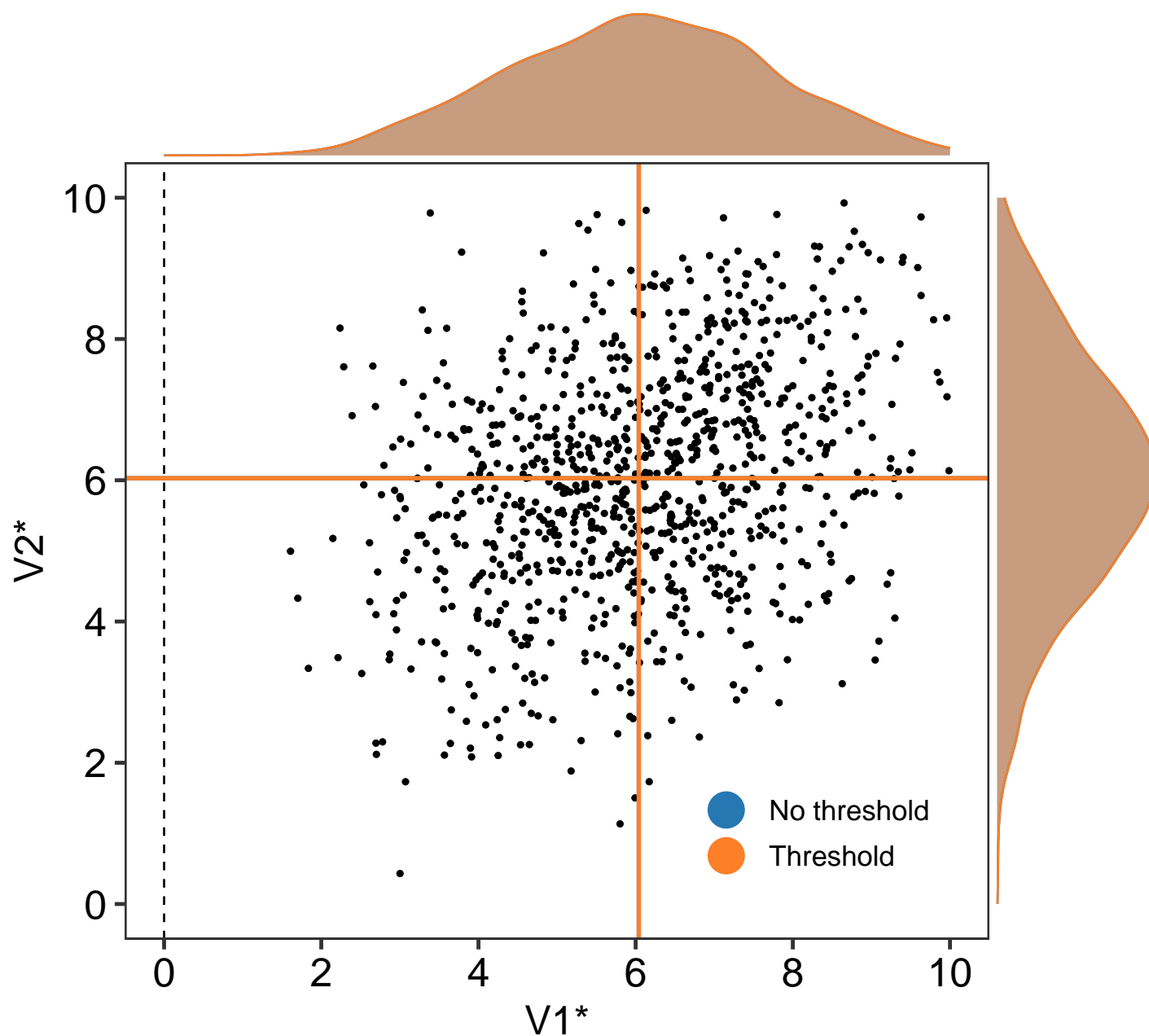
```
kable(diff_2.0)
```

.id	n	Mean	Conf.level	Bca.lower	Bca.upper
0	976	0.0113	0.95	-0.106	0.128

```
# Plot the data
```

```
ggMarginal(placebo_2.0[, 1:3] %>%  
  bind_rows(cor_037) %>%  
  mutate(group = factor(group,  
    levels = c('No threshold', 'Threshold'),  
    ordered = TRUE)) %>%  
  
  ggplot(data = .) +  
  aes(x = V1, y = V2) +  
  geom_point(aes(colour = group, fill = group),  
    size = 1) +  
  guides(colour = guide_legend(override.aes = list(size = 8))) +  
  geom_point(data = cor_037,  
    colour = '#999999',  
    size = 1) +  
  geom_point(data = placebo_2.0,  
    size = 1,  
    colour = '#000000') +  
  geom_vline(xintercept = mean(cor_037$V1),  
    colour = pal[1], size = 1) +  
  geom_vline(xintercept = mean(placebo_2.0$V1),  
    colour = pal[2], size = 1) +  
  geom_vline(xintercept = 0, linetype = 2) +  
  geom_hline(yintercept = mean(cor_037$V2),  
    colour = pal[1], size = 1) +  
  geom_hline(yintercept = mean(placebo_2.0$V2),  
    colour = pal[2], size = 1) +  
  scale_y_continuous(limits = c(0, 10),  
    breaks = c(0, 2, 4, 6, 8, 10)) +  
  scale_x_continuous(limits = c(0, 10),  
    breaks = c(0, 2, 4, 6, 8, 10)) +  
  scale_fill_manual(values = pal) +  
  scale_colour_manual(values = pal) +  
  labs(title = 'Scenario 2B: Pain inclusion threshold = 0',  
    caption = '*Pain rated on a 0 to 10 numerical pain rating scale',  
    x = 'V1*',  
    y = 'V2*') +  
  theme(legend.title = element_blank(),  
    legend.position = c(0.8, 0.15)),  
groupColour = TRUE,  
groupFill = TRUE)
```


Scenario 2B: Pain inclusion threshold = 0



*Pain rated on a 0 to 10 numerical pain rating scale

```
# Special plot for thresholds figure
threshold_0 <- ggMarginal(placebo_2.0[, 1:3] %>%
  bind_rows(cor_037) %>%
  mutate(group = factor(group,
    levels = c('No threshold', 'Threshold'),
    ordered = TRUE)) %>%

  ggplot(data = .) +
  aes(x = V1, y = V2) +
  geom_point(aes(colour = group, fill = group),
    size = 1) +
  guides(colour = guide_legend(override.aes = list(size = 8))) +
  geom_point(data = cor_037,
    colour = '#999999',
    size = 1) +
```

```

geom_point(data = placebo_2.0,
           size = 1,
           colour = '#000000') +
geom_vline(xintercept = mean(cor_037$V1),
           colour = pal[1], size = 1) +
geom_vline(xintercept = mean(placebo_2.0$V1),
           colour = pal[2], size = 1) +
geom_vline(xintercept = 0, linetype = 2) +
geom_hline(yintercept = mean(cor_037$V2),
           colour = pal[1], size = 1) +
geom_hline(yintercept = mean(placebo_2.0$V2),
           colour = pal[2], size = 1) +
scale_y_continuous(limits = c(0, 10),
                   breaks = c(0, 2, 4, 6, 8, 10)) +
scale_x_continuous(limits = c(0, 10),
                   breaks = c(0, 2, 4, 6, 8, 10)) +
scale_fill_manual(values = pal) +
scale_colour_manual(values = pal) +
labs(title = 'Pain inclusion threshold: 0/10',
     x = 'Pain intensity at baseline',
     y = 'Pain intensity at endpoint') +
theme(legend.title = element_blank(),
      legend.position = c(0.8, 0.15)),
groupColour = TRUE,
groupFill = TRUE)

```

```
nrow(cor_037) - nrow(placebo_2.0)
```

4.4.1.1 Points lost by cutoff

```
## [1] 0
```

4.4.2 Threshold: 3

```

# Process data
placebo_2.3 <- cor_037 %>%
  filter(V1 >= 3) %>%
  mutate(difference = V1 - V2) %>%
  mutate(group = 'Threshold')

# Set seed
set.seed(2019)

# Calculate the mean (95%CI) difference between V1 and V2
diff_2.3 <- groupwiseMean(difference ~ 1,
                          data = placebo_2.3,
                          R = 2000,
                          traditional = FALSE,
                          bca = TRUE)

diff_2.3$id <- 3

kable(diff_2.3)

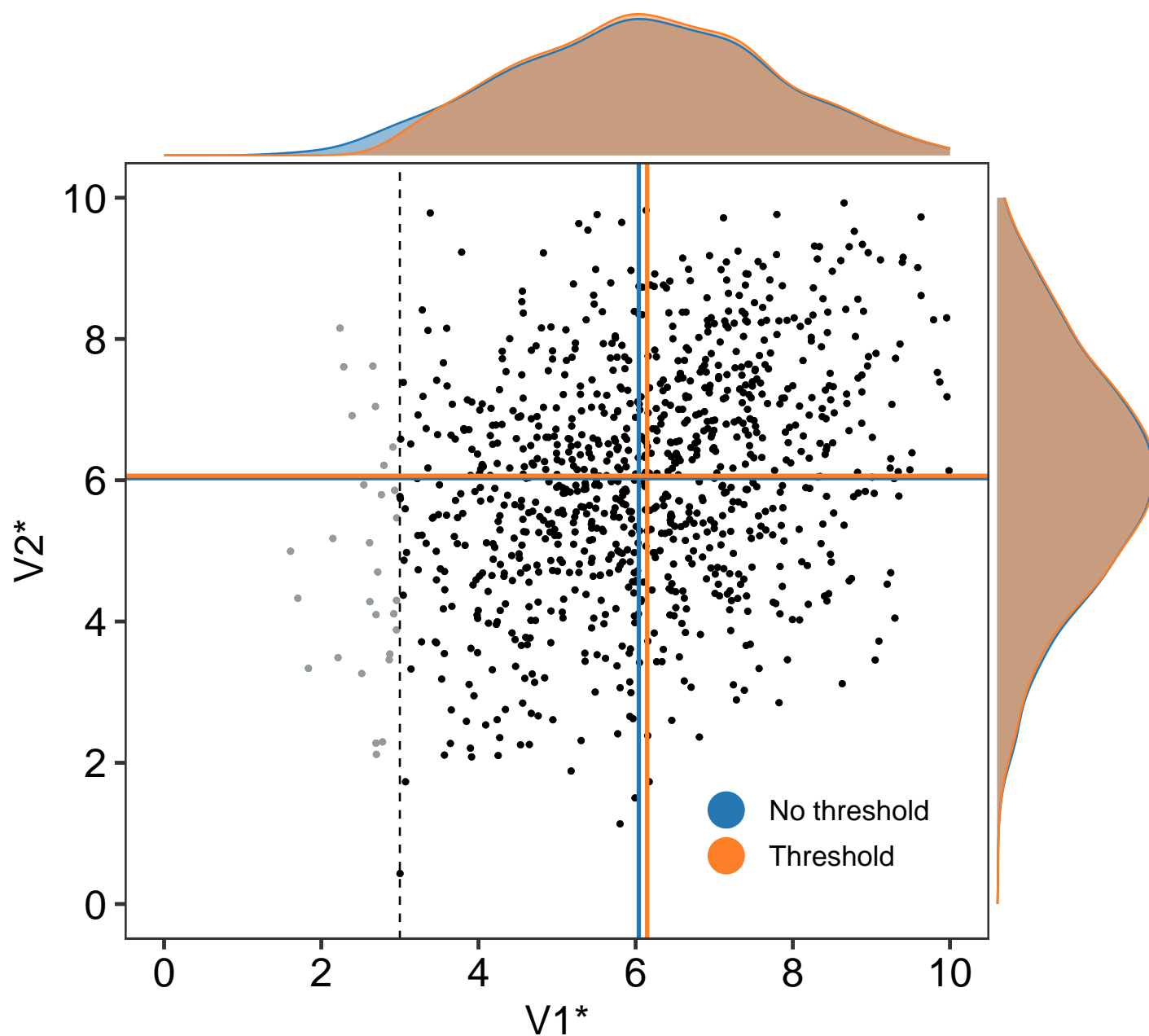
```

.id	n	Mean	Conf.level	Bca.lower	Bca.upper
.id	n	Mean	Conf.level	Bca.lower	Bca.upper
3	947	0.0827	0.95	-0.0378	0.204

```
# Plot the data
ggMarginal(placebo_2.3[, 1:3] %>%
  bind_rows(cor_037) %>%
  mutate(group = factor(group,
                        levels = c('No threshold', 'Threshold'),
                        ordered = TRUE)) %>%

  ggplot(data = .) +
  aes(x = V1, y = V2) +
  geom_point(aes(colour = group, fill = group),
             size = 1) +
  guides(colour = guide_legend(override.aes = list(size = 8))) +
  geom_point(data = cor_037,
             colour = '#999999',
             size = 1) +
  geom_point(data = placebo_2.3,
             size = 1,
             colour = '#000000') +
  geom_vline(xintercept = mean(cor_037$V1),
             colour = pal[1], size = 1) +
  geom_vline(xintercept = mean(placebo_2.3$V1),
             colour = pal[2], size = 1) +
  geom_vline(xintercept = 3, linetype = 2) +
  geom_hline(yintercept = mean(cor_037$V2),
             colour = pal[1], size = 1) +
  geom_hline(yintercept = mean(placebo_2.3$V2),
             colour = pal[2], size = 1) +
  scale_y_continuous(limits = c(0, 10),
                    breaks = c(0, 2, 4, 6, 8, 10)) +
  scale_x_continuous(limits = c(0, 10),
                    breaks = c(0, 2, 4, 6, 8, 10)) +
  scale_fill_manual(values = pal) +
  scale_colour_manual(values = pal) +
  labs(title = 'Scenario 2B: Pain inclusion threshold = 3',
       caption = '*Pain rated on a 0 to 10 numerical pain rating scale',
       x = 'V1*',
       y = 'V2*') +
  theme(legend.title = element_blank(),
        legend.position = c(0.8, 0.15)),
groupColour = TRUE,
groupFill = TRUE)
```

Scenario 2B: Pain inclusion threshold = 3



*Pain rated on a 0 to 10 numerical pain rating scale

```
# Special plot for threshold figure
threshold_3 <- ggMarginal(placebo_2.3[, 1:3] %>%
  bind_rows(cor_037) %>%
  mutate(group = factor(group,
    levels = c('No threshold', 'Threshold'),
    ordered = TRUE)) %>%
  ggplot(data = .) +
  aes(x = V1, y = V2) +
  geom_point(aes(colour = group, fill = group),
    size = 1) +
  guides(colour = guide_legend(override.aes = list(size = 8))) +
  geom_point(data = cor_037,
    colour = '#999999',
    size = 1) +
```

```

geom_point(data = placebo_2.3,
           size = 1,
           colour = '#000000') +
geom_vline(xintercept = mean(cor_037$V1),
           colour = pal[1], size = 1) +
geom_vline(xintercept = mean(placebo_2.3$V1),
           colour = pal[2], size = 1) +
geom_vline(xintercept = 3, linetype = 2) +
geom_hline(yintercept = mean(cor_037$V2),
           colour = pal[1], size = 1) +
geom_hline(yintercept = mean(placebo_2.3$V2),
           colour = pal[2], size = 1) +
scale_y_continuous(limits = c(0, 10),
                   breaks = c(0, 2, 4, 6, 8, 10)) +
scale_x_continuous(limits = c(0, 10),
                   breaks = c(0, 2, 4, 6, 8, 10)) +
scale_fill_manual(values = pal) +
scale_colour_manual(values = pal) +
labs(title = 'Pain inclusion threshold: 3/10',
     x = 'Pain intensity at baseline',
     y = 'Pain intensity at endpoint') +
theme(legend.title = element_blank(),
      legend.position = c(0.8, 0.15)),
groupColour = TRUE,
groupFill = TRUE)

```

```
nrow(cor_037) - nrow(placebo_2.3)
```

4.4.2.1 Points lost by cutoff

```
## [1] 29
```

4.4.3 Threshold: 4

```

# Process that data
placebo_2.4 <- cor_037 %>%
  filter(V1 >= 4) %>%
  mutate(difference = V1 - V2) %>%
  mutate(group = 'Threshold')

# Set seed
set.seed(2019)

# Calculate the mean (95%CI) difference between V1 and V2
diff_2.4 <- groupwiseMean(difference ~ 1,
                          data = placebo_2.4,
                          R = 2000,
                          traditional = FALSE,
                          bca = TRUE)

diff_2.4$.id <- 4

kable(diff_2.4)

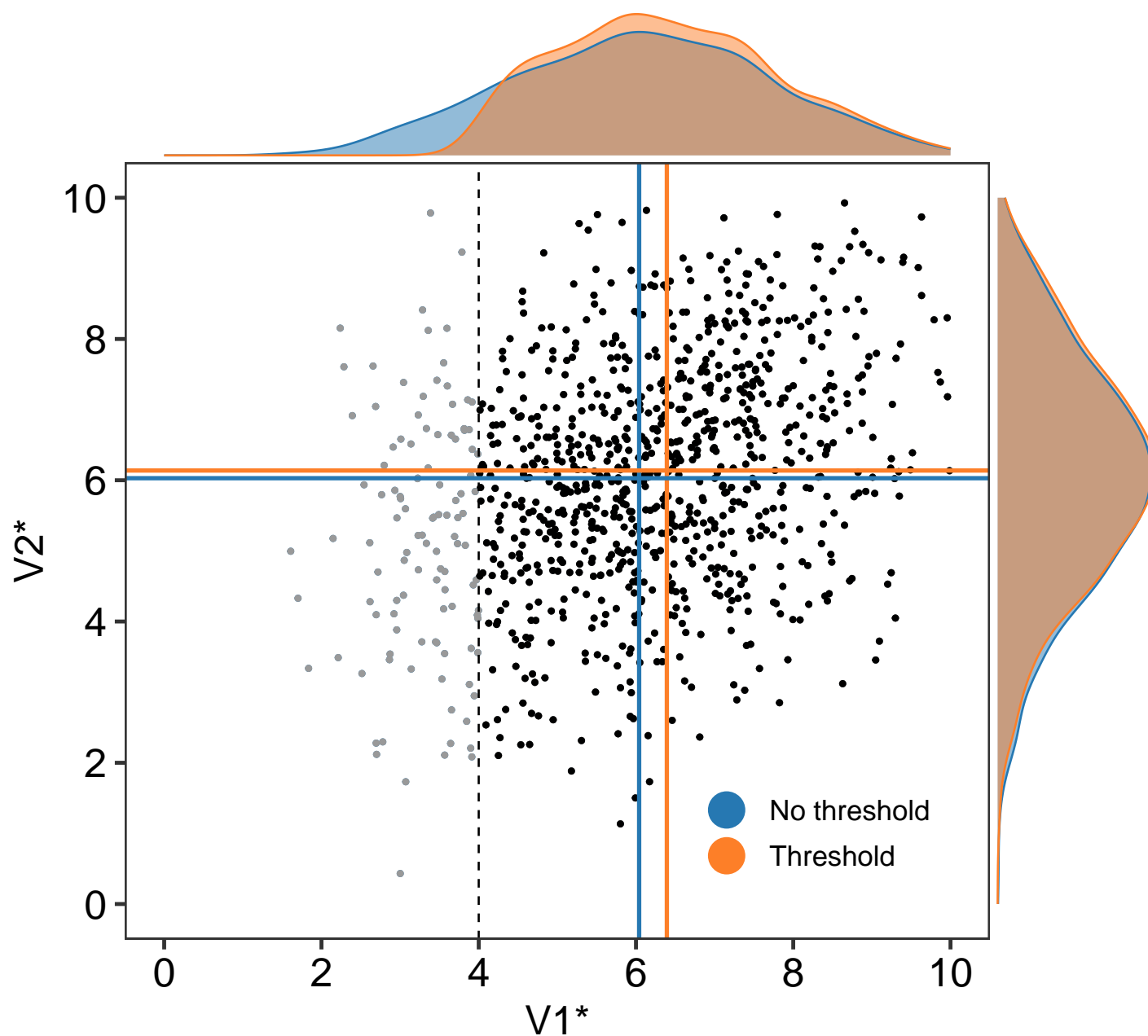
```

.id	n	Mean	Conf.level	Bca.lower	Bca.upper
.id	n	Mean	Conf.level	Bca.lower	Bca.upper
4	865	0.255	0.95	0.137	0.372

```
# Plot the data
ggMarginal(placebo_2.4[, 1:3] %>%
  bind_rows(cor_037) %>%
  mutate(group = factor(group,
                        levels = c('No threshold', 'Threshold'),
                        ordered = TRUE)) %>%

  ggplot(data = .) +
  aes(x = V1, y = V2) +
  geom_point(aes(colour = group, fill = group),
             size = 1) +
  guides(colour = guide_legend(override.aes = list(size = 8))) +
  geom_point(data = cor_037,
             colour = '#999999',
             size = 1) +
  geom_point(data = placebo_2.4,
             size = 1,
             colour = '#000000') +
  geom_vline(xintercept = mean(cor_037$V1),
             colour = pal[1], size = 1) +
  geom_vline(xintercept = mean(placebo_2.4$V1),
             colour = pal[2], size = 1) +
  geom_vline(xintercept = 4, linetype = 2) +
  geom_hline(yintercept = mean(cor_037$V2),
             colour = pal[1], size = 1) +
  geom_hline(yintercept = mean(placebo_2.4$V2),
             colour = pal[2], size = 1) +
  scale_y_continuous(limits = c(0, 10),
                    breaks = c(0, 2, 4, 6, 8, 10)) +
  scale_x_continuous(limits = c(0, 10),
                    breaks = c(0, 2, 4, 6, 8, 10)) +
  scale_fill_manual(values = pal) +
  scale_colour_manual(values = pal) +
  labs(title = 'Scenario 2B: Pain inclusion threshold = 4',
       caption = '*Pain rated on a 0 to 10 numerical pain rating scale',
       x = 'V1*',
       y = 'V2*') +
  theme(legend.title = element_blank(),
        legend.position = c(0.8, 0.15)),
groupColour = TRUE,
groupFill = TRUE)
```

Scenario 2B: Pain inclusion threshold = 4



*Pain rated on a 0 to 10 numerical pain rating scale

```
# Special plot for threshold figure
threshold_4 <- ggMarginal(placebo_2.4[, 1:3] %>%
  bind_rows(cor_037) %>%
  mutate(group = factor(group,
    levels = c('No threshold', 'Threshold'),
    ordered = TRUE)) %>%

  ggplot(data = .) +
  aes(x = V1, y = V2) +
  geom_point(aes(colour = group, fill = group),
    size = 1) +
  guides(colour = guide_legend(override.aes = list(size = 8))) +
  geom_point(data = cor_037,
    colour = '#999999',
    size = 1) +
```

```

geom_point(data = placebo_2.4,
           size = 1,
           colour = '#000000') +
geom_vline(xintercept = mean(cor_037$V1),
           colour = pal[1], size = 1) +
geom_vline(xintercept = mean(placebo_2.4$V1),
           colour = pal[2], size = 1) +
geom_vline(xintercept = 4, linetype = 2) +
geom_hline(yintercept = mean(cor_037$V2),
           colour = pal[1], size = 1) +
geom_hline(yintercept = mean(placebo_2.4$V2),
           colour = pal[2], size = 1) +
scale_y_continuous(limits = c(0, 10),
                   breaks = c(0, 2, 4, 6, 8, 10)) +
scale_x_continuous(limits = c(0, 10),
                   breaks = c(0, 2, 4, 6, 8, 10)) +
scale_fill_manual(values = pal) +
scale_colour_manual(values = pal) +
labs(title = 'Pain inclusion threshold: 4/10',
     x = 'Pain intensity at baseline',
     y = 'Pain intensity at endpoint') +
theme(legend.title = element_blank(),
      legend.position = c(0.8, 0.15)),
groupColour = TRUE,
groupFill = TRUE)

```

```
nrow(cor_037) - nrow(placebo_2.4)
```

4.4.3.1 Points lost by cutoff

```
## [1] 111
```

4.4.4 Threshold: 5

```

# Process that data
placebo_2.5 <- cor_037 %>%
  filter(V1 >= 5) %>%
  mutate(difference = V1 - V2) %>%
  mutate(group = 'Threshold')

# Set seed
set.seed(2019)

# Calculate the mean (95%CI) difference between V1 and V2
diff_2.5 <- groupwiseMean(difference ~ 1,
                          data = placebo_2.5,
                          R = 2000,
                          traditional = FALSE,
                          bca = TRUE)

diff_2.5$.id <- 5

kable(diff_2.5)

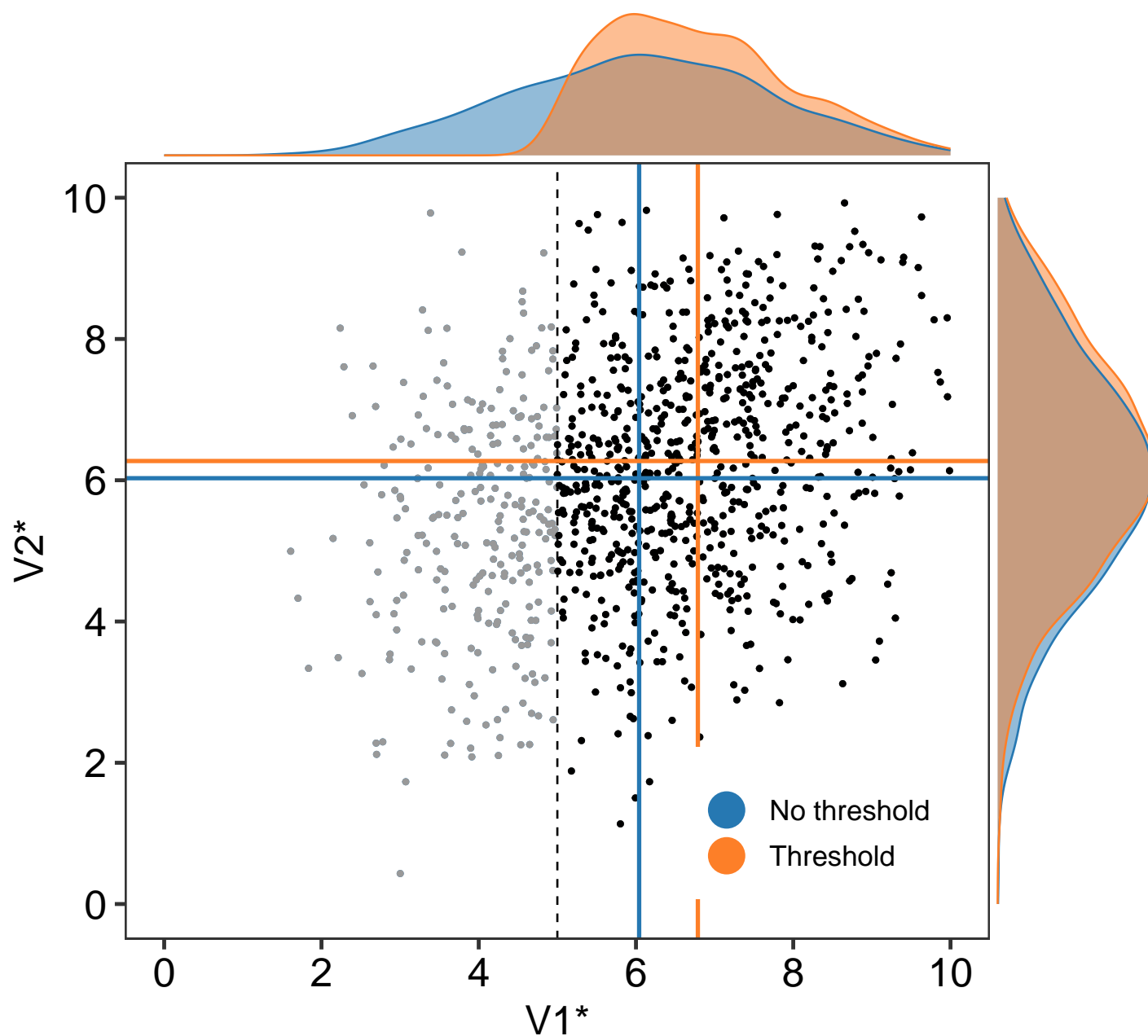
```


.id	n	Mean	Conf.level	Bca.lower	Bca.upper
.id	n	Mean	Conf.level	Bca.lower	Bca.upper
5	714	0.515	0.95	0.393	0.639

```
# Plot the data
ggMarginal(placebo_2.5[, 1:3] %>%
  bind_rows(cor_037) %>%
  mutate(group = factor(group,
    levels = c('No threshold', 'Threshold'),
    ordered = TRUE)) %>%

  ggplot(data = .) +
  aes(x = V1, y = V2) +
  geom_point(aes(colour = group, fill = group),
    size = 1) +
  guides(colour = guide_legend(override.aes = list(size = 8))) +
  geom_point(data = cor_037,
    colour = '#999999',
    size = 1) +
  geom_point(data = placebo_2.5,
    size = 1,
    colour = '#000000') +
  geom_vline(xintercept = mean(cor_037$V1),
    colour = pal[1], size = 1) +
  geom_vline(xintercept = mean(placebo_2.5$V1),
    colour = pal[2], size = 1) +
  geom_vline(xintercept = 5, linetype = 2) +
  geom_hline(yintercept = mean(cor_037$V2),
    colour = pal[1], size = 1) +
  geom_hline(yintercept = mean(placebo_2.5$V2),
    colour = pal[2], size = 1) +
  scale_y_continuous(limits = c(0, 10),
    breaks = c(0, 2, 4, 6, 8, 10)) +
  scale_x_continuous(limits = c(0, 10),
    breaks = c(0, 2, 4, 6, 8, 10)) +
  scale_fill_manual(values = pal) +
  scale_colour_manual(values = pal) +
  labs(title = 'Scenario 2B: Pain inclusion threshold = 5',
    caption = '*Pain rated on a 0 to 10 numerical pain rating scale',
    x = 'V1*',
    y = 'V2*') +
  theme(legend.title = element_blank(),
    legend.position = c(0.8, 0.15)),
groupColour = TRUE,
groupFill = TRUE)
```

Scenario 2B: Pain inclusion threshold = 5



*Pain rated on a 0 to 10 numerical pain rating scale

```
# Special plot for threshold figure
threshold_5 <- ggMarginal(placebo_2.5[, 1:3] %>%
  bind_rows(cor_037) %>%
  mutate(group = factor(group,
    levels = c('No threshold', 'Threshold'),
    ordered = TRUE)) %>%
  ggplot(data = .) +
  aes(x = V1, y = V2) +
  geom_point(aes(colour = group, fill = group),
    size = 1) +
  guides(colour = guide_legend(override.aes = list(size = 8))) +
  geom_point(data = cor_037,
    colour = '#999999',
    size = 1) +
```

```

geom_point(data = placebo_2.5,
           size = 1,
           colour = '#000000') +
geom_vline(xintercept = mean(cor_037$V1),
           colour = pal[1], size = 1) +
geom_vline(xintercept = mean(placebo_2.5$V1),
           colour = pal[2], size = 1) +
geom_vline(xintercept = 5, linetype = 2) +
geom_hline(yintercept = mean(cor_037$V2),
           colour = pal[1], size = 1) +
geom_hline(yintercept = mean(placebo_2.5$V2),
           colour = pal[2], size = 1) +
scale_y_continuous(limits = c(0, 10),
                   breaks = c(0, 2, 4, 6, 8, 10)) +
scale_x_continuous(limits = c(0, 10),
                   breaks = c(0, 2, 4, 6, 8, 10)) +
scale_fill_manual(values = pal) +
scale_colour_manual(values = pal) +
labs(title = 'Pain inclusion threshold: 5/10',
     x = 'Pain intensity at baseline',
     y = 'Pain intensity at endpoint') +
theme(legend.title = element_blank(),
      legend.position = c(0.8, 0.15)),
groupColour = TRUE,
groupFill = TRUE)

```

```
nrow(cor_037) - nrow(placebo_2.5)
```

4.4.4.1 Points lost by cutoff

```
## [1] 262
```

4.5 Summary plots

```

# Plot 1
shift_B <- cor_037V1.df %>%
  bind_rows(cor_037V2.df) %>%
  filter(cutoff != 1 & cutoff != 2) %>%
  mutate(cutoff2 = c(-0.1, 0.9, 1.9, 2.9, 0.1, 1.1, 2.1, 3.1)) %>%
  ggplot(data = .) +
  aes(y = mean,
      x = cutoff2,
      fill= time) +
  geom_hline(yintercept = 6.04,
            linetype = 2) +
  geom_point(shape = 21,
            size = 8) +
  labs(title = 'Scenario 2B',
       subtitle = 'Threshold 0:\nBASELINE = 6.0 (1.6), ENDPOINT = 6.0 (1.6), r = 0.32',
       x = 'Baseline pain intensity inclusion threshold',
       y = 'Mean pain intensity') +
  scale_x_continuous(breaks = 0:3,
                    labels = c(0, 3, 4, 5)) +
  scale_y_continuous(limits = c(5, 10)) +
  scale_fill_manual(values = pal,
                    labels = c('BASELINE', 'ENDPOINT')) +

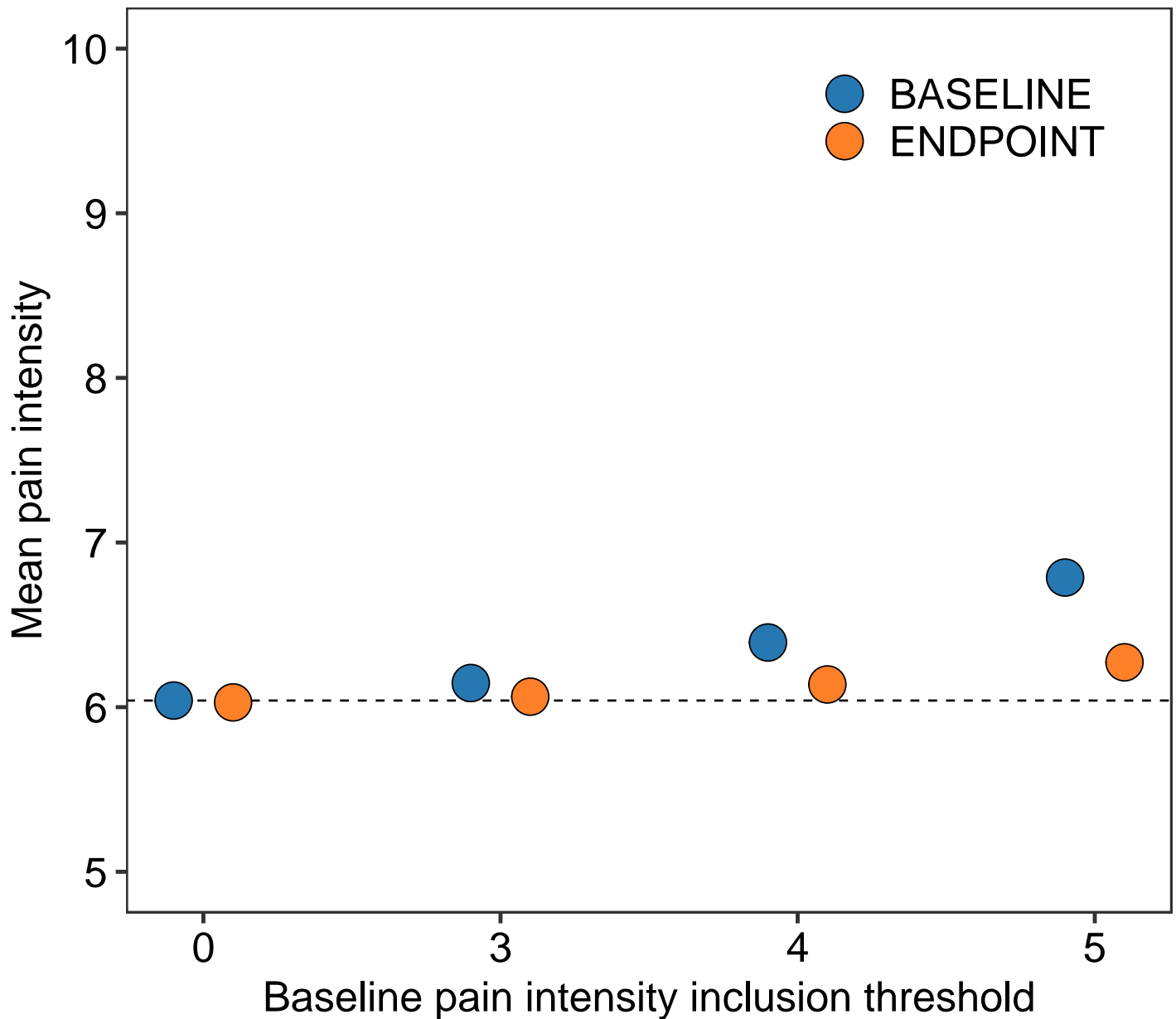
```

```
theme(legend.title = element_blank(),
      legend.position = c(0.8, 0.89),
      legend.text = element_text(size = 20)); shift_B
```

Scenario 2B

Threshold 0:

BASELINE = 6.0 (1.6), ENDPOINT = 6.0 (1.6), $r = 0.32$



```
# Plot 2
# Bind diff_*. dataframes
diff_all_1 <- diff_2.0 %>%
  bind_rows(diff_2.3, diff_2.4, diff_2.5)

diff_B <- diff_all_1 %>%
  mutate(Threshold = factor(.id)) %>%
  ggplot(data = .) +
  aes(x = Threshold,
      y = Mean,
```

```

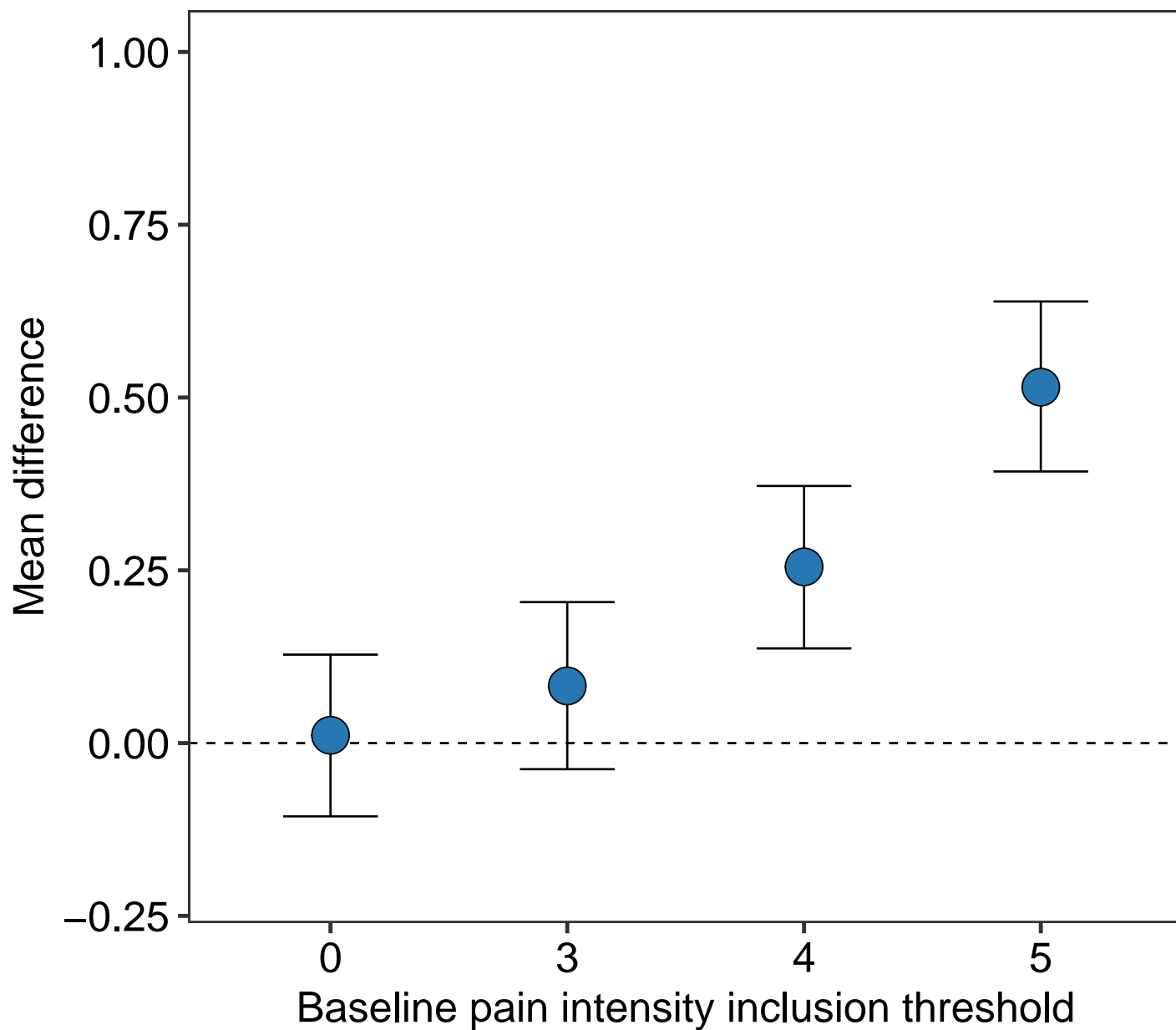
ymin = Bca.lower,
ymax = Bca.upper) +
geom_hline(yintercept = 0,
           linetype = 2) +
geom_errorbar(width = 0.4) +
geom_point(shape = 21,
           fill = pal[[1]],
           size = 8) +
labs(title = 'Scenario 2B',
     subtitle = 'Threshold 0:\nBASELINE = 6.0 (1.6), ENDPOINT = 6.0 (1.6), r = 0.32',
     x = 'Baseline pain intensity inclusion threshold',
     y = 'Mean difference') +
scale_y_continuous(limits = c(-0.2, 1.0)); diff_B

```

Scenario 2B

Threshold 0:

BASELINE = 6.0 (1.6), ENDPOINT = 6.0 (1.6), $r = 0.32$



5 Scenario 2C: Inter-measurement correlation = 0.51

5.1 Generate and summarise data

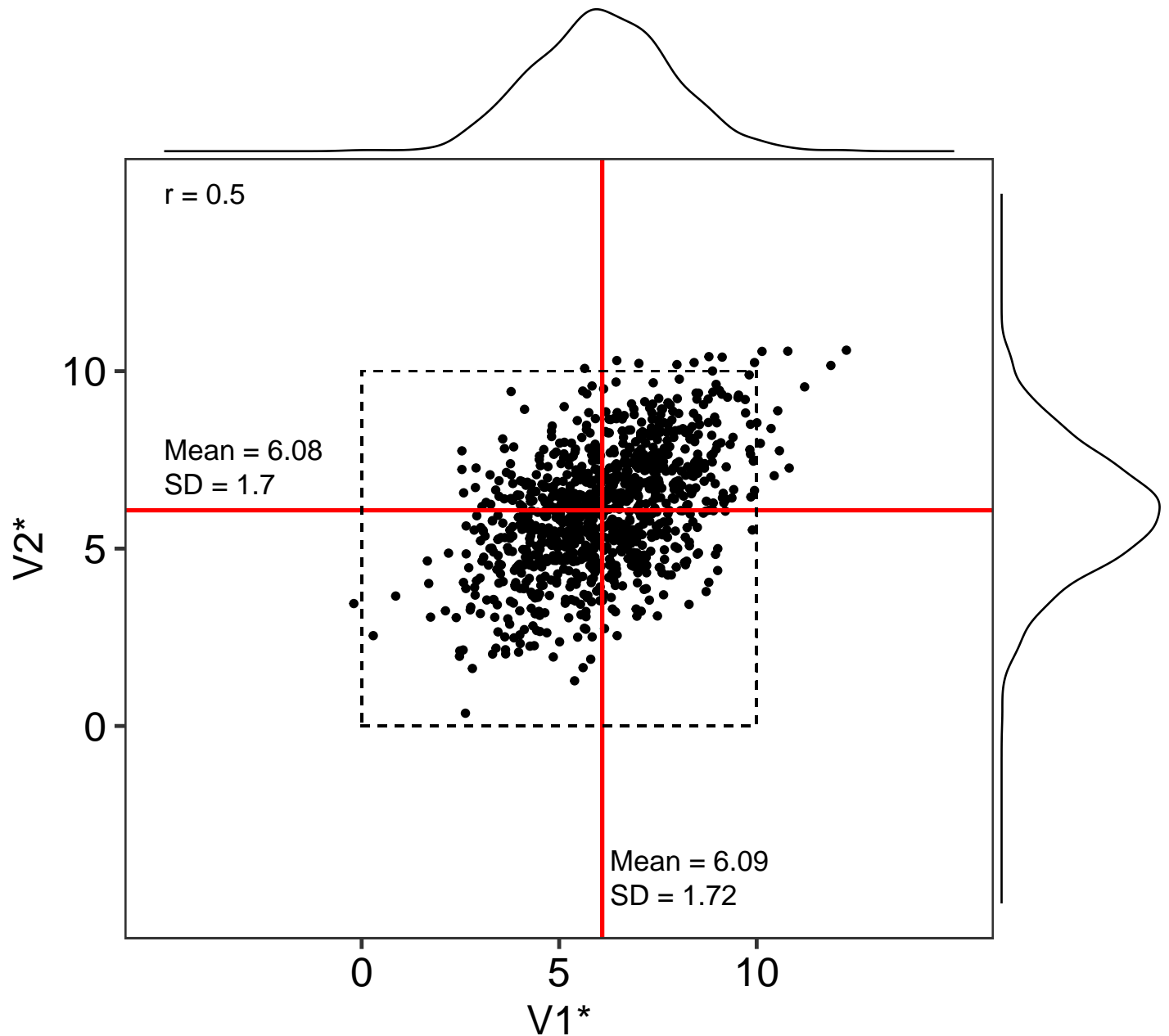
5.1.1 Unconstrained data

```
# Set the random seed for reproducibility
set.seed(2019)

# Generate the data
cor_051.base <- as.data.frame(mvrnorm(n = 1000, mu = c(6.2, 6.2), Sigma = cov_051))

# Plot unconstrained data
ggMarginal(ggplot(data = cor_051.base) +
  aes(x = V1, y = V2) +
  geom_point() +
  geom_hline(yintercept = mean(cor_051.base$V2),
    colour = 'red', size = 1) +
  geom_vline(xintercept = mean(cor_051.base$V1),
    colour = 'red', size = 1) +
  geom_rect(ymin = 0, ymax = 10,
    xmin = 0, xmax = 10,
    colour = '#000000',
    alpha = 0,
    linetype = 2) +
  annotate(geom = 'text', x = -5, y = 15, hjust = 0, size = 5,
    label = str_glue("r = {round(cor(cor_051.base$V1,
      cor_051.base$V2), 2)}")) +
  annotate(geom = 'text', x = -5, y = mean(cor_051.base$V2) + 1.7,
    hjust = 0, size = 5,
    label = str_glue("Mean = {round(mean(cor_051.base$V2), 2)}")) +
  annotate(geom = 'text', x = -5, y = mean(cor_051.base$V2) + 0.75,
    hjust = 0, size = 5,
    label = str_glue("SD = {round(sd(cor_051.base$V2), 2)}")) +
  annotate(geom = 'text', x = mean(cor_051.base$V1) + 0.2, y = -3.8,
    hjust = 0, size = 5,
    label = str_glue("Mean = {round(mean(cor_051.base$V1), 2)}")) +
  annotate(geom = 'text', x = mean(cor_051.base$V1) + 0.2, y = -4.75,
    hjust = 0, size = 5,
    label = str_glue("SD = {round(sd(cor_051.base$V1), 2)}")) +
  labs(title = 'Scenario 2C: Unconstained',
    caption = '*Pain rated on a 0 to 10 numerical pain rating scale',
    x = 'V1*',
    y = 'V2*') +
  scale_y_continuous(limits = c(-5, 15),
    breaks = c(0, 5, 10)) +
  scale_x_continuous(limits = c(-5, 15),
    breaks = c(0, 5, 10)))
```

Scenario 2C: Unconstrained



*Pain rated on a 0 to 10 numerical pain rating scale

5.1.2 Constrained data

```
# Constrain data
cor_051 <- cor_051.base %>%
  filter(V1 >= 1 & V1 <= 10) %>%
  filter(V2 >= 0 & V2 <= 10) %>%
  mutate(group = 'No threshold')

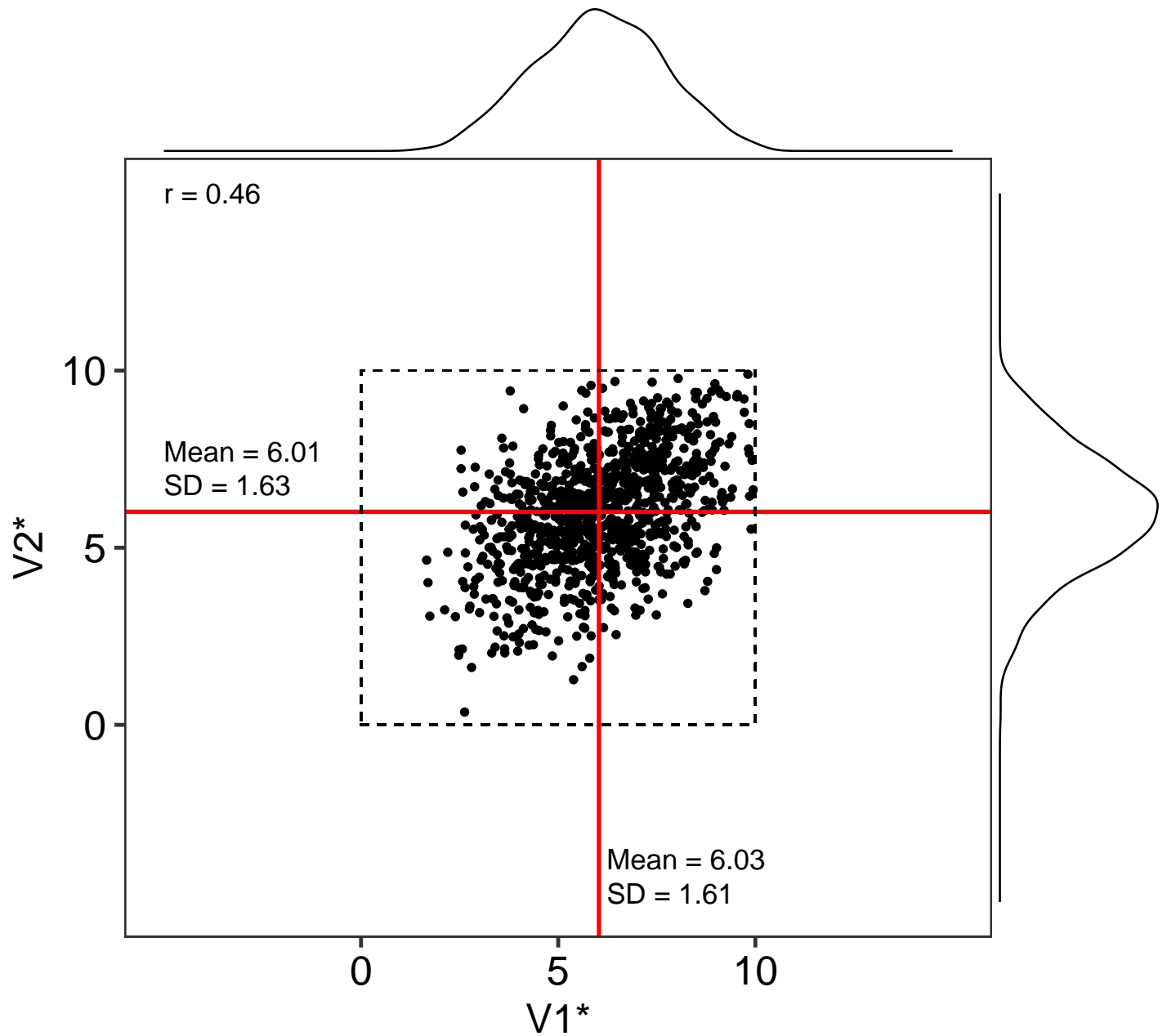
# Plot constrained data
ggMarginal(ggplot(data = cor_051) +
  aes(x = V1, y = V2) +
  geom_point() +
```

```

geom_hline(yintercept = mean(cor_051$V2),
           colour = 'red', size = 1) +
geom_vline(xintercept = mean(cor_051$V1),
           colour = 'red', size = 1) +
geom_rect(ymin = 0, ymax = 10,
          xmin = 0, xmax = 10,
          colour = '#000000',
          alpha = 0,
          linetype = 2) +
annotate(geom = 'text', x = -5, y = 15, hjust = 0, size = 5,
         label = str_glue("r = {round(cor(cor_051$V1,
          cor_051$V2), 2)}")) +
annotate(geom = 'text', x = -5, y = mean(cor_051$V2) + 1.7,
         hjust = 0, size = 5,
         label = str_glue("Mean = {round(mean(cor_051$V2), 2)}")) +
annotate(geom = 'text', x = -5, y = mean(cor_051$V2) + 0.75,
         hjust = 0, size = 5,
         label = str_glue("SD = {round(sd(cor_051$V2), 2)}")) +
annotate(geom = 'text', x = mean(cor_051$V1) + 0.2, y = -3.8,
         hjust = 0, size = 5,
         label = str_glue("Mean = {round(mean(cor_051$V1), 2)}")) +
annotate(geom = 'text', x = mean(cor_051$V1) + 0.2, y = -4.75,
         hjust = 0, size = 5,
         label = str_glue("SD = {round(sd(cor_051$V1), 2)}")) +
labs(title = 'Scenario 2C: Constrained',
     caption = '*Pain rated on a 0 to 10 numerical pain rating scale',
     x = 'V1*',
     y = 'V2*') +
scale_y_continuous(limits = c(-5, 15),
                   breaks = c(0, 5, 10)) +
scale_x_continuous(limits = c(-5, 15),
                   breaks = c(0, 5, 10)))

```


Scenario 2C: Constrained



*Pain rated on a 0 to 10 numerical pain rating scale

5.2 Sample size after constraining data

```
nrow(cor_051)
```

```
## [1] 976
```

5.3 Effect of having a threshold on mean pain intensity scores

Constrained data only

5.3.1 Model mean of V1 with increasing pain inclusion thresholds from 0 to 5

```
# Extract visit 1 data
cor_051V1 <- cor_051$V1

# Generate a vector of threshold values to iterate over
cutoff <- 0:5

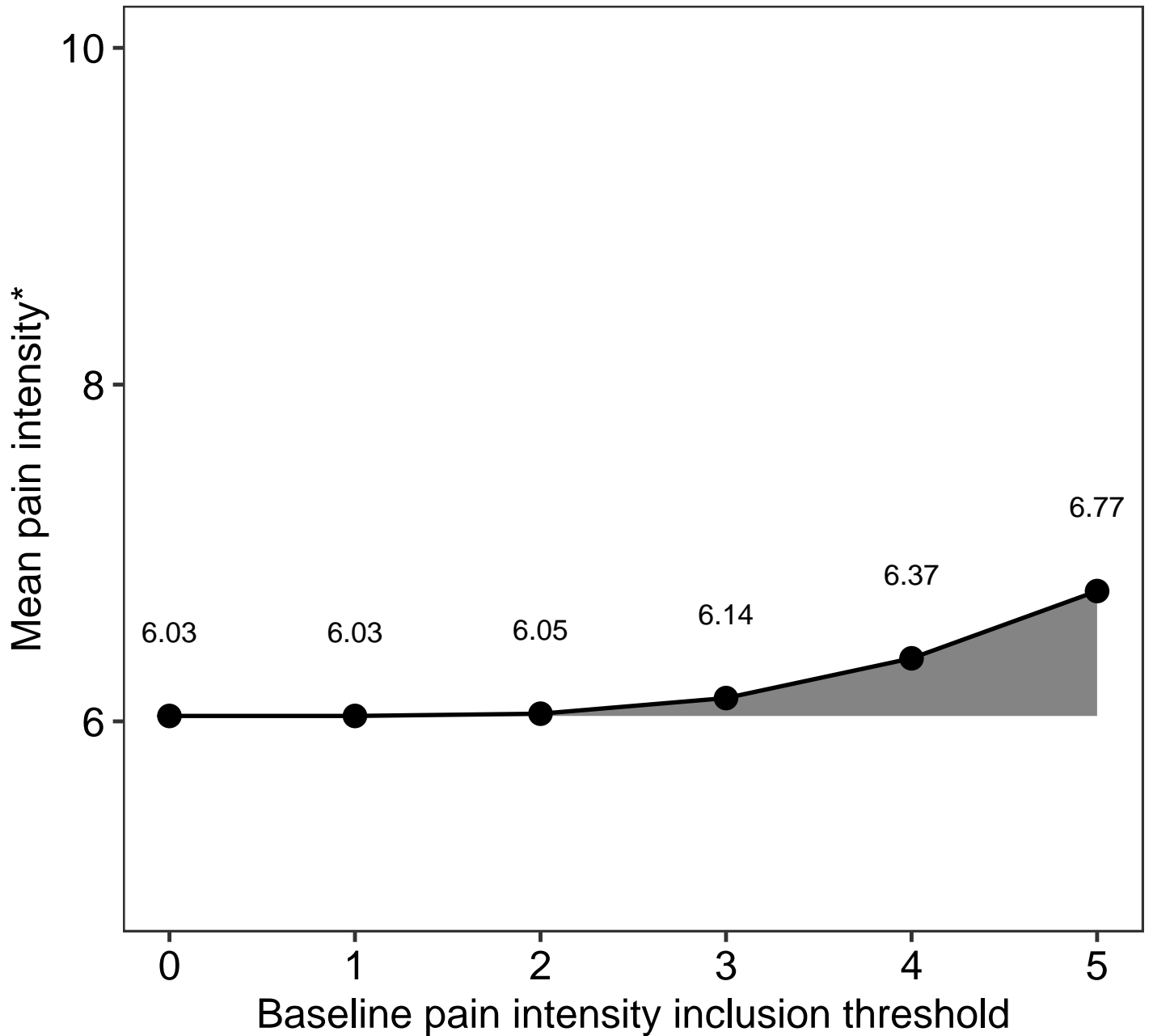
# Generate a vector of V1 means at each V1 threshold
cor_051V1.shift <- sapply(cutoff, function(x){mean(cor_051V1[cor_051V1 > x])})

# Calculate deviation
(cor_051V1.df <- data.frame(time = 'V1',
                             cutoff = cutoff,
                             cutoff2 = cutoff - 0.15, # Offset for plotting purposes
                             mean = cor_051V1.shift) %>%
  mutate(deviation = mean - mean(cor_051V1),
         time = as.character(time)))

##   time cutoff cutoff2    mean deviation
## 1   V1      0   -0.15 6.032152 0.00000000
## 2   V1      1    0.85 6.032152 0.00000000
## 3   V1      2    1.85 6.045501 0.01334924
## 4   V1      3    2.85 6.138361 0.10620956
## 5   V1      4    3.85 6.374323 0.34217072
## 6   V1      5    4.85 6.773859 0.74170741

# Plot data
ggplot(data = cor_051V1.df) +
  aes(x = cutoff, y = mean, ymin = mean(cor_051V1), ymax = mean) +
  geom_ribbon(alpha = 0.6) +
  geom_point(size = 5) +
  geom_line(size = 1) +
  geom_text(aes(label = round(mean, 2)),
            nudge_y = 0.5, size = 5) +
  scale_y_continuous(limits = c(5, 10),
                     breaks = c(0, 2, 4, 6, 8, 10)) +
  labs(title = 'Scenario 2C: Shift in V1 mean pain intensity',
       caption = '*Pain rated on a 0 to 10 numerical pain rating scale',
       x = 'Baseline pain intensity inclusion threshold',
       y = 'Mean pain intensity*')
```

Scenario 2C: Shift in V1 mean pain intensity



*Pain rated on a 0 to 10 numerical pain rating scale

5.3.2 Model mean of V2 with increasing V1 thresholds from 0 to 5

```
# Extract visit 2 data
cor_051V2 <- cor_051$V2

# Generate a vector of threshold values to iterate over
cutoff <- 0:5

# Generate a vector of V2 means at each V1 threshold
cor_051V2.shift <- map_dbl(.x = cutoff,
  ~ cor_051 %>%
    filter(V1 > .x) %>%
```

```

        .$V2 %>%
        mean(.))

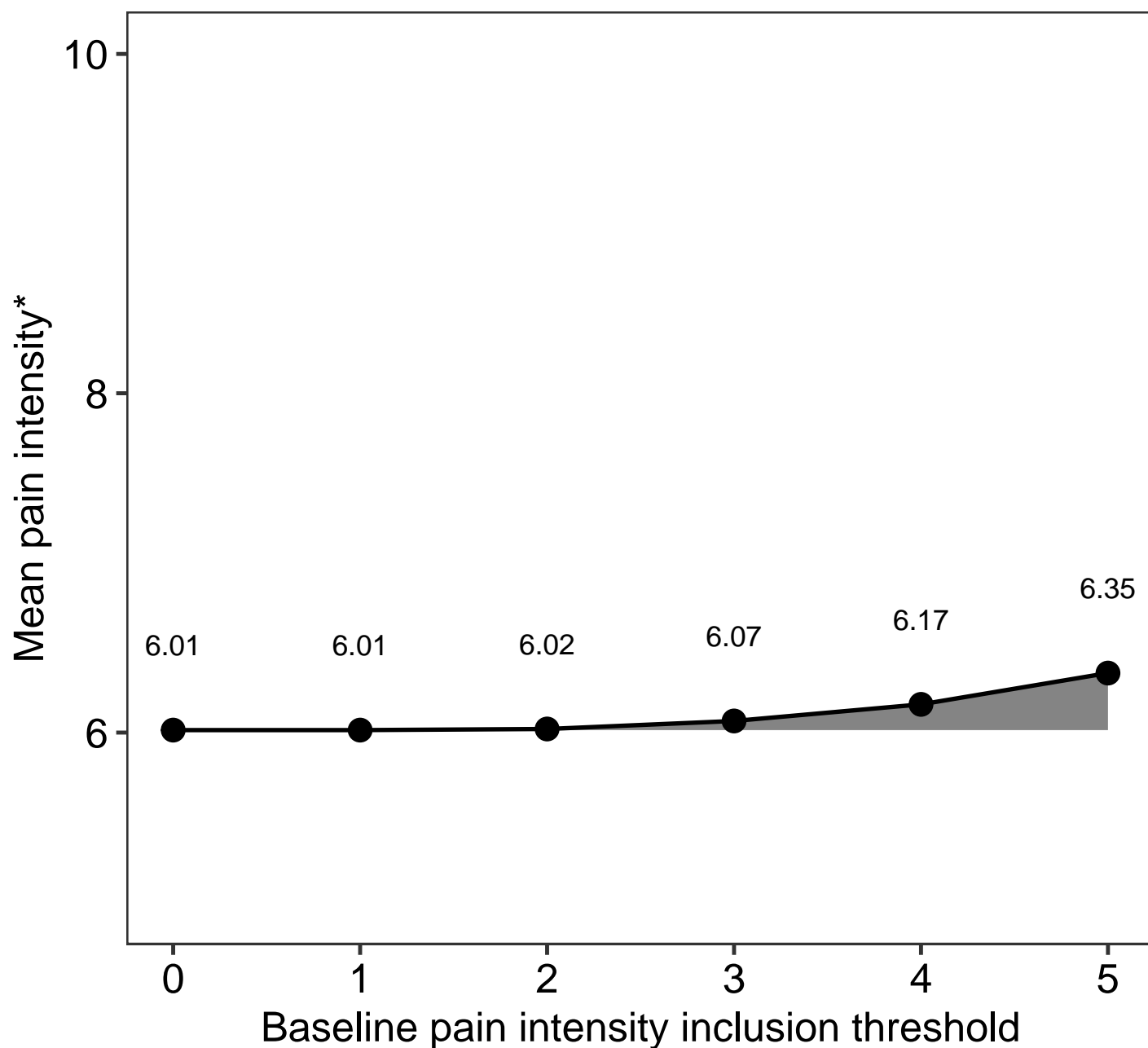
# Calculate deviation
(cor_051V2.df <- data.frame(time = 'V2',
                           cutoff = cutoff,
                           cutoff2 = cutoff + 0.15, # Offset for plotting purposes
                           mean = cor_051V2.shift) %>%
  mutate(deviation = mean - mean(cor_051V2),
         time = as.character(time)))

##   time cutoff cutoff2    mean  deviation
## 1   V2      0    0.15 6.014627 0.000000000
## 2   V2      1    1.15 6.014627 0.000000000
## 3   V2      2    2.15 6.021112 0.006484735
## 4   V2      3    3.15 6.068455 0.053827735
## 5   V2      4    4.15 6.166292 0.151664742
## 6   V2      5    5.15 6.350826 0.336198641

# Plot data
ggplot(data = cor_051V2.df) +
  aes(x = cutoff, y = mean, ymin = mean(cor_051V2), ymax = mean) +
  geom_ribbon(alpha = 0.6) +
  geom_point(size = 5) +
  geom_line(size = 1) +
  geom_text(aes(label = round(mean, 2)),
            nudge_y = 0.5, size = 5) +
  scale_y_continuous(limits = c(5, 10),
                    breaks = c(0, 2, 4, 6, 8, 10)) +
  labs(title = 'Scenario 2C: Shift in V2 mean pain intensity',
       caption = '*Pain rated on a 0 to 10 numerical pain rating scale',
       x = 'Baseline pain intensity inclusion threshold',
       y = 'Mean pain intensity*')

```

Scenario 2C: Shift in V2 mean pain intensity



*Pain rated on a 0 to 10 numerical pain rating scale

5.4 Distributional shifts caused by having a threshold

5.4.1 Threshold: 0

```
# Process data
placebo_3.0 <- cor_051 %>%
  filter(V1 >= 0) %>%
  mutate(difference = V1 - V2) %>%
  mutate(group = 'Threshold')

# Set seed
set.seed(2019)
```

```
# Calculate the mean (95%CI) difference between V1 and V2
```

```
diff_3.0 <- groupwiseMean(difference ~ 1,  
  data = placebo_3.0,  
  R = 2000,  
  traditional = FALSE,  
  bca = TRUE)
```

```
diff_3.0$.id <- 0
```

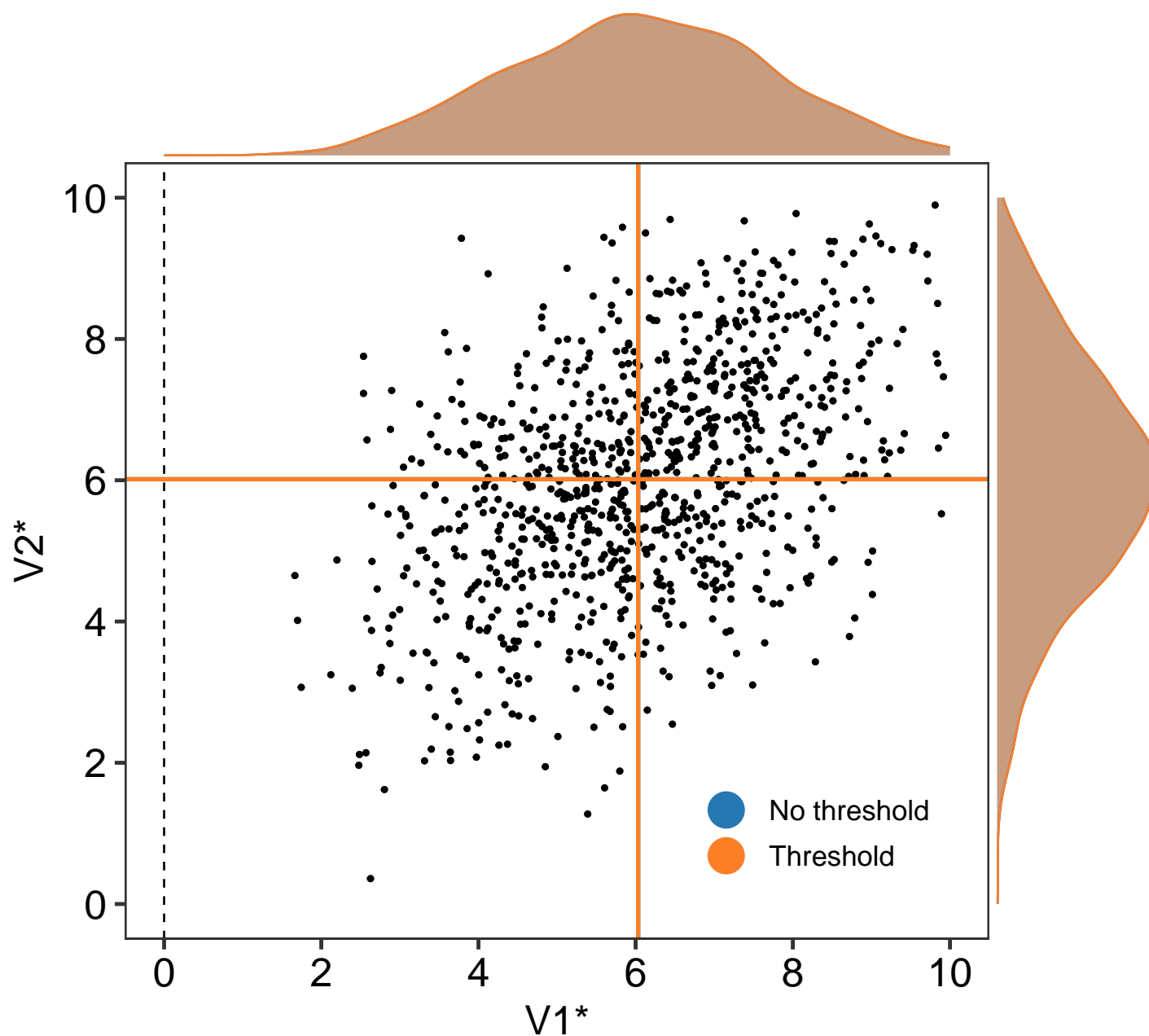
```
kable(diff_3.0)
```

.id	n	Mean	Conf.level	Bca.lower	Bca.upper
0	976	0.0175	0.95	-0.0902	0.117

```
# Plot the data
```

```
ggMarginal(placebo_3.0[, 1:3] %>%  
  bind_rows(cor_051) %>%  
  mutate(group = factor(group,  
    levels = c('No threshold', 'Threshold'),  
    ordered = TRUE)) %>%  
  
  ggplot(data = .) +  
  aes(x = V1, y = V2) +  
  geom_point(aes(colour = group, fill = group),  
    size = 1) +  
  guides(colour = guide_legend(override.aes = list(size = 8))) +  
  geom_point(data = cor_051,  
    colour = '#999999',  
    size = 1) +  
  geom_point(data = placebo_3.0,  
    size = 1,  
    colour = '#000000') +  
  geom_vline(xintercept = mean(cor_051$V1),  
    colour = pal[1], size = 1) +  
  geom_vline(xintercept = mean(placebo_3.0$V1),  
    colour = pal[2], size = 1) +  
  geom_vline(xintercept = 0, linetype = 2) +  
  geom_hline(yintercept = mean(cor_051$V2),  
    colour = pal[1], size = 1) +  
  geom_hline(yintercept = mean(placebo_3.0$V2),  
    colour = pal[2], size = 1) +  
  scale_y_continuous(limits = c(0, 10),  
    breaks = c(0, 2, 4, 6, 8, 10)) +  
  scale_x_continuous(limits = c(0, 10),  
    breaks = c(0, 2, 4, 6, 8, 10)) +  
  scale_fill_manual(values = pal) +  
  scale_colour_manual(values = pal) +  
  labs(title = 'Scenario 2C: Pain inclusion threshold = 0',  
    caption = '*Pain rated on a 0 to 10 numerical pain rating scale',  
    x = 'V1*',  
    y = 'V2*') +  
  theme(legend.title = element_blank(),  
    legend.position = c(0.8, 0.15)),  
  groupColour = TRUE,  
  groupFill = TRUE)
```

Scenario 2C: Pain inclusion threshold = 0



*Pain rated on a 0 to 10 numerical pain rating scale

```
nrow(cor_051) - nrow(placebo_3.0)
```

5.4.1.1 Points lost by cutoff

```
## [1] 0
```

5.4.2 Threshold: 3

```
# Process data  
placebo_3.3 <- cor_051 %>%  
  filter(V1 >= 3) %>%
```

```

mutate(difference = V1 - V2) %>%
mutate(group = 'Threshold')

# Set seed
set.seed(2019)

# Calculate the mean (95%CI) difference between V1 and V2
diff_3.3 <- groupwiseMean(difference ~ 1,
  data = placebo_3.3,
  R = 2000,
  traditional = FALSE,
  bca = TRUE)

diff_3.3$id <- 3

kable(diff_3.3)

```

.id	n	Mean	Conf.level	Bca.lower	Bca.upper
3	947	0.0699	0.95	-0.0373	0.176

```

# Plot the data
ggMarginal(placebo_3.3[, 1:3] %>%
  bind_rows(cor_051) %>%
  mutate(group = factor(
    levels = c('No threshold', 'Threshold'),
    ordered = TRUE)) %>%

  ggplot(data = .) +
  aes(x = V1, y = V2) +
  geom_point(aes(colour = group, fill = group),
    size = 1) +
  guides(colour = guide_legend(override.aes = list(size = 8))) +
  geom_point(data = cor_051,
    colour = '#999999',
    size = 1) +
  geom_point(data = placebo_3.3,
    size = 1,
    colour = '#000000') +
  geom_vline(xintercept = mean(cor_051$V1),
    colour = pal[1], size = 1) +
  geom_vline(xintercept = mean(placebo_3.3$V1),
    colour = pal[2], size = 1) +
  geom_vline(xintercept = 3, linetype = 2) +
  geom_hline(yintercept = mean(cor_051$V2),
    colour = pal[1], size = 1) +
  geom_hline(yintercept = mean(placebo_3.3$V2),
    colour = pal[2], size = 1) +
  scale_y_continuous(limits = c(0, 10),
    breaks = c(0, 2, 4, 6, 8, 10)) +
  scale_x_continuous(limits = c(0, 10),
    breaks = c(0, 2, 4, 6, 8, 10)) +
  scale_fill_manual(values = pal) +
  scale_colour_manual(values = pal) +
  labs(title = 'Scenario 2C: Pain inclusion threshold = 3',
    caption = '*Pain rated on a 0 to 10 numerical pain rating scale',
    x = 'V1*',
    y = 'V2*') +
  theme(legend.title = element_blank(),

```

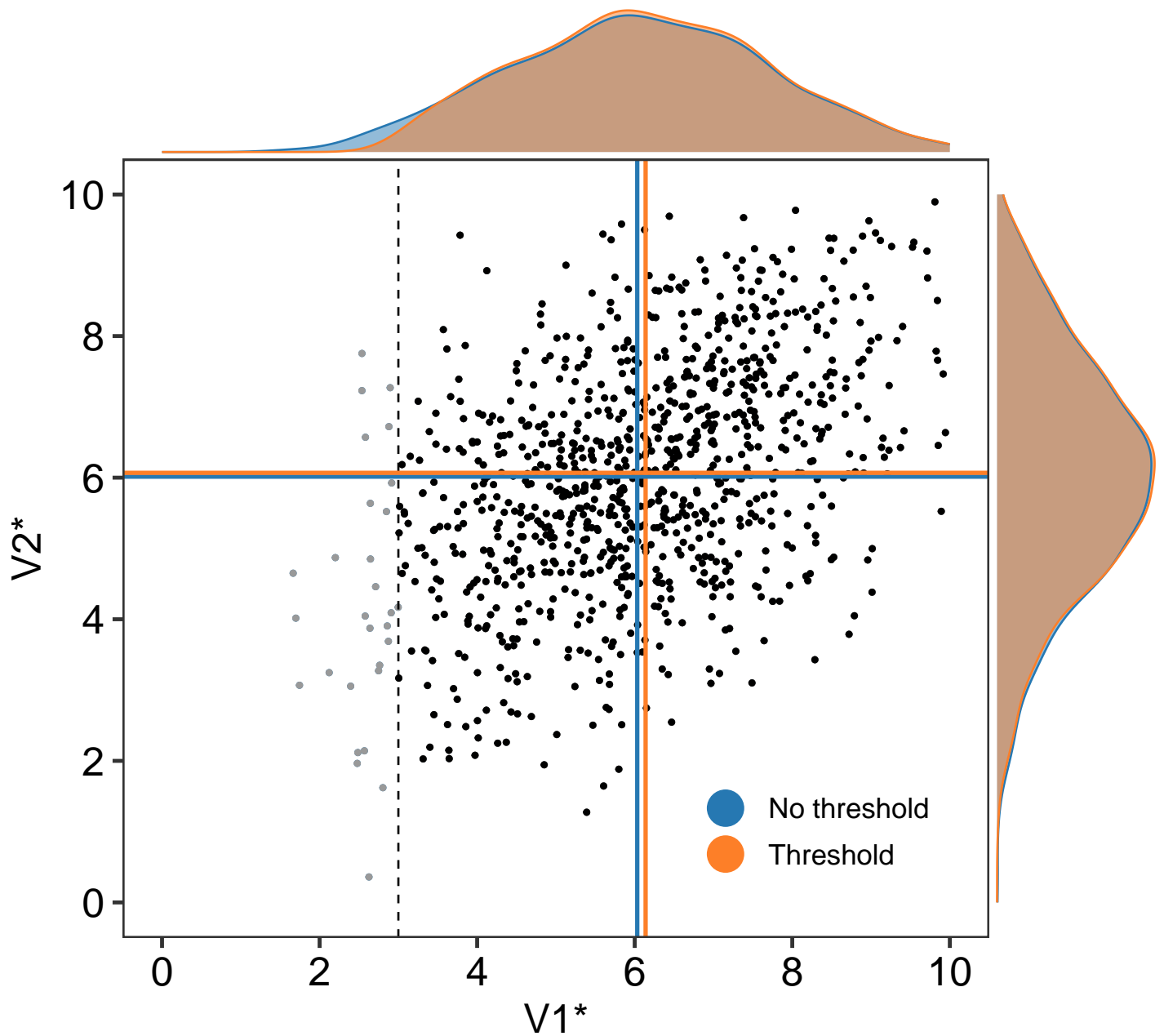


```

legend.position = c(0.8, 0.15)),
groupColour = TRUE,
groupFill = TRUE)

```

Scenario 2C: Pain inclusion threshold = 3



*Pain rated on a 0 to 10 numerical pain rating scale

```
nrow(cor_051) - nrow(placebo_3.3)
```

5.4.2.1 Points lost by cutoff

```
## [1] 29
```

5.4.3 Threshold: 4

```
# Process that data
placebo_3.4 <- cor_051 %>%
  filter(V1 >= 4) %>%
  mutate(difference = V1 - V2) %>%
  mutate(group = 'Threshold')

# Set seed
set.seed(2019)

# Calculate the mean (95%CI) difference between V1 and V2
diff_3.4 <- groupwiseMean(difference ~ 1,
  data = placebo_3.4,
  R = 2000,
  traditional = FALSE,
  bca = TRUE)

diff_3.4$.id <- 4

kable(diff_3.4)
```

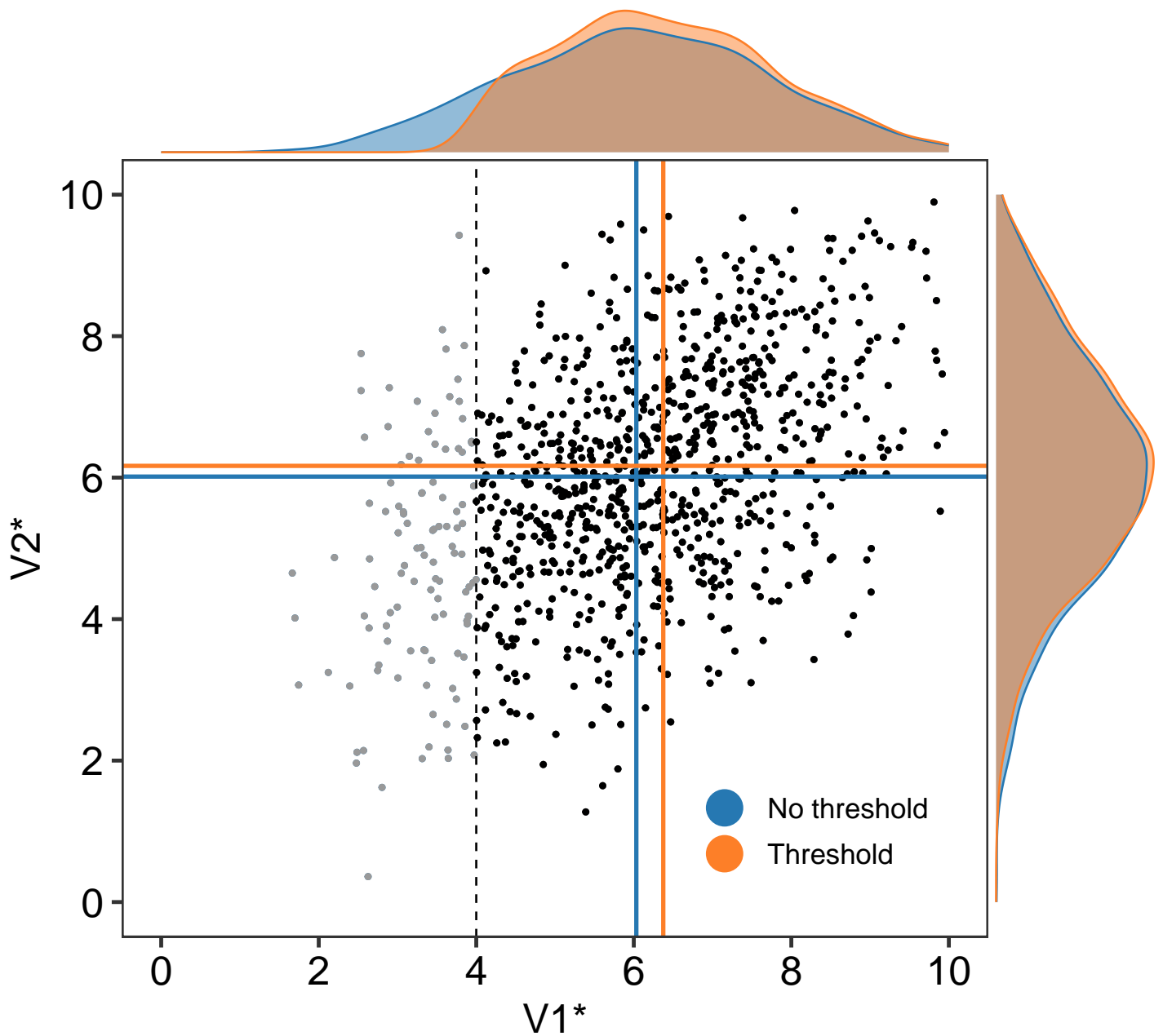
.id	n	Mean	Conf.level	Bca.lower	Bca.upper
4	868	0.208	0.95	0.103	0.318

```
# Plot the data
ggMarginal(placebo_3.4[, 1:3] %>%
  bind_rows(cor_051) %>%
  mutate(group = factor(group,
    levels = c('No threshold', 'Threshold'),
    ordered = TRUE)) %>%

  ggplot(data = .) +
  aes(x = V1, y = V2) +
  geom_point(aes(colour = group, fill = group),
    size = 1) +
  guides(colour = guide_legend(override.aes = list(size = 8))) +
  geom_point(data = cor_051,
    colour = '#999999',
    size = 1) +
  geom_point(data = placebo_3.4,
    size = 1,
    colour = '#000000') +
  geom_vline(xintercept = mean(cor_051$V1),
    colour = pal[1], size = 1) +
  geom_vline(xintercept = mean(placebo_3.4$V1),
    colour = pal[2], size = 1) +
  geom_vline(xintercept = 4, linetype = 2) +
  geom_hline(yintercept = mean(cor_051$V2),
    colour = pal[1], size = 1) +
  geom_hline(yintercept = mean(placebo_3.4$V2),
    colour = pal[2], size = 1) +
  scale_y_continuous(limits = c(0, 10),
    breaks = c(0, 2, 4, 6, 8, 10)) +
  scale_x_continuous(limits = c(0, 10),
    breaks = c(0, 2, 4, 6, 8, 10)) +
  scale_fill_manual(values = pal) +
  scale_colour_manual(values = pal) +
```

```
labs(title = 'Scenario 2C: Pain inclusion threshold = 4',
     caption = '*Pain rated on a 0 to 10 numerical pain rating scale',
     x = 'V1*',
     y = 'V2*') +
theme(legend.title = element_blank(),
     legend.position = c(0.8, 0.15)),
groupColour = TRUE,
groupFill = TRUE)
```

Scenario 2C: Pain inclusion threshold = 4



*Pain rated on a 0 to 10 numerical pain rating scale

```
nrow(cor_051) - nrow(placebo_3.4)
```

5.4.3.1 Points lost by cutoff

```
## [1] 108
```

5.4.4 Threshold: 5

```
# Process that data
placebo_3.5 <- cor_051 %>%
  filter(V1 >= 5) %>%
  mutate(difference = V1 - V2) %>%
  mutate(group = 'Threshold')

# Set seed
set.seed(2019)

# Calculate the mean (95%CI) difference between V1 and V2
diff_3.5 <- groupwiseMean(difference ~ 1,
  data = placebo_3.5,
  R = 2000,
  traditional = FALSE,
  bca = TRUE)

diff_3.5$.id <- 5

kable(diff_3.5)
```

.id	n	Mean	Conf.level	Bca.lower	Bca.upper
5	715	0.423	0.95	0.302	0.536

```
# Plot the data
ggMarginal(placebo_3.5[, 1:3] %>%
  bind_rows(cor_051) %>%
  mutate(group = factor(group,
    levels = c('No threshold', 'Threshold'),
    ordered = TRUE)) %>%

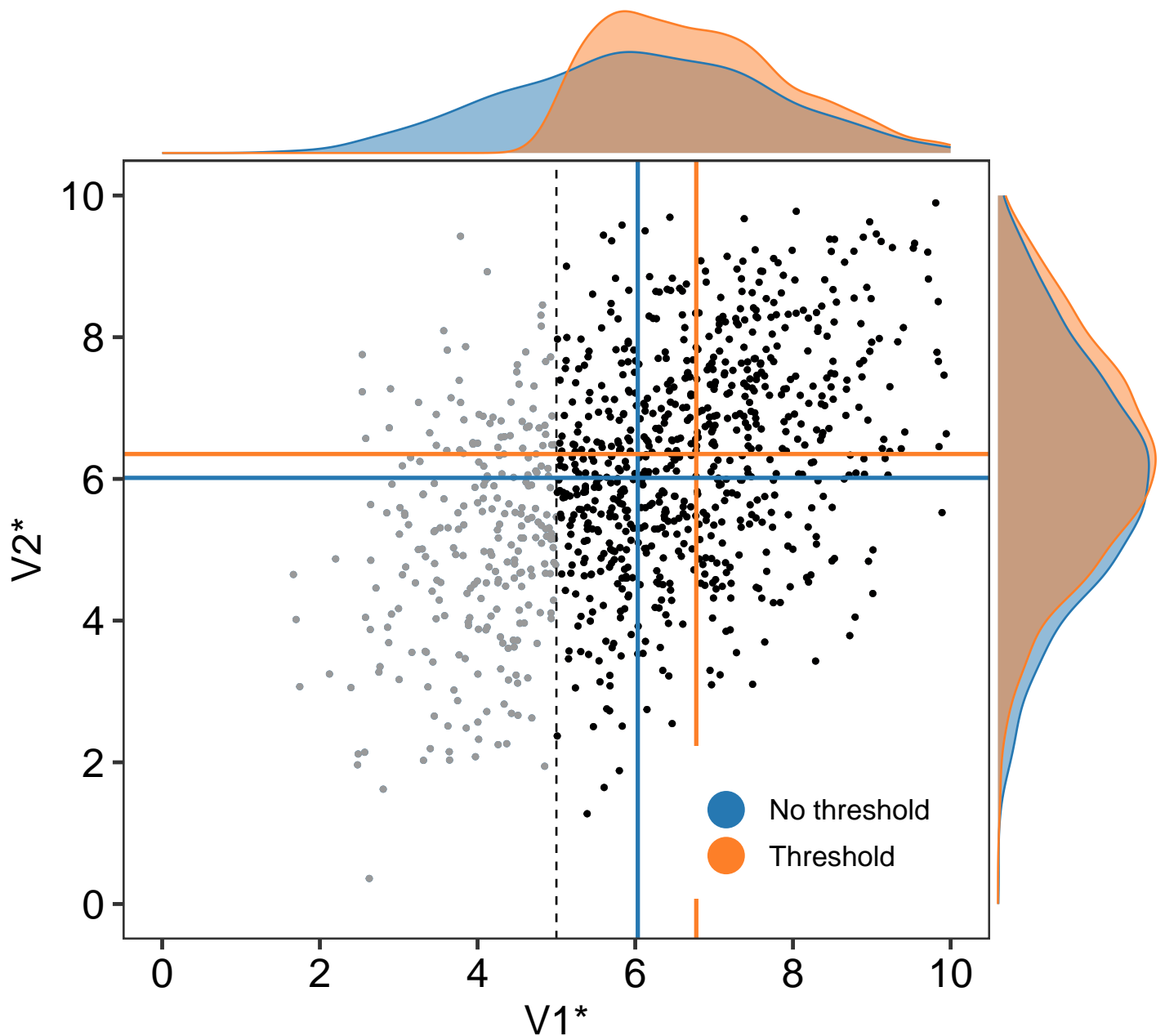
  ggplot(data = .) +
  aes(x = V1, y = V2) +
  geom_point(aes(colour = group, fill = group),
    size = 1) +
  guides(colour = guide_legend(override.aes = list(size = 8))) +
  geom_point(data = cor_051,
    colour = '#999999',
    size = 1) +
  geom_point(data = placebo_3.5,
    size = 1,
    colour = '#000000') +
  geom_vline(xintercept = mean(cor_051$V1),
    colour = pal[1], size = 1) +
  geom_vline(xintercept = mean(placebo_3.5$V1),
    colour = pal[2], size = 1) +
  geom_vline(xintercept = 5, linetype = 2) +
  geom_hline(yintercept = mean(cor_051$V2),
    colour = pal[1], size = 1) +
  geom_hline(yintercept = mean(placebo_3.5$V2),
    colour = pal[2], size = 1) +
  scale_y_continuous(limits = c(0, 10),
    breaks = c(0, 2, 4, 6, 8, 10)) +
  scale_x_continuous(limits = c(0, 10),
```

```

breaks = c(0, 2, 4, 6, 8, 10)) +
scale_fill_manual(values = pal) +
scale_colour_manual(values = pal) +
labs(title = 'Scenario 2C: Pain inclusion threshold = 5',
caption = '*Pain rated on a 0 to 10 numerical pain rating scale',
x = 'V1*',
y = 'V2*') +
theme(legend.title = element_blank(),
legend.position = c(0.8, 0.15)),
groupColour = TRUE,
groupFill = TRUE)

```

Scenario 2C: Pain inclusion threshold = 5



*Pain rated on a 0 to 10 numerical pain rating scale

```
nrow(cor_051) - nrow(placebo_3.5)
```

5.4.4.1 Points lost by cutoff

```
## [1] 261
```

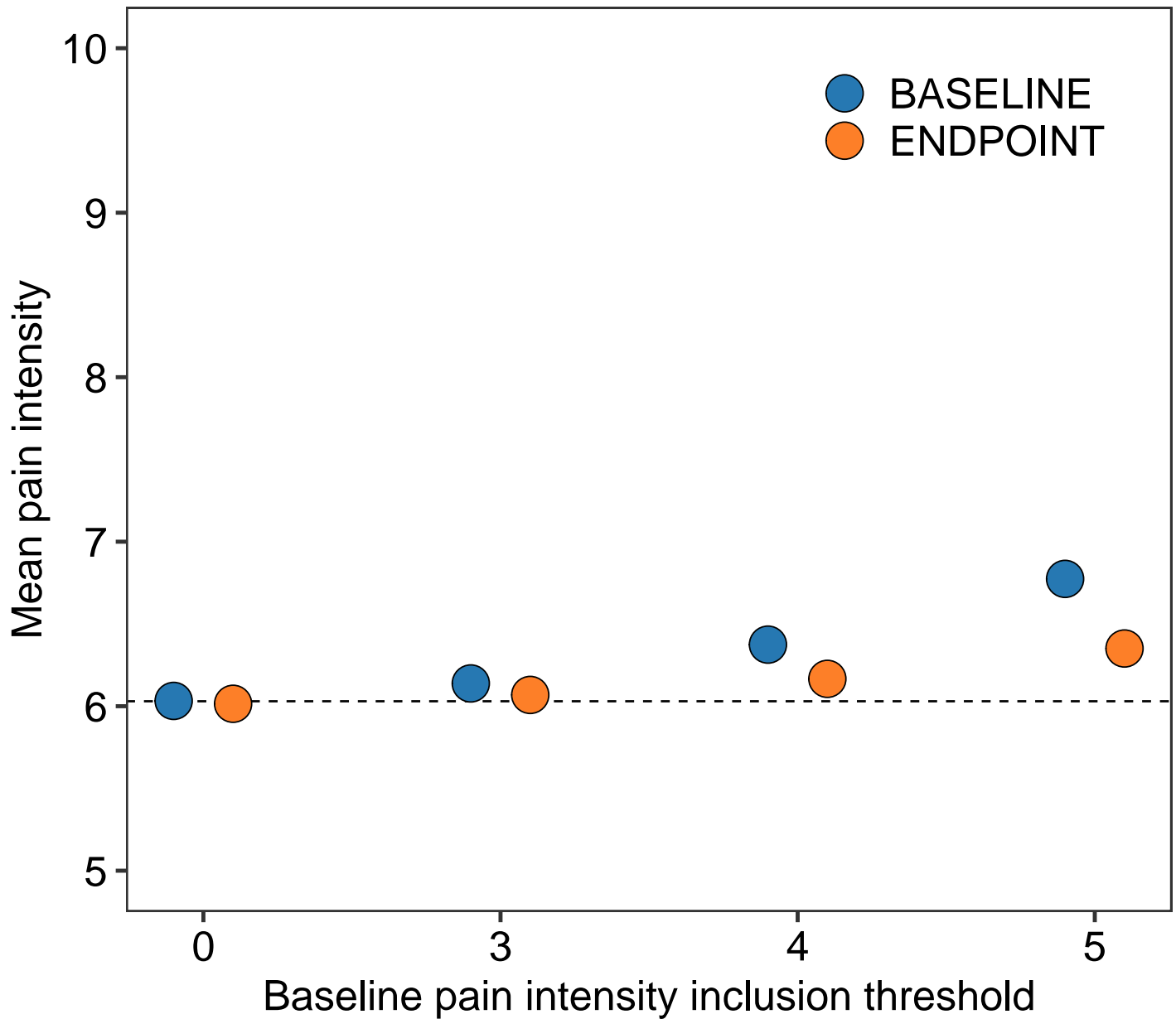
5.5 Summary plots

```
# Plot 1
shift_C <- cor_051V1.df %>%
  bind_rows(cor_051V2.df) %>%
  filter(cutoff != 1 & cutoff != 2) %>%
  mutate(cutoff2 = c(-0.1, 0.9, 1.9, 2.9, 0.1, 1.1, 2.1, 3.1)) %>%
  ggplot(data = .) +
  aes(y = mean,
      x = cutoff2,
      fill = time) +
  geom_hline(yintercept = 6.03,
             linetype = 2) +
  geom_point(shape = 21,
             size = 8) +
  labs(title = 'Scenario 2C',
       subtitle = 'Threshold 0:\nBASELINE = 6.0 (1.6), ENDPOINT = 6.0 (1.6), r = 0.46',
       x = 'Baseline pain intensity inclusion threshold',
       y = 'Mean pain intensity') +
  scale_x_continuous(breaks = 0:3,
                    labels = c(0, 3, 4, 5)) +
  scale_y_continuous(limits = c(5, 10)) +
  scale_fill_manual(values = pal,
                   labels = c('BASELINE', 'ENDPOINT')) +
  theme(legend.title = element_blank(),
        legend.position = c(0.80, 0.89),
        legend.text = element_text(size = 20)); shift_C
```

Scenario 2C

Threshold 0:

BASELINE = 6.0 (1.6), ENDPOINT = 6.0 (1.6), $r = 0.46$



```
# Plot 2
# Bind diff_*. dataframes
diff_all_1 <- diff_3.0 %>%
  bind_rows(diff_3.3, diff_3.4, diff_3.5)

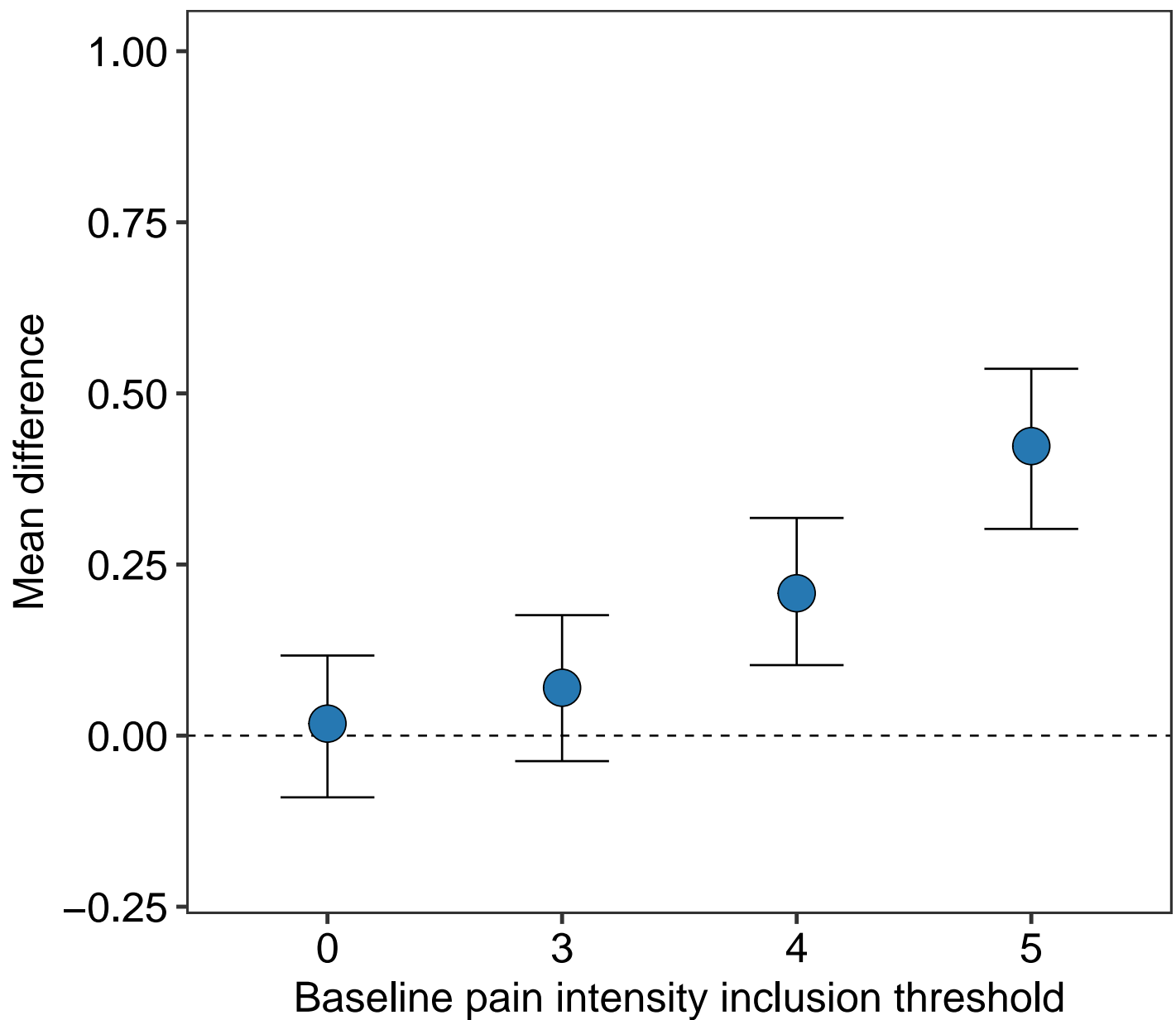
diff_C <- diff_all_1 %>%
  mutate(Threshold = factor(.id)) %>%
  ggplot(data = .) +
  aes(x = Threshold,
      y = Mean,
      ymin = Bca.lower,
      ymax = Bca.upper) +
  geom_hline(yintercept = 0,
             linetype = 2) +
```

```
geom_errorbar(width = 0.4) +
geom_point(shape = 21,
           fill = pal[[1]],
           size = 8) +
labs(title = 'Scenario 2C',
     subtitle = 'Threshold 0:\nBASELINE = 6.0 (1.6), ENDPOINT = 6.0 (1.6), r = 0.46',
     x = 'Baseline pain intensity inclusion threshold',
     y = 'Mean difference') +
scale_y_continuous(limits = c(-0.2, 1.0)); diff_C
```

Scenario 2C

Threshold 0:

BASELINE = 6.0 (1.6), ENDPOINT = 6.0 (1.6), $r = 0.46$



6 Publication plots

Code only, outputs to file.

```
# Shifts
shift_A2 <- cor_026V1.df %>%
  bind_rows(cor_026V2.df) %>%
  filter(cutoff != 1 & cutoff != 2) %>%
  mutate(cutoff2 = c(-0.1, 0.9, 1.9, 2.9, 0.1, 1.1, 2.1, 3.1)) %>%
  ggplot(data = .) +
  aes(y = mean,
      x = cutoff2,
      fill = time) +
  geom_hline(yintercept = 6.05,
             linetype = 2) +
  geom_point(shape = 21,
             size = 10,
             stroke = 0.8) +
  labs(title = 'Scenario 2A',
       x = NULL,
       y = NULL,
       subtitle = 'Threshold 0:\nBASELINE = 6.1 (1.6)\nENDPOINT = 6.0 (1.7), r = 0.21') +
  scale_x_continuous(breaks = c(0, 1, 2, 3),
                    labels = c(0, 3, 4, 5)) +
  scale_y_continuous(limits = c(5, 10)) +
  scale_fill_manual(labels = c('BASELINE', 'ENDPOINT'),
                   values = pal) +
  theme_bw(base_size = 24) +
  theme(legend.position = 'none',
        axis.text = element_text(colour = '#000000',
                                   size = 24),
        panel.grid = element_blank(),
        plot.title = element_text(size = 24),
        plot.subtitle = element_text(size = 20))

shift_B2 <- cor_037V1.df %>%
  bind_rows(cor_037V2.df) %>%
  filter(cutoff != 1 & cutoff != 2) %>%
  mutate(cutoff2 = c(-0.1, 0.9, 1.9, 2.9, 0.1, 1.1, 2.1, 3.1)) %>%
  ggplot(data = .) +
  aes(y = mean,
      x = cutoff2,
      fill = time) +
  geom_hline(yintercept = 6.04,
             linetype = 2) +
  geom_point(shape = 21,
             size = 10,
             stroke = 0.8) +
  labs(title = 'Scenario 2B',
       x = NULL,
       y = NULL) +
  scale_x_continuous(breaks = 0:3,
                    labels = c(0, 3, 4, 5)) +
  scale_y_continuous(limits = c(5, 10)) +
  scale_fill_manual(values = pal,
                   labels = c('BASELINE', 'ENDPOINT')) +
  theme_bw(base_size = 24) +
  theme(legend.position = 'none',
```

```

    axis.text = element_text(colour = '#000000',
                             size = 24),
    panel.grid = element_blank(),
    plot.title = element_text(size = 24),
    plot.subtitle = element_text(size = 20))

shift_C2 <- cor_051V1.df %>%
  bind_rows(cor_051V2.df) %>%
  filter(cutoff != 1 & cutoff != 2) %>%
  mutate(cutoff2 = c(-0.1, 0.9, 1.9, 2.9, 0.1, 1.1, 2.1, 3.1)) %>%
  ggplot(data = .) +
  aes(y = mean,
       x = cutoff2,
       fill= time) +
  geom_hline(yintercept = 6.03,
             linetype = 2) +
  geom_point(shape = 21,
            size = 10,
            stroke = 0.8) +
  labs(title = 'Scenario 2C',
       subtitle = 'Threshold 0:\nBASELINE = 6.0 (1.6)\nENDPOINT = 6.0 (1.6), r = 0.46',
       x = NULL,
       y = NULL) +
  scale_x_continuous(breaks = 0:3,
                    labels = c(0, 3, 4, 5)) +
  scale_y_continuous(limits = c(5, 10)) +
  scale_fill_manual(values = pal,
                   labels = c('BASELINE', 'ENDPOINT')) +
  theme_bw(base_size = 24) +
  theme(legend.position = 'none',
        axis.text = element_text(colour = '#000000',
                                   size = 24),
        panel.grid = element_blank(),
        plot.title = element_text(size = 24),
        plot.subtitle = element_text(size = 20))

shifts <- shift_A2 + shift_B2 + shift_C2 +
  plot_layout(ncol = 3)

ggsave(filename = 'figures/figure-scenario-2-baseline-shift.png',
       plot = shifts,
       height = 7.5,
       width = 21)

# Threshold
ggsave(filename = 'figures/figure-scenario-2-threshold-0.png',
       plot = threshold_0,
       height = 7,
       width = 7)

ggsave(filename = 'figures/figure-scenario-2-threshold-3.png',
       plot = threshold_3,
       height = 7,
       width = 7)

ggsave(filename = 'figures/figure-scenario-2-threshold-4.png',
       plot = threshold_4,
       height = 7,

```

```

width = 7)

ggsave(filename = 'figures/figure-scenario-2-threshold-5.png',
        plot = threshold_5,
        height = 7,
        width = 7)

# Diffs
diff_A2 <- diff_all_1 %>%
  mutate(Threshold = factor(.id)) %>%
  ggplot(data = .) +
  aes(x = Threshold,
       y = Mean,
       ymin = Bca.lower,
       ymax = Bca.upper) +
  geom_hline(yintercept = 0,
             linetype = 2) +
  geom_errorbar(width = 0.4,
               size = 0.8) +
  geom_point(shape = 21,
            fill = pal[[1]],
            stroke = 0.8,
            size = 10) +
  labs(title = 'Scenario 2A',
       subtitle = 'Threshold 0:\nBASELINE = 6.1 (1.6)\nENDPOINT = 6.0 (1.7), r = 0.21',
       x = NULL,
       y = NULL) +
  scale_y_continuous(limits = c(-0.2, 1.0)) +
  theme_bw(base_size = 24) +
  theme(axis.text = element_text(colour = '#000000',
                                size = 24),
        panel.grid = element_blank(),
        plot.title = element_text(size = 24),
        plot.subtitle = element_text(size = 20))

diff_B2 <- diff_all_1 %>%
  mutate(Threshold = factor(.id)) %>%
  ggplot(data = .) +
  aes(x = Threshold,
       y = Mean,
       ymin = Bca.lower,
       ymax = Bca.upper) +
  geom_hline(yintercept = 0,
             linetype = 2) +
  geom_errorbar(width = 0.4,
               size = 0.8) +
  geom_point(shape = 21,
            fill = pal[[1]],
            stroke = 0.8,
            size = 10) +
  labs(title = 'Scenario 2B',
       subtitle = 'Threshold 0:\nBASELINE = 6.0 (1.6)\nENDPOINT = 6.0 (1.6), r = 0.32',
       x = NULL,
       y = NULL) +
  scale_y_continuous(limits = c(-0.2, 1.0)) +
  theme_bw(base_size = 24) +
  theme(axis.text = element_text(colour = '#000000',
                                size = 24),

```

```

    panel.grid = element_blank(),
    plot.title = element_text(size = 24),
    plot.subtitle = element_text(size = 20))

diff_C2 <- diff_all_1 %>%
  mutate(Threshold = factor(.id)) %>%
  ggplot(data = .) +
  aes(x = Threshold,
      y = Mean,
      ymin = Bca.lower,
      ymax = Bca.upper) +
  geom_hline(yintercept = 0,
             linetype = 2) +
  geom_errorbar(width = 0.4,
                size = 0.8) +
  geom_point(shape = 21,
             fill = pal[[1]],
             stroke = 0.8,
             size = 10) +
  labs(title = 'Scenario 2C',
       subtitle = 'Threshold 0:\nBASELINE = 6.0 (1.6)\nENDPOINT = 6.0 (1.6), r = 0.46',
       x = NULL,
       y = NULL) +
  scale_y_continuous(limits = c(-0.2, 1.0)) +
  theme_bw(base_size = 24) +
  theme(axis.text = element_text(colour = '#000000',
                                 size = 24),
        panel.grid = element_blank(),
        plot.title = element_text(size = 24),
        plot.subtitle = element_text(size = 20))

diffs <- diff_A2 + diff_B2 + diff_C2 +
  plot_layout(ncol = 3)

ggsave(filename = 'figures/figure-scenario-2-V1V2-difference.png',
       plot = diffs,
       height = 7.5,
       width = 21)

```

7 Session information

```
sessionInfo()
```

```

## R version 4.0.4 (2021-02-15)
## Platform: x86_64-apple-darwin17.0 (64-bit)
## Running under: macOS Big Sur 10.16
##
## Matrix products: default
## BLAS: /Library/Frameworks/R.framework/Versions/4.0/Resources/lib/libRblas.dylib
## LAPACK: /Library/Frameworks/R.framework/Versions/4.0/Resources/lib/libRlapack.dylib
##
## locale:
## [1] en_US.UTF-8/en_US.UTF-8/en_US.UTF-8/C/en_US.UTF-8/en_US.UTF-8
##
## attached base packages:

```

```
## [1] stats      graphics  grDevices utils      datasets  methods  base
##
## other attached packages:
## [1] patchwork_1.1.1 knitr_1.31      MBESS_4.8.0      ggExtra_0.9
## [5] rcompanion_2.3.27 MASS_7.3-53.1    magrittr_2.0.1   forcats_0.5.1
## [9] stringr_1.4.0    dplyr_1.0.5      purrr_0.3.4      readr_1.4.0
## [13] tidyr_1.1.3      tibble_3.1.0     ggplot2_3.3.3    tidyverse_1.3.0
##
## loaded via a namespace (and not attached):
## [1] matrixStats_0.58.0 fs_1.5.0          lubridate_1.7.10  httr_1.4.2
## [5] tools_4.0.4        backports_1.2.1   utf8_1.2.1        R6_2.5.0
## [9] nortest_1.0-4       DBI_1.1.1         colorspace_2.0-0  withr_2.4.1
## [13] tidyselect_1.1.0   Exact_2.1         compiler_4.0.4    cli_2.3.1
## [17] rvest_1.0.0        expm_0.999-6      xml2_1.3.2        sandwich_3.0-0
## [21] labeling_0.4.2     scales_1.1.1      lmtest_0.9-38     mvtnorm_1.1-1
## [25] multcompView_0.1-8 digest_0.6.27      rmarkdown_2.7     pkgconfig_2.0.3
## [29] htmltools_0.5.1.1 highr_0.8          fastmap_1.1.0     dbplyr_2.1.0
## [33] rlang_0.4.10       readxl_1.3.1      rstudioapi_0.13   shiny_1.6.0
## [37] farver_2.1.0       generics_0.1.0    zoo_1.8-9         jsonlite_1.7.2
## [41] modeltools_0.2-23  Matrix_1.3-2      Rcpp_1.0.6        DescTools_0.99.40
## [45] munsell_0.5.0      fansi_0.4.2       lifecycle_1.0.0   stringi_1.5.3
## [49] multcomp_1.4-16    yaml_2.2.1        rootSolve_1.8.2.1 plyr_1.8.6
## [53] grid_4.0.4         promises_1.2.0.1  parallel_4.0.4    crayon_1.4.1
## [57] lmom_2.8           miniUI_0.1.1.1    lattice_0.20-41   haven_2.3.1
## [61] splines_4.0.4      hms_1.0.0         pillar_1.5.1      EMT_1.1
## [65] boot_1.3-27        gld_2.6.2         codetools_0.2-18  stats4_4.0.4
## [69] reprex_1.0.0       glue_1.4.2        evaluate_0.14     modelr_0.1.8
## [73] httpuv_1.5.5       vctrs_0.3.6       cellranger_1.1.0  gtable_0.3.0
## [77] assertthat_0.2.1   xfun_0.22         mime_0.10         coin_1.4-1
## [81] xtable_1.8-4       libcoin_1.0-8     broom_0.7.5       e1071_1.7-4
## [85] later_1.1.0.1      class_7.3-18      survival_3.2-9    TH.data_1.0-10
## [89] ellipsis_0.3.1
```