Data Analysis for 'Punishment is Slower than Cooperation or Defection'

Table of contents

1. Setup

Load required packages

```
library(tidyverse)
library(igraph)
library(lme4)
library(lmerTest)
library(DescTools)
library(data.table)
library(patchwork)
library(stringr)
library(ggpattern)
```

Load required data

```
## Experiment 1
exp1data = read_csv("~/Documents/Projects/harming_esn/data/final/exp1data_final.csv",
                    show_col_types = FALSE)

## Experiment 2
exp2data = read_csv("~/Documents/Projects/harming_esn/data/final/exp2data_final.csv",
                    show_col_types = FALSE)
```

Create helper functions

```
mean1 = function(x) {mean(x,na.rm=TRUE)}
median1 = function(x) {median(x, na.rm = TRUE)}
sd1 = function(x) {sd(x, na.rm = TRUE)}
se_mean = function(x) sd1(x)/sqrt(sum(is.na(x) == 0))
```

2. Analysis

Number of observations per experiment

Experiment 1

```
# Experiment 1
exp1data %>%
  filter(round > 0, is.na(behavior) == F) %>%
  nrow()
```

```
[1] 9776
```

Experiment 2

```
# Experiment 2
exp2data %>%
  filter(round > 0, is.na(behavior) == F) %>%
  nrow()
```

```
[1] 10654
```

Per-game characteristics

Experiment 1

```
exp1data %>%
  filter(round >= 1) %>%
  group_by(game) %>%
  select(superid) %>%
  unique() %>%
  nrow()
```

```
[1] 719
```

```
exp1data %>%
  filter(round >= 1) %>%
  group_by(game) %>%
```

```
    select(superid) %>%
    unique() %>%
    summarize(n = n()) %>%
    summarize(`Mean Players` = mean(n),
              `Min Players` = min(n),
              `Max Players` = max(n))
```

```
# A tibble: 1 x 3
  `Mean Players` `Min Players` `Max Players`
           <dbl>         <int>         <int>
1           14.4             8            25
```

Experiment 2

```
  # Players per game, min, max - Experiment 2
  exp2data %>%
    filter(round >=0) %>%
    group_by(game) %>%
    select(superid) %>%
    unique() %>%
    summarize(n = n()) %>%
    summarize(`Mean Players` = mean(n),
              `Min Players` = min(n),
              `Max Players` = max(n))
```

```
# A tibble: 1 x 3
  `Mean Players` `Min Players` `Max Players`
           <dbl>         <int>         <int>
1           14.8             8            20
```

Number of observations in Exp. 2, TP+/TP- settings

```
  exp2data %>%
    filter(time_pressure == "Plus", round >= 1, behavior %in% c("C", "D", "P")) %>%
    nrow()
```

```
[1] 5407
```

```r
exp2data %>%
  filter(time_pressure == "Minus", round >= 1, behavior %in% c("C", "D", "P")) %>%
  nrow()
```

```
[1] 5247
```

```r
# Total = 10654
```

Distribution of decision-making

Experiment 1

```r
# Decision distribution - Experiment 1
data1_behavior_count = exp1data %>%
  filter(round >= 1) %>%
  group_by(behavior) %>%
  filter(behavior %in% c("C", "D", "P")) %>%
  summarize(count = n()) %>%
  ungroup() %>%
  mutate(proportion = count/sum(count))

# Confidence Intervals
data1_behavior_CI = MultinomCI(x = c(4878, 4336, 562), sides = "two.sided") %>%
  as_tibble()
```

Experiment 2

```r
# Decision distribution - Experiment 2
exp2data_count = exp2data %>% filter(round >= 1) %>%
  group_by(behavior) %>%
  filter(behavior %in% c("C", "D", "P")) %>%
  summarize(count = n()) %>%
  ungroup() %>%
  mutate(proportion = count/sum(count))

exp2data_all_CI = MultinomCI(c(4185, 5790, 679), sides = "two.sided")
```

```r
exp2data_tp_plus_count = exp2data %>%
  group_by(behavior) %>%
  filter(time_pressure == "Plus", behavior %in% c("C", "D", "P")) %>%
  summarize(count = n()) %>%
  ungroup() %>%
  mutate(proportion = count/sum(count))

exp2data_tp_plus_CI = MultinomCI(c(2172, 2897, 338), sides = "two.sided")

exp2data_tp_plus_times = exp2data %>%
  group_by(behavior) %>%
  filter(time_pressure == "Plus", behavior %in% c("C", "D", "P")) %>%
  summarize(mean_dt = mean1(behaviorTime_sec),
            se_mean_dt = se_mean(behaviorTime_sec),
            LL_mean = mean_dt - 1.96*se_mean_dt,
            UL_mean = mean_dt + 1.96*se_mean_dt)

exp2data_tp_minus_count = exp2data %>%
  group_by(behavior) %>%
  filter(time_pressure == "Minus", behavior %in% c("C", "D", "P")) %>%
  summarize(count = n()) %>%
  ungroup() %>%
  mutate(proportion = count/sum(count))

exp2data_tp_minus_times = exp2data %>%
  group_by(behavior) %>%
  filter(time_pressure == "Minus", behavior %in% c("C", "D", "P")) %>%
  summarize(mean_dt = mean1(behaviorTime_sec),
            se_mean_dt = se_mean(behaviorTime_sec),
            LL_mean = mean_dt - 1.96*se_mean_dt,
            UL_mean = mean_dt + 1.96*se_mean_dt)

exp2data_tp_minus_CI = MultinomCI(c(2013, 2893, 341), sides = "two.sided")
```

```r
# Behavior breakdown - Experiment B, TP-
exp2data_tp_minus_count = exp2data %>%
  group_by(behavior) %>%
  filter(time_pressure == "Minus", behavior %in% c("C", "D", "P")) %>%
  summarize(count = n()) %>%
  ungroup() %>%
  mutate(proportion = count/sum(count))
```

```r
exp2data_tp_minus_CI = MultinomCI(c(2013, 2893, 341), sides = "two.sided")
```

```r
# Behavior breakdown - Experiment B, TP+
exp2data_tp_plus_count = exp2data %>%
  group_by(behavior) %>%
  filter(time_pressure == "Plus", behavior %in% c("C", "D", "P")) %>%
  summarize(count = n()) %>%
  ungroup() %>%
  mutate(proportion = count/sum(count))

exp2data_tp_plus_CI = MultinomCI(c(2172, 2897, 338), sides = "two.sided")
```

Network characteristics

Experiment 1

```r
mean1(exp1data$degree)
```

```
[1] 5.911319
```

```r
min(exp1data$degree, na.rm = T)
```

```
[1] 1
```

```r
max(exp1data$degree, na.rm = T)
```

```
[1] 17
```

Experiment 2

```r
mean1(exp2data$degree)
```

```
[1] 5.721265
```

```r
min(exp2data$degree, na.rm = T)
```

```
[1] 1
```

```r
max(exp2data$degree, na.rm = T)
```

```
[1] 16
```

Decision times

Experiment 1

```r
data1_times = exp1data %>%
  group_by(behavior) %>%
  filter(behavior %in% c("C", "D", "P")) %>%
  summarize(mean_dt = mean1(behaviorTime_sec),
            se_mean_dt = se_mean(behaviorTime_sec),
            LL_mean = mean_dt - 1.96*se_mean_dt,
            UL_mean = mean_dt + 1.96*se_mean_dt)
```

Experiment 2

```r
exp2data %>%
  group_by(behavior, time_pressure) %>%
  filter(behavior %in% c("C", "D", "P")) %>%
  summarize(mean_dt = mean1(behaviorTime_sec),
            se_mean_dt = se_mean(behaviorTime_sec),
            UL_mean = mean_dt + 1.96*se_mean_dt,
            LL_mean = mean_dt - 1.96*se_mean_dt)
```

```
`summarise()` has grouped output by 'behavior'. You can override using the
`.groups` argument.
```

```
# A tibble: 6 x 6
# Groups:   behavior [3]
  behavior time_pressure mean_dt se_mean_dt UL_mean LL_mean
  <chr>    <chr>           <dbl>      <dbl>   <dbl>   <dbl>
```

```
1 C        Minus            3.13    0.0537     3.24    3.03
2 C        Plus             2.02    0.00987    2.04    2.00
3 D        Minus            2.85    0.0419     2.93    2.77
4 D        Plus             1.92    0.00826    1.94    1.91
5 P        Minus            3.82    0.203      4.22    3.42
6 P        Plus             2.11    0.0301     2.17    2.05
```

3. Regression Modeling

Punishment vs. time pressure

```
m1 = glmer(behavior_punish ~ time_pressure + round + (1|game) + (1|superid),
           data = exp2data %>% filter(round > 0), family = binomial, nAGQ=0,
           control = glmerControl(optimizer = c("bobyqa"),
                                  optCtrl=list(maxfun=2e5),
                                  calc.derivs=FALSE))
summary(m1)
```

```
Generalized linear mixed model fit by maximum likelihood (Adaptive
  Gauss-Hermite Quadrature, nAGQ = 0) [glmerMod]
 Family: binomial  ( logit )
Formula: behavior_punish ~ time_pressure + round + (1 | game) + (1 | superid)
   Data: exp2data %>% filter(round > 0)
Control: glmerControl(optimizer = c("bobyqa"), optCtrl = list(maxfun = 2e+05),
    calc.derivs = FALSE)

     AIC      BIC   logLik deviance df.resid
  3639.8   3676.2  -1814.9   3629.8    10742

Scaled residuals:
    Min      1Q  Median      3Q     Max
-2.9801 -0.1020 -0.0884 -0.0793  4.6005

Random effects:
 Groups  Name        Variance Std.Dev.
 superid (Intercept) 6.908    2.6283
 game    (Intercept) 0.641    0.8006
Number of obs: 10747, groups:  superid, 739; game, 50

Fixed effects:
```

```
                  Estimate Std. Error z value Pr(>|z|)
(Intercept)       -3.69099    0.25747 -14.335   <2e-16 ***
time_pressurePlus -0.24888    0.34838  -0.714   0.4750
round             -0.02644    0.01120  -2.362   0.0182 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) tm_prP
tm_prssrPls -0.661
round       -0.324 -0.001
```

```
# p = 0.475
```

Cooperation vs. time pressure

```
m1.1 = glmer(behavior_coop ~ time_pressure + round + (1|game) + (1|superid),
             data = exp2data %>% filter(round > 0), family = binomial, nAGQ=0,
             control = glmerControl(optimizer = c("bobyqa"),
                                    optCtrl=list(maxfun=2e5),
                                    calc.derivs=FALSE))
summary(m1.1)
```

```
Generalized linear mixed model fit by maximum likelihood (Adaptive
  Gauss-Hermite Quadrature, nAGQ = 0) [glmerMod]
 Family: binomial  ( logit )
Formula: behavior_coop ~ time_pressure + round + (1 | game) + (1 | superid)
   Data: exp2data %>% filter(round > 0)
Control: glmerControl(optimizer = c("bobyqa"), optCtrl = list(maxfun = 2e+05),
    calc.derivs = FALSE)

     AIC      BIC   logLik deviance df.resid
  6102.1   6138.5  -3046.0   6092.1    10742

Scaled residuals:
    Min      1Q  Median      3Q     Max
-4.2875 -0.1092 -0.0839  0.1164  4.4511

Random effects:
 Groups  Name        Variance Std.Dev.
```

```
 superid (Intercept) 27.00    5.196
 game    (Intercept)  2.42    1.556
Number of obs: 10747, groups:  superid, 739; game, 50

Fixed effects:
                  Estimate Std. Error z value Pr(>|z|)
(Intercept)       -0.815089   0.434020  -1.878   0.0604 .
time_pressurePlus  0.265534   0.605401   0.439   0.6609
round             -0.048143   0.008987  -5.357 8.46e-08 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) tm_prP
tm_prssrPls -0.699
round       -0.157 -0.002
```

```
# p = 0.661
```

Defection vs. time pressure

```
m1.2 = glmer(behavior_defect ~ time_pressure + round + (1|game) + (1|superid),
             data = exp2data %>% filter(round > 0), family = binomial, nAGQ=0,
             control = glmerControl(optimizer = c("bobyqa"),
                                    optCtrl=list(maxfun=2e5),
                                    calc.derivs=FALSE))

summary(m1.2)
```

```
Generalized linear mixed model fit by maximum likelihood (Adaptive
  Gauss-Hermite Quadrature, nAGQ = 0) [glmerMod]
 Family: binomial  ( logit )
Formula: behavior_defect ~ time_pressure + round + (1 | game) + (1 | superid)
   Data: exp2data %>% filter(round > 0)
Control: glmerControl(optimizer = c("bobyqa"), optCtrl = list(maxfun = 2e+05),
    calc.derivs = FALSE)

     AIC      BIC   logLik deviance df.resid
  5658.6   5695.0  -2824.3   5648.6    10742
```

```
Scaled residuals:
    Min      1Q  Median      3Q     Max
-4.5487 -0.1017  0.0728  0.1006  4.4163

Random effects:
 Groups  Name        Variance Std.Dev.
 superid (Intercept) 35.060   5.921
 game    (Intercept)  3.392   1.842
Number of obs: 10747, groups:  superid, 739; game, 50

Fixed effects:
                   Estimate Std. Error z value Pr(>|z|)
(Intercept)        0.034318   0.502767   0.068    0.946
time_pressurePlus -0.216417   0.703295  -0.308    0.758
round              0.055394   0.009602   5.769 7.97e-09 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) tm_prP
tm_prssrPls -0.699
round       -0.147 -0.002
```

```
# p = 0.758
```

Decision times vs. time pressure (not useful)

```
model_dt_coop = lmer(behaviorTime_sec ~ time_pressure + round + (1|game) + (1|superid),
                     data = exp2data %>% filter(round > 0, behavior_coop == 1))
summary(model_dt_coop)
```

```
Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]
Formula: behaviorTime_sec ~ time_pressure + round + (1 | game) + (1 |
    superid)
   Data: exp2data %>% filter(round > 0, behavior_coop == 1)

REML criterion at convergence: 13885.1

Scaled residuals:
```

```
    Min      1Q  Median      3Q     Max
-3.8000 -0.2551 -0.0807  0.1074 21.7822

Random effects:
 Groups   Name        Variance Std.Dev.
 superid  (Intercept) 1.15374  1.0741
 game     (Intercept) 0.06439  0.2538
 Residual             2.33938  1.5295
Number of obs: 3588, groups:  superid, 432; game, 50

Fixed effects:
                    Estimate Std. Error         df t value Pr(>|t|)
(Intercept)        3.404e+00  1.107e-01  5.194e+01  30.744  < 2e-16 ***
time_pressurePlus -1.275e+00  1.435e-01  3.649e+01  -8.887 1.17e-10 ***
round             -8.243e-03  6.150e-03  3.285e+03  -1.340     0.18
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) tm_prP
tm_prssrPls -0.627
round       -0.423 -0.014
```

```
model_dt_def = lmer(behaviorTime_sec ~ time_pressure + round + (1|game) + (1|superid),
                    data = exp2data %>% filter(round > 0, behavior_defect == 1))
summary(model_dt_def)
```

```
Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]
Formula: behaviorTime_sec ~ time_pressure + round + (1 | game) + (1 |
    superid)
   Data: exp2data %>% filter(round > 0, behavior_defect == 1)

REML criterion at convergence: 19604.6

Scaled residuals:
    Min      1Q  Median      3Q     Max
-5.6180 -0.2482 -0.0776  0.1050 27.1570

Random effects:
 Groups   Name        Variance Std.Dev.
```

```
 superid  (Intercept) 0.945248 0.97224
 game     (Intercept) 0.001146 0.03385
 Residual             2.171540 1.47361
Number of obs: 5200, groups:  superid, 509; game, 50

Fixed effects:
                    Estimate Std. Error         df t value Pr(>|t|)
(Intercept)        3.162e+00  7.875e-02  7.030e+01  40.155  < 2e-16 ***
time_pressurePlus -1.055e+00  9.991e-02  4.290e+01 -10.564 1.64e-13 ***
round             -1.729e-02  4.853e-03  4.794e+03  -3.563 0.000371 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) tm_prP
tm_prssrPls -0.593
round       -0.489 -0.014
```

```
model_dt_pun = lmer(behaviorTime_sec ~ time_pressure + round + (1|game) + (1|superid),
                    data = exp2data %>% filter(round > 0, behavior_punish == 1))
```

```
boundary (singular) fit: see help('isSingular')
```

```
summary(model_dt_pun)
```

```
Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]
Formula: behaviorTime_sec ~ time_pressure + round + (1 | game) + (1 |
    superid)
   Data: exp2data %>% filter(round > 0, behavior_punish == 1)

REML criterion at convergence: 2607.7

Scaled residuals:
    Min      1Q  Median      3Q     Max
-2.9474 -0.2663 -0.0885  0.0699  9.1708

Random effects:
 Groups   Name        Variance Std.Dev.
 superid  (Intercept) 3.673    1.917
```

```
 game     (Intercept) 0.000    0.000
 Residual             6.146    2.479
Number of obs: 525, groups:  superid, 176; game, 49

Fixed effects:
                   Estimate Std. Error        df t value Pr(>|t|)
(Intercept)         4.17743    0.32280 283.53251  12.941  < 2e-16 ***
time_pressurePlus  -1.87849    0.39484 127.32898  -4.758 5.23e-06 ***
round              -0.01823    0.02866 450.29088  -0.636    0.525
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) tm_prP
tm_prssrPls -0.437
round       -0.637 -0.077
optimizer (nloptwrap) convergence code: 0 (OK)
boundary (singular) fit: see help('isSingular')
```

Punishment mechanisms vs. time pressure

Punishment for copying/retaliation

```
m2.1 = glmer(punish_type_CR ~ time_pressure + round + (1|game) + (1|superid),
             data = exp2data %>% filter(round > 0), family = binomial, nAGQ=0,
             control = glmerControl(optimizer = c("bobyqa"),
                                    optCtrl=list(maxfun=2e5),
                                    calc.derivs=FALSE))

summary(m2.1)
```

```
Generalized linear mixed model fit by maximum likelihood (Adaptive
  Gauss-Hermite Quadrature, nAGQ = 0) [glmerMod]
 Family: binomial  ( logit )
Formula: punish_type_CR ~ time_pressure + round + (1 | game) + (1 | superid)
   Data: exp2data %>% filter(round > 0)
Control: glmerControl(optimizer = c("bobyqa"), optCtrl = list(maxfun = 2e+05),
    calc.derivs = FALSE)

     AIC      BIC   logLik deviance df.resid
  1559.8   1596.2   -774.9   1549.8    10742
```

```
Scaled residuals:
    Min      1Q  Median      3Q     Max
-1.1200 -0.1048 -0.0669 -0.0467  6.6001

Random effects:
 Groups  Name        Variance Std.Dev.
 superid (Intercept) 2.722    1.650
 game    (Intercept) 2.117    1.455
Number of obs: 10747, groups:  superid, 739; game, 50

Fixed effects:
                  Estimate Std. Error z value Pr(>|z|)
(Intercept)       -5.15894    0.38747 -13.315   <2e-16 ***
time_pressurePlus -0.07021    0.50659  -0.139     0.89
round              0.02031    0.01840   1.104     0.27
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) tm_prP
tm_prssrPls -0.647
round       -0.392  0.000
```

```
# p = 0.89
```

Punishment for negative reinforcement

```
m2.2 = glmer(punish_type_NR ~ time_pressure + round + (1|game) + (1|superid),
             data = exp2data %>% filter(round > 0), family = binomial, nAGQ=0,
             control = glmerControl(optimizer = c("bobyqa"),
                                    optCtrl=list(maxfun=2e5),
                                    calc.derivs=FALSE))

summary(m2.2)
```

```
Generalized linear mixed model fit by maximum likelihood (Adaptive
  Gauss-Hermite Quadrature, nAGQ = 0) [glmerMod]
 Family: binomial  ( logit )
Formula: punish_type_NR ~ time_pressure + round + (1 | game) + (1 | superid)
```

```
   Data: exp2data %>% filter(round > 0)
Control: glmerControl(optimizer = c("bobyqa"), optCtrl = list(maxfun = 2e+05),
    calc.derivs = FALSE)

     AIC      BIC   logLik deviance df.resid
  2747.8   2784.2  -1368.9   2737.8    10742

Scaled residuals:
    Min      1Q  Median      3Q     Max
-1.5280 -0.1039 -0.0845 -0.0722  5.0321

Random effects:
 Groups  Name        Variance Std.Dev.
 superid (Intercept) 4.903    2.214
 game    (Intercept) 1.007    1.004
Number of obs: 10747, groups:  superid, 739; game, 50

Fixed effects:
                  Estimate Std. Error z value Pr(>|z|)
(Intercept)       -4.55764    0.29037 -15.696   <2e-16 ***
time_pressurePlus -0.18463    0.38230  -0.483   0.6291
round              0.03579    0.01325   2.702   0.0069 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) tm_prP
tm_prssrPls -0.647
round       -0.384  0.000
```

```
# p = 0.629
```

Punishment for inequality aversion

```
m2.3 = glmer(punish_type_IA ~ time_pressure + round + (1|game) + (1|superid),
             data = exp2data %>% filter(round > 0), family = binomial, nAGQ=0,
             control = glmerControl(optimizer = c("bobyqa"),
                                    optCtrl=list(maxfun=2e5),
                                    calc.derivs=FALSE))
summary(m2.3)
```

```
Generalized linear mixed model fit by maximum likelihood (Adaptive
  Gauss-Hermite Quadrature, nAGQ = 0) [glmerMod]
 Family: binomial  ( logit )
Formula: punish_type_IA ~ time_pressure + round + (1 | game) + (1 | superid)
   Data: exp2data %>% filter(round > 0)
Control: glmerControl(optimizer = c("bobyqa"), optCtrl = list(maxfun = 2e+05),
    calc.derivs = FALSE)

     AIC      BIC   logLik deviance df.resid
  2697.2   2733.6  -1343.6   2687.2    10742

Scaled residuals:
    Min      1Q  Median      3Q     Max
-1.3832 -0.0838 -0.0767 -0.0709  4.6221

Random effects:
 Groups  Name        Variance Std.Dev.
 superid (Intercept) 6.9558   2.6374
 game    (Intercept) 0.4017   0.6338
Number of obs: 10747, groups:  superid, 739; game, 50

Fixed effects:
                  Estimate Std. Error z value Pr(>|z|)
(Intercept)       -4.56425    0.25976 -17.571   <2e-16 ***
time_pressurePlus -0.26515    0.33947  -0.781   0.4348
round              0.02203    0.01332   1.654   0.0981 .
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) tm_prP
tm_prssrPls -0.630
round       -0.420 -0.001
```

```
# p = 0.435
```

Unclassified punishment

```
m2.4 = glmer(punish_type_U ~ time_pressure + round + (1|game) + (1|superid),
             data = exp2data %>% filter(round > 0), family = binomial, nAGQ=0,
             control = glmerControl(optimizer = c("bobyqa"),
```

```
                                    optCtrl=list(maxfun=2e5),
                                    calc.derivs=FALSE))
summary(m2.4)
```

```
Generalized linear mixed model fit by maximum likelihood (Adaptive
  Gauss-Hermite Quadrature, nAGQ = 0) [glmerMod]
 Family: binomial  ( logit )
Formula: punish_type_U ~ time_pressure + round + (1 | game) + (1 | superid)
   Data: exp2data %>% filter(round > 0)
Control: glmerControl(optimizer = c("bobyqa"), optCtrl = list(maxfun = 2e+05),
    calc.derivs = FALSE)

     AIC      BIC   logLik deviance df.resid
  1220.2   1256.6   -605.1   1210.2    10742

Scaled residuals:
    Min      1Q  Median      3Q     Max
-1.4674 -0.0904 -0.0623 -0.0419 11.0773

Random effects:
 Groups  Name        Variance Std.Dev.
 superid (Intercept) 3.919    1.9798
 game    (Intercept) 0.358    0.5984
Number of obs: 10747, groups:  superid, 739; game, 50

Fixed effects:
                  Estimate Std. Error z value Pr(>|z|)
(Intercept)       -3.86428    0.26454 -14.607  < 2e-16 ***
time_pressurePlus -0.15285    0.33542  -0.456    0.649
round             -0.18400    0.02469  -7.452  9.2e-14 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) tm_prP
tm_prssrPls -0.614
round       -0.471  0.000
```

```
# p = 0.649
```

Decision time as the outcome

Exp 1 - Cooperation as reference

```
m4 = lmer(behaviorTime_sec ~ behavior + round + (1|game) + (1|superid), data = exp1data)
summary(m4)
```

```
Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]
Formula: behaviorTime_sec ~ behavior + round + (1 | game) + (1 | superid)
   Data: exp1data

REML criterion at convergence: 69452.7

Scaled residuals:
    Min      1Q  Median      3Q     Max
-2.9109 -0.3656 -0.1566  0.0373 10.4105

Random effects:
 Groups   Name        Variance Std.Dev.
 superid  (Intercept) 11.789   3.434
 game     (Intercept)  1.824   1.350
 Residual             64.809   8.050
Number of obs: 9776, groups:  superid, 719; game, 50

Fixed effects:
             Estimate Std. Error         df t value Pr(>|t|)
(Intercept)   6.79184    0.30462  110.40898  22.296  < 2e-16 ***
behaviorD     0.30411    0.23036 5471.24286   1.320  0.18684
behaviorP     1.21569    0.42149 9059.09346   2.884  0.00393 **
round        -0.16708    0.01916 9287.78482  -8.719  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
          (Intr) behvrD behvrP
behaviorD -0.322
behaviorP -0.180  0.263
round     -0.460 -0.058  0.023
```

Exp 1 - Defection as reference

```r
m4_1 = lmer(behaviorTime_sec ~ factor(behavior, levels = c("D", "C", "P")) +
              round + (1|game) + (1|superid), data = exp1data)
summary(m4_1)
```

```
Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]
Formula: behaviorTime_sec ~ factor(behavior, levels = c("D", "C", "P")) +
    round + (1 | game) + (1 | superid)
   Data: exp1data

REML criterion at convergence: 69452.7

Scaled residuals:
    Min      1Q  Median      3Q     Max
-2.9109 -0.3656 -0.1566  0.0373 10.4105

Random effects:
 Groups   Name        Variance Std.Dev.
 superid  (Intercept) 11.789   3.434
 game     (Intercept)  1.824   1.350
 Residual             64.809   8.050
Number of obs: 9776, groups:  superid, 719; game, 50

Fixed effects:
                                             Estimate Std. Error         df
(Intercept)                                   7.09595    0.31735  125.30780
factor(behavior, levels = c("D", "C", "P"))C -0.30411    0.23036 5471.24286
factor(behavior, levels = c("D", "C", "P"))P  0.91157    0.42392 8963.54749
round                                        -0.16708    0.01916 9287.78481
                                            t value Pr(>|t|)
(Intercept)                                  22.360   <2e-16 ***
factor(behavior, levels = c("D", "C", "P"))C -1.320   0.1868
factor(behavior, levels = c("D", "C", "P"))P  2.150   0.0316 *
round                                        -8.719   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
                     (Intr) f(,l=c("D","C","P"))C f(,l=c("D","C","P"))P
f(,l=c("D","C","P"))C -0.417
f(,l=c("D","C","P"))P -0.209  0.282
round                 -0.484  0.058                0.054
```

Exp 1 - Comparing the punishment mechanisms - CR punishment is the reference

```
m4_2 = lmer(behaviorTime_sec ~ punish_type_NR + punish_type_IA + punish_type_U +
              round + (1|game) + (1|superid),
            data = exp1data %>% filter(behavior_punish == 1))
summary(m4_2)
```

```
Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]
Formula: behaviorTime_sec ~ punish_type_NR + punish_type_IA + punish_type_U +
    round + (1 | game) + (1 | superid)
   Data: exp1data %>% filter(behavior_punish == 1)

REML criterion at convergence: 3686.3

Scaled residuals:
    Min      1Q  Median      3Q     Max
-1.7665 -0.4121 -0.1780  0.0855  6.0832

Random effects:
 Groups   Name        Variance Std.Dev.
 superid  (Intercept) 23.47    4.845
 game     (Intercept) 11.29    3.360
 Residual             64.44    8.028
Number of obs: 508, groups:  superid, 174; game, 48

Fixed effects:
               Estimate Std. Error       df t value Pr(>|t|)
(Intercept)      6.2481     1.5349 329.3702   4.071 5.88e-05 ***
punish_type_NR   0.5307     1.1866 487.8494   0.447   0.6549
punish_type_IA   1.5698     1.1200 424.9994   1.402   0.1618
punish_type_U    3.7815     1.6083 494.5013   2.351   0.0191 *
round           -0.1209     0.1023 479.7367  -1.182   0.2377
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) pn__NR pn__IA pns__U
pnsh_typ_NR -0.485
pnsh_typ_IA -0.531  0.084
punsh_typ_U -0.608  0.501  0.464
round       -0.364 -0.197 -0.061 -0.070
```

Exp 1 - Comparing copying/retaliation punishment vs. all others

```
m4_2_1 = lmer(behaviorTime_sec ~ punish_type_CR + round + (1|game) + (1|superid),
              data = exp1data %>%
  filter(behavior_punish == 1))
summary(m4_2_1)
```

```
Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]
Formula: behaviorTime_sec ~ punish_type_CR + round + (1 | game) + (1 |
    superid)
   Data: exp1data %>% filter(behavior_punish == 1)

REML criterion at convergence: 3690.5

Scaled residuals:
    Min      1Q  Median      3Q     Max
-1.7020 -0.4204 -0.1869  0.0978  6.1235

Random effects:
 Groups   Name        Variance Std.Dev.
 superid  (Intercept) 23.89    4.887
 game     (Intercept) 10.43    3.229
 Residual             64.10    8.006
Number of obs: 508, groups:  superid, 174; game, 48

Fixed effects:
               Estimate Std. Error       df t value Pr(>|t|)
(Intercept)      9.1691     1.1074 169.5893   8.280 3.54e-14 ***
punish_type_CR  -2.4355     0.9306 483.1002  -2.617  0.00914 **
round           -0.1489     0.1003 479.6408  -1.484  0.13842
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) pn__CR
pnsh_typ_CR -0.308
round       -0.693  0.113
```

Exp 1 - Comparing unclassified punishment vs. all others

```r
m4_2_2 = lmer(behaviorTime_sec ~ punish_type_U + round + (1|game) + (1|superid),
              data = exp1data %>%
  filter(behavior_punish == 1))
summary(m4_2_2)
```

```
Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]
Formula: behaviorTime_sec ~ punish_type_U + round + (1 | game) + (1 |
    superid)
   Data: exp1data %>% filter(behavior_punish == 1)

REML criterion at convergence: 4089.8

Scaled residuals:
    Min      1Q  Median      3Q     Max
-1.9010 -0.4359 -0.1943  0.0883  6.0749

Random effects:
 Groups   Name        Variance Std.Dev.
 superid  (Intercept) 24.642   4.964
 game     (Intercept)  8.374   2.894
 Residual             67.666   8.226
Number of obs: 560, groups:  superid, 184; game, 49

Fixed effects:
               Estimate Std. Error        df t value Pr(>|t|)
(Intercept)     7.80336    1.06843 157.29632   7.304 1.32e-11 ***
punish_type_U   2.10507    1.02123 549.35836   2.061   0.0397 *
round          -0.09103    0.09612 538.05539  -0.947   0.3440
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) pns__U
punsh_typ_U -0.464
round       -0.695  0.304
```

Exp 1 - Regression model with and without punishment in round t-1

```r
m13 = lmer(behaviorTime_sec ~ round + last_punished + (1|game) + (1|superid),
           data = exp1data %>% filter(behavior_punish == 1))

summary(m13)
```

```
Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]
Formula: behaviorTime_sec ~ round + last_punished + (1 | game) + (1 |
    superid)
   Data: exp1data %>% filter(behavior_punish == 1)

REML criterion at convergence: 3690.5

Scaled residuals:
    Min      1Q  Median      3Q     Max
-1.7020 -0.4204 -0.1869  0.0978  6.1235

Random effects:
 Groups   Name        Variance Std.Dev.
 superid  (Intercept) 23.89    4.887
 game     (Intercept) 10.43    3.229
 Residual             64.10    8.006
Number of obs: 508, groups:  superid, 174; game, 48

Fixed effects:
              Estimate Std. Error       df t value Pr(>|t|)
(Intercept)     9.1691     1.1074 169.5893   8.280 3.54e-14 ***
round          -0.1489     0.1003 479.6408  -1.484  0.13842
last_punished  -2.4355     0.9306 483.1002  -2.617  0.00914 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) round
round       -0.693
last_punshd -0.308  0.113
```

Exp 2 - Controlling for time pressure

Time pressure +

```r
exp2_tp_plus = exp2data %>% filter(time_pressure == "Plus")
exp2_tp_minus = exp2data %>% filter(time_pressure == "Minus")

m5a = lmer(behaviorTime_sec ~ behavior + round + (1|game) + (1|superid),
           data = exp2_tp_plus %>% filter(round > 0))
summary(m5a)
```

```
Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]
Formula: behaviorTime_sec ~ behavior + round + (1 | game) + (1 | superid)
   Data: exp2_tp_plus %>% filter(round > 0)

REML criterion at convergence: 2356.9

Scaled residuals:
    Min      1Q  Median      3Q     Max
-3.2207 -0.6608 -0.0951  0.5662  4.8321

Random effects:
 Groups   Name        Variance Std.Dev.
 superid  (Intercept) 0.07370  0.27147
 game     (Intercept) 0.00315  0.05613
 Residual             0.08420  0.29018
Number of obs: 4066, groups:  superid, 367; game, 25

Fixed effects:
             Estimate Std. Error         df t value Pr(>|t|)
(Intercept)  2.090e+00  2.348e-02  6.115e+01  88.999  < 2e-16 ***
behaviorD   -5.140e-02  1.966e-02  2.483e+03  -2.614  0.00899 **
behaviorP    1.155e-01  2.799e-02  4.043e+03   4.128 3.73e-05 ***
round       -6.124e-03  1.091e-03  3.751e+03  -5.611 2.15e-08 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
          (Intr) behvrD behvrP
behaviorD -0.456
behaviorP -0.206  0.315
round     -0.358 -0.043 -0.001
```

Time pressure -

```r
m5b = lmer(behaviorTime_sec ~ behavior + round + (1|game) + (1|superid),
           data = exp2_tp_minus %>% filter(round > 0))

summary(m5b)
```

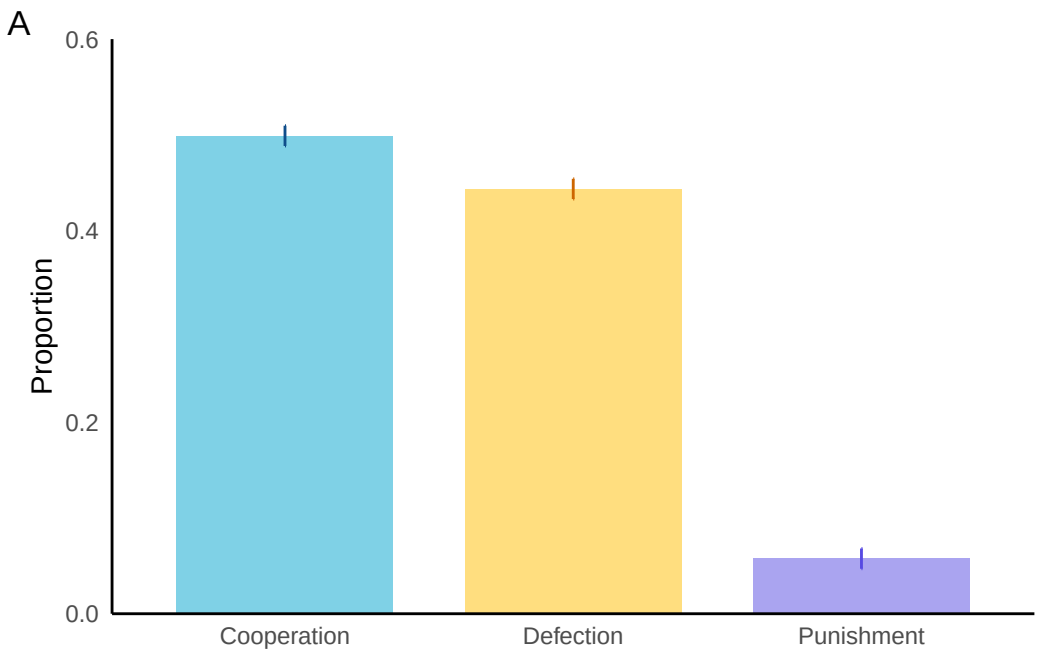
```
Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]
Formula: behaviorTime_sec ~ behavior + round + (1 | game) + (1 | superid)
   Data: exp2_tp_minus %>% filter(round > 0)

REML criterion at convergence: 23330.5

Scaled residuals:
    Min      1Q  Median      3Q     Max
-3.7670 -0.2960 -0.1224  0.0783 19.2939

Random effects:
 Groups   Name        Variance Std.Dev.
 superid  (Intercept) 1.58559  1.2592
 game     (Intercept) 0.08172  0.2859
 Residual             4.38568  2.0942
Number of obs: 5247, groups:  superid, 366; game, 25

Fixed effects:
             Estimate Std. Error         df t value Pr(>|t|)
(Intercept)  3.330e+00  1.228e-01  6.772e+01  27.117  < 2e-16 ***
behaviorD   -2.740e-01  1.069e-01  2.005e+03  -2.562  0.01048 *
behaviorP    4.700e-01  1.475e-01  5.177e+03   3.185  0.00145 **
round       -2.073e-02  6.745e-03  4.913e+03  -3.074  0.00213 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
          (Intr) behvrD behvrP
behaviorD -0.491
behaviorP -0.253  0.357
round     -0.412 -0.037  0.009
```

4. Figures

Figure 2 - Behavior Distribution, Decision Times, and Punishment Mechanisms, Experiment 1

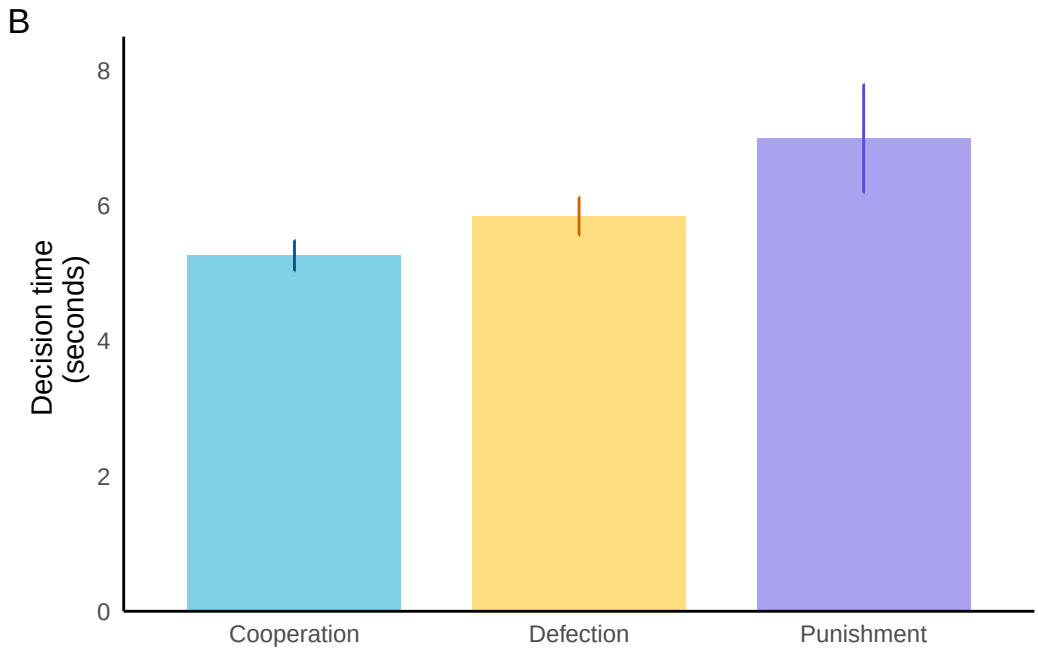
```
# Fig 1A
exp1_fig1_data = bind_cols(data1_behavior_count, data1_behavior_CI, data1_times)[-7]

names(exp1_fig1_data) = c("behavior", "count", "crude_prop", "adjusted_prop",
                          "LL_prop", "UL_prop", "mean_dt", "se_mean_dt",
                          "UL_mean_dt", "LL_mean_dt")
exp1_fig1_data = exp1_fig1_data %>%
  mutate(behavior = case_match(behavior,
                               "C" ~ "Cooperation",
                               "D" ~ "Defection",
                               "P" ~ "Punishment"))
```

```
exp1_fig1_A = exp1_fig1_data %>%
  ggplot() +
  aes(x = behavior, y = adjusted_prop, fill = behavior) +
  geom_bar(stat = "identity", width = 0.75, alpha = 0.5) +
  geom_errorbar(aes(ymin = LL_prop, ymax = UL_prop, color = factor(behavior)),
                width = 0) +
  theme_classic() +
  scale_y_continuous(limits = c(0, 0.6), breaks = seq(0, 0.6, by = 0.2),
                     expand = c(0, 0)) +
  ylab("Proportion") +
  scale_fill_manual(values = c("#00A5CF", "#FFBF00", "#574AE2")) +
  scale_color_manual(values = c("dodgerblue4", "darkorange3", "#574AE2")) +
  labs(tag = "A") +
  theme(panel.grid.minor = element_blank(),
        panel.grid.major = element_blank(),
        legend.position = "none",
        axis.text.x = element_text(size = 9),
        axis.title.x = element_blank(),
        axis.ticks.x = element_blank(),
        axis.ticks.y = element_blank())
exp1_fig1_A
```




```
exp1_fig1_B = exp1_fig1_data %>%
  ggplot() +
  aes(x = behavior, y = mean_dt, fill = behavior) +
  geom_bar(stat = "identity", width = 0.75, alpha = 0.5) +
  geom_errorbar(aes(ymin = mean_dt - 1.96*se_mean_dt,
                    ymax = mean_dt + 1.96*se_mean_dt,
                    color = factor(behavior)), width = 0) +
  theme_classic() +
  scale_y_continuous(limits = c(0, 8.5), breaks = seq(0, 8, by = 2),
                     expand = c(0, 0)) +
  ylab("Decision time \n (seconds)")+
  scale_fill_manual(values = c("#00A5CF", "#FFBF00", "#574AE2")) +
  scale_color_manual(values = c("dodgerblue4", "darkorange3", "#574AE2")) +
  labs(tag = "B") +
  theme(panel.grid.minor = element_blank(),
        panel.grid.major = element_blank(),
        legend.position = "none",
        axis.text.x = element_text(size = 9),
        axis.title.x = element_blank(),
        axis.ticks.x = element_blank(),
        axis.ticks.y = element_blank())
```

```
exp1_fig1_B
```




```
exp1data_NR = exp1data %>%
  group_by(punish_type_NR) %>%
  count() %>%
  ungroup() %>%
  mutate(punish_type = "NR",
         total = sum(n),
         perc = n/sum(n),
         se_perc = sqrt((perc*(1-perc))/total)) %>%
  filter(punish_type_NR == 1)  %>%
  select(punish_type, n, total, perc, se_perc)

exp1data_IA = exp1data %>%
  group_by(punish_type_IA) %>%
  count() %>%
  ungroup() %>%
  mutate(punish_type = "IA",
         total = sum(n),
         perc = n/sum(n),
         se_perc = sqrt((perc*(1-perc))/total)) %>%
```

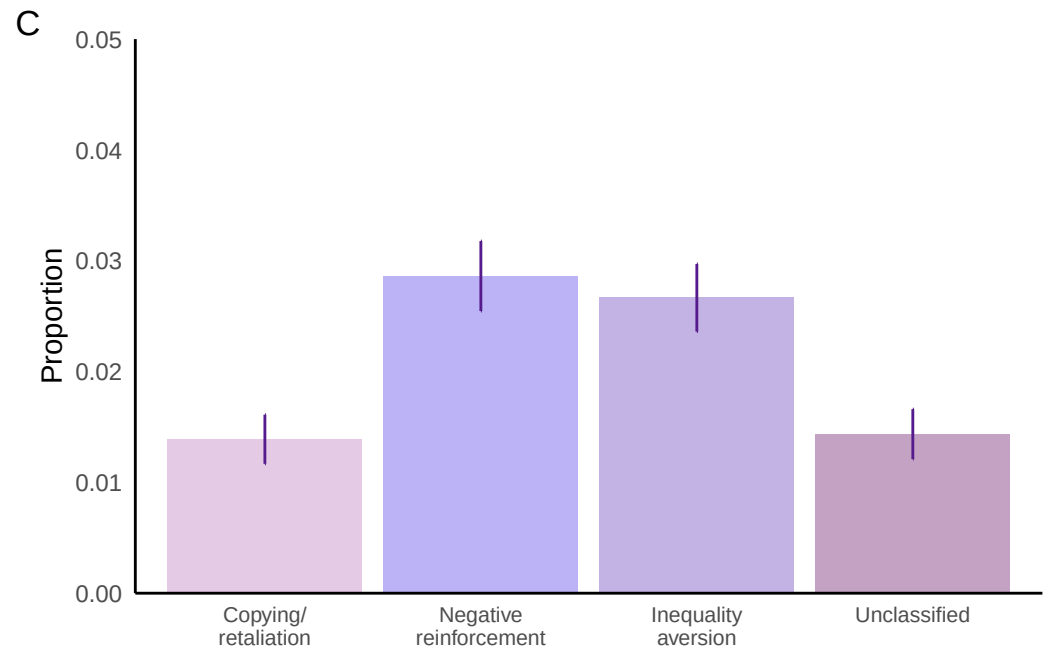
```
  filter(punish_type_IA == 1)  %>%
  select(punish_type, n, total, perc, se_perc)

exp1data_CR = exp1data %>%
  group_by(punish_type_CR) %>%
  count() %>%
  ungroup() %>%
  mutate(punish_type = "CR",
         total = sum(n),
         perc = n/sum(n),
         se_perc = sqrt((perc*(1-perc))/total)) %>%
  filter(punish_type_CR == 1)  %>%
  select(punish_type, n, total, perc, se_perc)

exp1data_U = exp1data %>%
  group_by(punish_type_U) %>%
  count() %>%
  ungroup() %>%
  mutate(punish_type = "U",
         total = sum(n),
         perc = n/sum(n),
         se_perc = sqrt((perc*(1-perc))/total)) %>%
  filter(punish_type_U == 1)  %>%
  select(punish_type, n, total, perc, se_perc)

figS1data = bind_rows(exp1data_CR, exp1data_IA, exp1data_NR, exp1data_U)

figS1data = figS1data %>%
  mutate(perc_LL = perc - 1.96*se_perc,
         perc_UL = perc + 1.96*se_perc)
```

```
# Decision times by punish type

exp1data_NR_times = exp1data %>%
  filter(punish_type_NR == 1, behavior_punish == 1) %>%
  summarize(mean_dt = mean1(behaviorTime_sec),
            se_mean_dt = se_mean(behaviorTime_sec)) %>%
  mutate(punish_type = "NR",
         mean_LL = mean_dt - 1.96*se_mean_dt,
         mean_UL = mean_dt + 1.96*se_mean_dt)
```

```r
exp1data_IA_times = exp1data %>%
  filter(punish_type_IA == 1, behavior_punish == 1) %>%
  summarize(mean_dt = mean1(behaviorTime_sec),
            se_mean_dt = se_mean(behaviorTime_sec),
) %>%
  mutate(punish_type = "IA",   mean_LL = mean_dt - 1.96*se_mean_dt,
         mean_UL = mean_dt + 1.96*se_mean_dt)

exp1data_CR_times = exp1data %>%
  filter(punish_type_CR == 1, behavior_punish == 1) %>%
  summarize(mean_dt = mean1(behaviorTime_sec),
            se_mean_dt = se_mean(behaviorTime_sec)) %>%
  mutate(punish_type = "CR",
           mean_LL = mean_dt - 1.96*se_mean_dt,
         mean_UL = mean_dt + 1.96*se_mean_dt)

exp1data_U_times = exp1data %>%
  filter(punish_type_U == 1, behavior_punish == 1) %>%
  summarize(mean_dt = mean1(behaviorTime_sec),
            se_mean_dt = se_mean(behaviorTime_sec)) %>%
  mutate(punish_type = "U",
         mean_LL = mean_dt - 1.96*se_mean_dt,
         mean_UL = mean_dt + 1.96*se_mean_dt)

exp1data_punish_types_times = bind_rows(exp1data_NR_times,
                                        exp1data_CR_times,
                                        exp1data_IA_times,
                                        exp1data_U_times) %>%
  select(punish_type, mean_dt, se_mean_dt, mean_LL, mean_UL)

fig1data = figS1data %>%
  left_join(exp1data_punish_types_times, by = "punish_type") %>%
  mutate(punish_type = case_match(punish_type,
              "CR" ~ "Copying/retaliation",
              "IA" ~ "Inequality aversion",
              "NR" ~ "Negative reinforcement",
              "U" ~ "Unclassified")) %>%
  mutate(punish_type_fct = factor(punish_type, levels = c("Copying/retaliation", "Negative
```

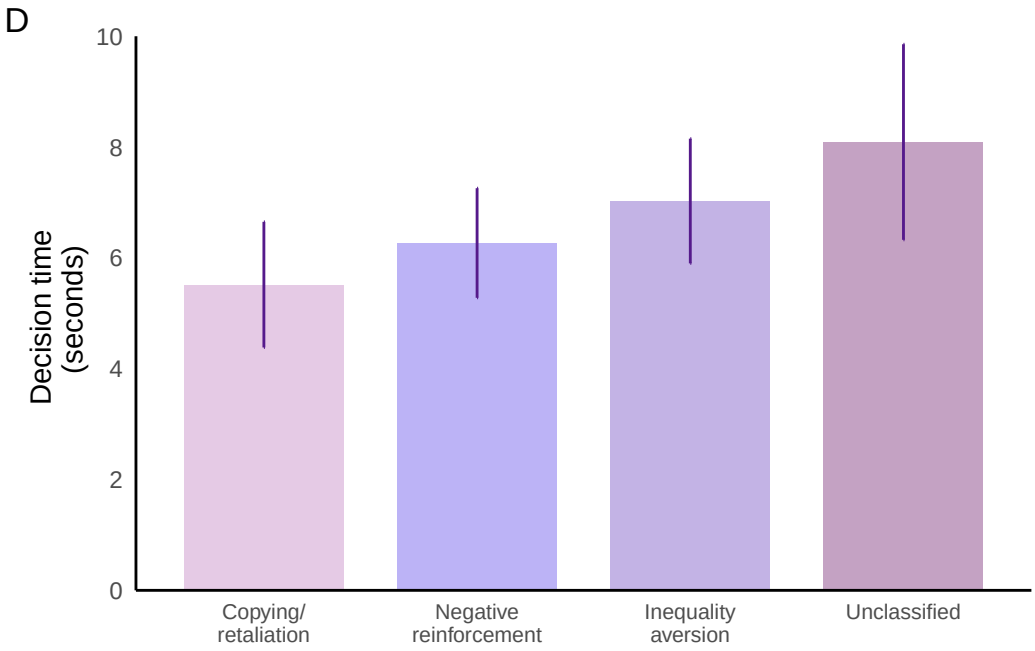
```r
exp1_fig1_C = fig1data %>%
  ggplot(aes(x = punish_type_fct, y = perc, fill = punish_type_fct)) +
```

```
  geom_bar(position = "dodge", stat = "identity", alpha = 0.5, show.legend = F) +
  geom_errorbar(aes(ymin = perc + 1.96*se_perc,
                    ymax = perc - 1.96*se_perc,
                    width = 0),
                color = "purple4",
                position = position_dodge(.9),
                show.legend = F) +
  scale_fill_manual(values = c("Copying/retaliation" = "plum3",
                               "Negative reinforcement" = "mediumslateblue",
                               "Inequality aversion" = "mediumpurple3",
                               "Unclassified" = "orchid4"), guide = "none") +
  scale_color_manual(guide = "none") +
  scale_x_discrete(labels = c("Copying/\nretaliation", "Negative\nreinforcement",
                              "Inequality\naversion", "Unclassified")) +
  scale_y_continuous(limits = c(0, 0.05), expand = c(0, 0)) +
  ylab("Proportion") +
  xlab("") +
  labs(tag = "C") +
  theme_classic() +
  theme(panel.grid.minor = element_blank(),
        panel.grid.major = element_blank(),
        legend.position = "bottom",
        legend.title = element_blank(),
        axis.text.x = element_text(size = 8),
        axis.title.x = element_blank(),
        axis.ticks.x = element_blank(),
        axis.ticks.y = element_blank())
exp1_fig1_C
```



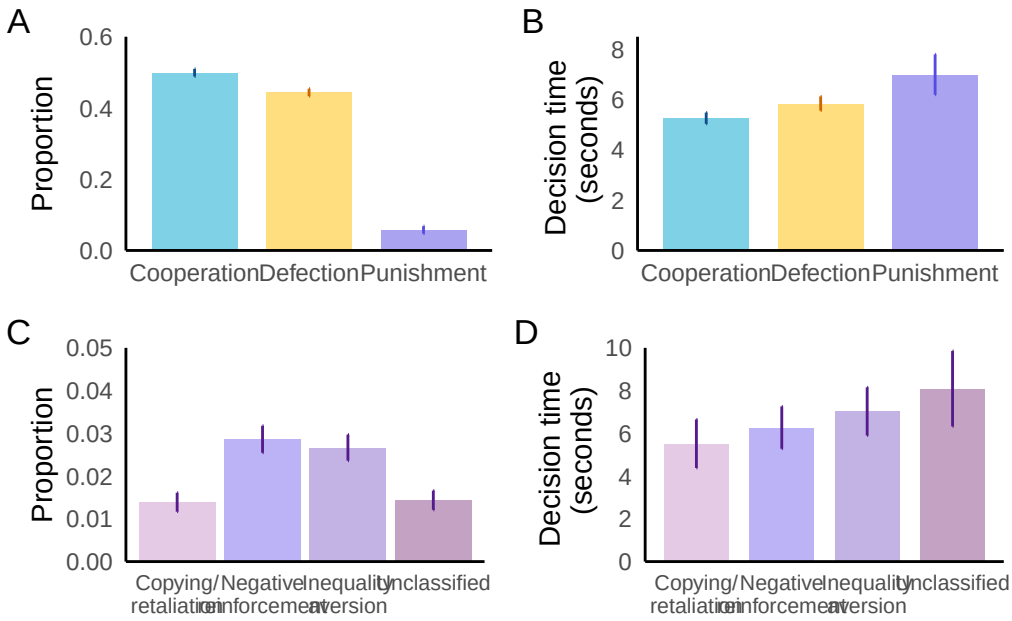

```
exp1_fig1_D = fig1data %>%
  ggplot(aes(x = punish_type_fct, y = mean_dt, fill = punish_type_fct)) +
  geom_bar(stat = "identity", width = 0.75,  alpha = 0.5) +
  geom_errorbar(aes(ymin = mean_LL,
                    ymax = mean_UL),
                color = "purple4", width = 0) +
  theme_classic() +
  scale_y_continuous(limits = c(0, 10), breaks = seq(0, 10, by = 2), expand = c(0, 0)) +
  ylab("Decision time \n (seconds)")+
  scale_fill_manual(values = c("Copying/retaliation" = "plum3",
                               "Negative reinforcement" = "mediumslateblue",
                               "Inequality aversion" = "mediumpurple3",
                               "Unclassified" = "orchid4"), guide = "none") +
  scale_x_discrete(labels = c("Copying/\nretaliation", "Negative\nreinforcement",
                              "Inequality\naversion", "Unclassified")) +
  scale_color_manual(guide = "none") +
  theme_classic() +
  labs(tag = "D") +
  theme(panel.grid.minor = element_blank(),
        panel.grid.major = element_blank(),
        legend.position = "none",
        axis.text.x = element_text(size = 8),
```

```
        axis.title.x = element_blank(),
        axis.ticks.x = element_blank(),
        axis.ticks.y = element_blank())
exp1_fig1_D
```



Main

```
(exp1_fig1_A + exp1_fig1_B)/ (exp1_fig1_C + exp1_fig1_D)
```




```
# ggsave(filename = "~/Documents/Projects/harming_esn/figures/fig2.png",
#        width = 8, height = 8, units = "in")
```

Figure 3 - Behavior Distribution, Decision Times, and Punishment Mechanisms, Experiment 2

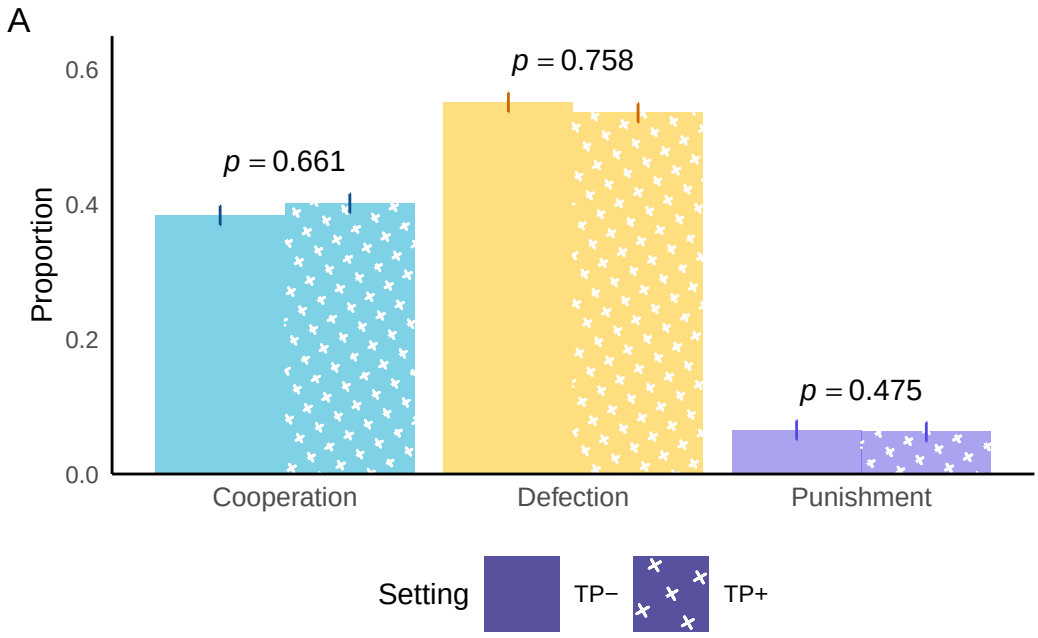
```
exp2_tp_plus_fig3_data = bind_cols(exp2data_tp_plus_count, exp2data_tp_plus_CI,
                                   exp2data_tp_plus_times)[-7]
names(exp2_tp_plus_fig3_data) = c("behavior", "count", "crude_prop",
                                  "adjusted_prop", "LL_prop", "UL_prop", "mean_dt",
                                  "se_mean_dt", "LL_mean_dt", "UL_mean_dt")
exp2_tp_plus_fig3_data$setting = "TP+"

exp2_tp_minus_fig3_data = bind_cols(exp2data_tp_minus_count, exp2data_tp_minus_CI,
                                    exp2data_tp_minus_times)[-7]
names(exp2_tp_minus_fig3_data) = c("behavior", "count", "crude_prop",
                                   "adjusted_prop", "LL_prop", "UL_prop", "mean_dt",
                                   "se_mean_dt", "LL_mean_dt", "UL_mean_dt")

exp2_tp_minus_fig3_data$setting = "TP-"
```

```
fig3data = bind_rows(exp2_tp_minus_fig3_data, exp2_tp_plus_fig3_data)

fig3data = fig3data %>%
  mutate(behavior = case_match(behavior, "C" ~ "Cooperation",
                               "D" ~ "Defection", "P" ~ "Punishment"))
```

Main

```
fig3A = fig3data %>%
  ggplot(aes(x = behavior, y = adjusted_prop, fill = behavior, pattern = setting)) +
  geom_bar_pattern(position = "dodge", stat = "identity", alpha = 0.5,
                   pattern_density = 0.4, pattern_color = "white",
                   pattern_shape = 3) +
  geom_errorbar(aes(ymin = LL_prop,
                    ymax = UL_prop,
                    color = behavior,
                    width = 0),
                position = position_dodge(.9),
                show.legend = F) +
  scale_pattern_manual(values = c("none", "pch")) +
  scale_fill_manual(values = c("Cooperation" = "#00A5CF", "Defection" = "#FFBF00",
                               "Punishment" = "#574AE2")) +
  scale_color_manual(values = c("dodgerblue4", "darkorange3", "#574AE2")) +
  scale_y_continuous(limits = c(0, 0.65), expand = c(0, 0)) +
  guides(color = "none", fill = "none", pattern = guide_legend(title = "Setting")) +
  ylab("Proportion") +
  xlab("") +
  theme_classic() +
  labs(tag = "A") +
  theme(panel.grid.minor = element_blank(),
        panel.grid.major = element_blank(),
        axis.text.x = element_text(size = 10),
        axis.title.x = element_blank(),
        axis.ticks.x = element_blank(),
        axis.ticks.y = element_blank(),
        legend.position = "bottom",
        legend.key.size = unit(1, "cm"),
        legend.key = element_rect(fill = "#574AE2", color = NA)) +
  annotate("text", x = 1:3,
           y = c(0.46, 0.61, 0.12),
```

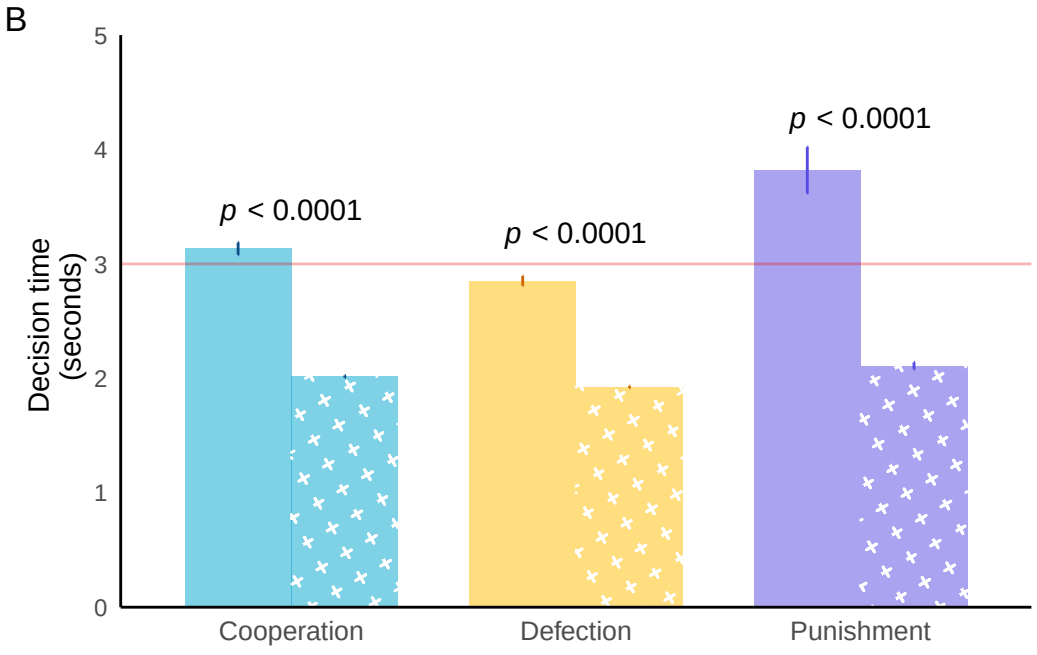
```
          label = c("italic(p) == 0.661", "italic(p) == 0.758", "italic(p) == 0.475"),
          parse = T)
fig3A
```




```
fig3B = fig3data %>%
  ggplot() +
  aes(x = behavior, y = mean_dt, fill = behavior, pattern = setting) +
  geom_bar_pattern(stat = "identity", width = 0.75, alpha = 0.5,
                   position = "dodge",
                   pattern_density = 0.4,
                   pattern_color = "white",
                   pattern_shape = 3, show.legend = F) +
  geom_errorbar(aes(ymin = mean_dt - se_mean_dt,
                    ymax = mean_dt + se_mean_dt,
                    color = factor(behavior)),
                    position = position_dodge(0.75),
                    width = 0,
                show.legend = F) +
  geom_hline(yintercept = 3, color = "red2", alpha = 0.3) +
  theme_classic() +
  scale_pattern_manual(values = c("none", "pch")) +
```

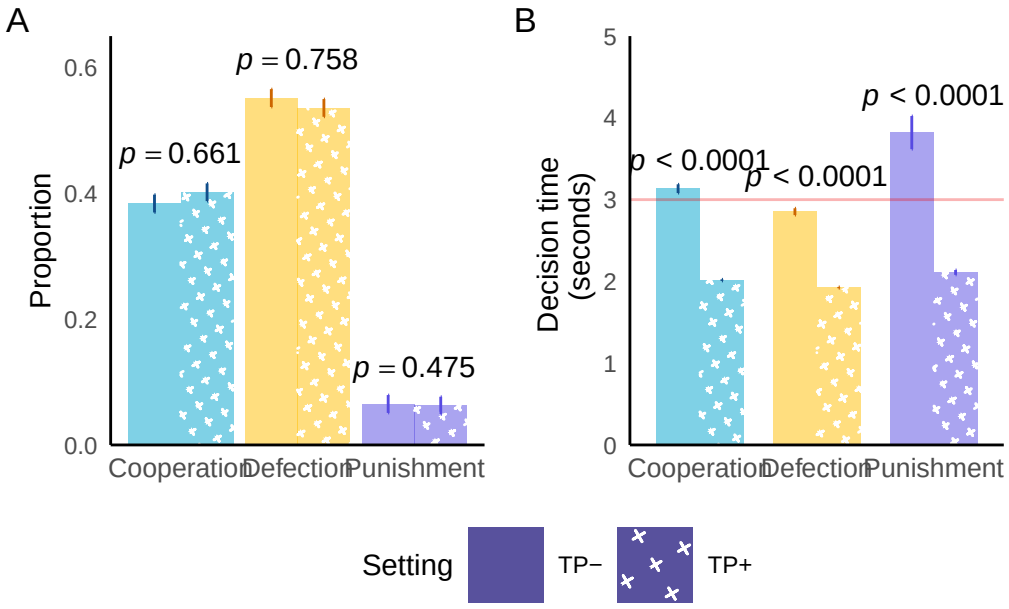
```
  scale_y_continuous(limits = c(0, 5), expand = c(0, 0)) +
  scale_x_discrete(limits = c("Cooperation", "Defection", "Punishment")) +
  ylab("Decision time \n (seconds)")+
  scale_fill_manual(values = c("#00A5CF", "#FFBF00", "#574AE2")) +
  scale_color_manual(values = c("dodgerblue4", "darkorange3", "#574AE2")) +
  labs(tag = "B") +
  theme(panel.grid.minor = element_blank(),
        panel.grid.major = element_blank(),
        legend.position = "none",
        axis.text.x = element_text(size = 10),
        axis.title.x = element_blank(),
        axis.ticks.x = element_blank(),
        axis.ticks.y = element_blank()) +
    annotate("text", x = 1:3,
             y = c(3.45, 3.25, 4.25),
             label = c(rep(expression(paste(italic("p")," < 0.0001")), 3)))
```

```
fig3B
```



```
fig3A + fig3B +
  plot_annotation(tag_levels = c("A", "B")) +
  plot_layout(guides = "collect") &
  theme(legend.position = "bottom")
```

```
Warning in is.na(x): is.na() applied to non-(list or vector) of type
'expression'
```




```
# ggsave(filename = "~/Documents/Projects/harming_esn/figures/fig3.png",
# width = 7, height = 5, units = "in")
```

Figure 4 - Punishment Mechanism Decision Times, Experiment 2

```
# Get the frequencies stratified by TP status and by punishment type
exp2data = exp2data %>%
  mutate(punish_type_U =
           ifelse(is.na(punish_type_CR) == 1 & is.na(punish_type_NR) == 1 |
                    is.na(punish_type_IA) == 1 & is.na(punish_type_U) == 1,
                  1, punish_type_U),
```

```
         punish_type_CR = ifelse(punish_type_U == 1, 0, punish_type_CR),
         punish_type_NR = ifelse(punish_type_U == 1, 0, punish_type_NR),
         punish_type_IA = ifelse(punish_type_U == 1, 0, punish_type_IA))

fig4_tp_minus_CR = exp2data %>%
  filter(time_pressure == "Minus") %>%
  group_by(punish_type_CR) %>%
  count() %>%
  ungroup() %>%
  mutate(setting = "TP-",
         punish_type = "CR",
         total = sum(n),
         perc = n/sum(n),
         se_perc = sqrt((perc*(1-perc))/total)) %>%
  filter(punish_type_CR == 1)  %>%
  select(setting, punish_type, n, total, perc, se_perc)

fig4_tp_minus_IA = exp2data %>%
  filter(time_pressure == "Minus") %>%
  group_by(punish_type_IA) %>%
  count() %>%
  ungroup() %>%
  mutate(setting = "TP-",
         punish_type = "IA",
         total = sum(n),
         perc = n/sum(n),
         se_perc = sqrt((perc*(1-perc))/total)) %>%
  filter(punish_type_IA == 1)  %>%
  select(setting, punish_type, n, total, perc, se_perc)

fig4_tp_minus_NR = exp2data %>%
  filter(time_pressure == "Minus") %>%
  group_by(punish_type_NR) %>%
  count() %>%
  ungroup() %>%
  mutate(setting = "TP-",
         punish_type = "NR",
         total = sum(n),
         perc = n/sum(n),
         se_perc = sqrt((perc*(1-perc))/total)) %>%
  filter(punish_type_NR == 1)  %>%
```

```
  select(setting, punish_type, n, total, perc, se_perc)

fig4_tp_minus_U = exp2data %>%
  filter(time_pressure == "Minus") %>%
  group_by(punish_type_U) %>%
  count() %>%
  ungroup() %>%
  mutate(setting = "TP-",
         punish_type = "U",
         total = sum(n),
         perc = n/sum(n),
         se_perc = sqrt((perc*(1-perc))/total)) %>%
  filter(punish_type_U == 1)  %>%
  select(setting, punish_type, n, total, perc, se_perc)

fig4_tp_minus_data = bind_rows(fig4_tp_minus_CR, fig4_tp_minus_IA,
                               fig4_tp_minus_NR, fig4_tp_minus_U)
```

```
fig4_tp_Plus_CR = exp2data %>%
  filter(time_pressure == "Plus") %>%
  group_by(punish_type_CR) %>%
  count() %>%
  ungroup() %>%
  mutate(setting = "TP+",
         punish_type = "CR",
         total = sum(n),
         perc = n/sum(n),
         se_perc = sqrt((perc*(1-perc))/total)) %>%
  filter(punish_type_CR == 1)  %>%
  select(setting, punish_type, n, total, perc, se_perc)

fig4_tp_Plus_IA = exp2data %>%
  filter(time_pressure == "Plus") %>%
  group_by(punish_type_IA) %>%
  count() %>%
  ungroup() %>%
  mutate(setting = "TP+",
         punish_type = "IA",
         total = sum(n),
         perc = n/sum(n),
         se_perc = sqrt((perc*(1-perc))/total)) %>%
```

```
  filter(punish_type_IA == 1)  %>%
  select(setting, punish_type, n, total, perc, se_perc)

fig4_tp_Plus_NR = exp2data %>%
  filter(time_pressure == "Plus") %>%
  group_by(punish_type_NR) %>%
  count() %>%
  ungroup() %>%
  mutate(setting = "TP+",
         punish_type = "NR",
         total = sum(n),
         perc = n/sum(n),
         se_perc = sqrt((perc*(1-perc))/total)) %>%
  filter(punish_type_NR == 1)  %>%
  select(setting, punish_type, n, total, perc, se_perc)

fig4_tp_Plus_U = exp2data %>%
  filter(time_pressure == "Plus") %>%
  group_by(punish_type_U) %>%
  count() %>%
  ungroup() %>%
  mutate(setting = "TP+",
         punish_type = "U",
         total = sum(n),
         perc = n/sum(n),
         se_perc = sqrt((perc*(1-perc))/total)) %>%
  filter(punish_type_U == 1)  %>%
  select(setting, punish_type, n, total, perc, se_perc)

fig4_tp_Plus_data = bind_rows(fig4_tp_Plus_CR, fig4_tp_Plus_IA,
                              fig4_tp_Plus_NR, fig4_tp_Plus_U)

exp2data_combined = bind_rows(fig4_tp_minus_data, fig4_tp_Plus_data)
```

```
exp2data_plus_NR_times = exp2data %>%
  filter(punish_type_NR == 1,
         behavior_punish == 1,
         time_pressure == "Plus") %>%
  summarize(mean_dt = mean1(behaviorTime_sec),
            se_mean_dt = se_mean(behaviorTime_sec)) %>%
  mutate(punish_type = "NR",
```

```
          setting = "TP+",
            mean_LL = mean_dt - 1.96*se_mean_dt,
          mean_UL = mean_dt + 1.96*se_mean_dt)

exp2data_plus_CR_times = exp2data %>%
  filter(punish_type_CR == 1,
          behavior_punish == 1,
          time_pressure == "Plus") %>%
  summarize(mean_dt = mean1(behaviorTime_sec),
             se_mean_dt = se_mean(behaviorTime_sec)) %>%
  mutate(punish_type = "CR",
          setting = "TP+",
          mean_LL = mean_dt - 1.96*se_mean_dt,
          mean_UL = mean_dt + 1.96*se_mean_dt)

exp2data_plus_IA_times = exp2data %>%
  filter(punish_type_IA == 1,
          behavior_punish == 1,
          time_pressure == "Plus") %>%
  summarize(mean_dt = mean1(behaviorTime_sec),
             se_mean_dt = se_mean(behaviorTime_sec)) %>%
  mutate(punish_type = "IA",
                  setting = "TP+",
            mean_LL = mean_dt - 1.96*se_mean_dt,
          mean_UL = mean_dt + 1.96*se_mean_dt)

exp2data_plus_U_times = exp2data %>%
  filter(punish_type_U == 1,
          behavior_punish == 1,
          time_pressure == "Plus") %>%
  summarize(mean_dt = mean1(behaviorTime_sec),
             se_mean_dt = se_mean(behaviorTime_sec)) %>%
  mutate(punish_type = "U",
          setting = "TP+",
          mean_LL = mean_dt - 1.96*se_mean_dt,
          mean_UL = mean_dt + 1.96*se_mean_dt)

exp2data_minus_NR_times = exp2data %>%
  filter(punish_type_NR == 1,
          behavior_punish == 1,
          time_pressure == "Minus") %>%
```

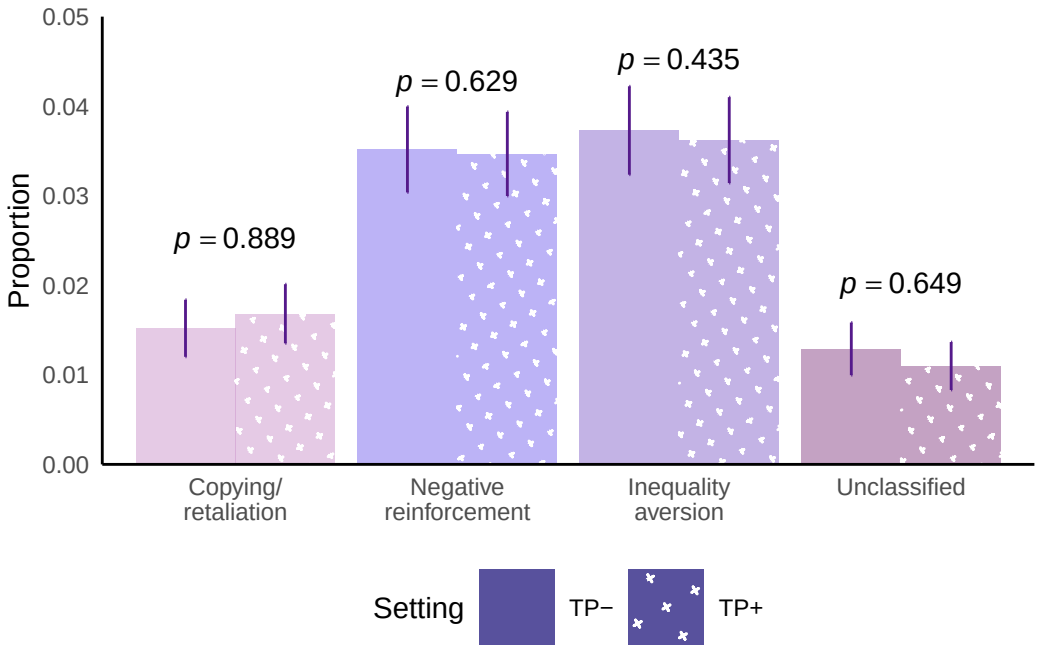
```
  summarize(mean_dt = mean1(behaviorTime_sec),
            se_mean_dt = se_mean(behaviorTime_sec)) %>%
  mutate(punish_type = "NR",
                  setting = "TP-",
           mean_LL = mean_dt - 1.96*se_mean_dt,
         mean_UL = mean_dt + 1.96*se_mean_dt)

exp2data_minus_CR_times = exp2data %>%
  filter(punish_type_CR == 1,
         behavior_punish == 1,
         time_pressure == "Minus") %>%
  summarize(mean_dt = mean1(behaviorTime_sec),
            se_mean_dt = se_mean(behaviorTime_sec)) %>%
  mutate(punish_type = "CR",
         setting = "TP-",
        mean_LL = mean_dt - 1.96*se_mean_dt,
         mean_UL = mean_dt + 1.96*se_mean_dt)

exp2data_minus_IA_times = exp2data %>%
  filter(punish_type_IA == 1,
         behavior_punish == 1,
         time_pressure == "Minus") %>%
  summarize(mean_dt = mean1(behaviorTime_sec),
            se_mean_dt = se_mean(behaviorTime_sec)) %>%
  mutate(punish_type = "IA",
         setting = "TP-",
         mean_LL = mean_dt - 1.96*se_mean_dt,
         mean_UL = mean_dt + 1.96*se_mean_dt)

exp2data_minus_U_times = exp2data %>%
  filter(punish_type_U == 1,
         behavior_punish == 1,
         time_pressure == "Minus") %>%
  summarize(mean_dt = mean1(behaviorTime_sec),
            se_mean_dt = se_mean(behaviorTime_sec)) %>%
  mutate(punish_type = "U",
         setting = "TP-",
         mean_LL = mean_dt - 1.96*se_mean_dt,
         mean_UL = mean_dt + 1.96*se_mean_dt)

exp2data_times = bind_rows(exp2data_minus_CR_times, exp2data_minus_IA_times,
```

```
                          exp2data_minus_NR_times, exp2data_minus_U_times,
                          exp2data_plus_CR_times, exp2data_plus_IA_times,
                          exp2data_plus_NR_times, exp2data_plus_U_times)
```

Main

```
# Create the combined figure
exp2data_combined = exp2data_combined %>%
         mutate(punish_type_fct = factor(punish_type,
                                         levels = c("CR", "NR", "IA", "U")))

exp2data_combined %>%
  ggplot(aes(x = punish_type_fct, y = perc, fill = punish_type_fct,
             pattern = setting)) +
  geom_bar_pattern(position = "dodge", stat = "identity", alpha = 0.5,
                   pattern_density = 0.25, pattern_color = "white",
                   pattern_shape = 3) +
  geom_errorbar(aes(ymin = perc + 1.96*se_perc,
                    ymax = perc - 1.96*se_perc,
                    width = 0),
                    color = "purple4",
                position = position_dodge(.9),
                show.legend = F) +
  scale_pattern_manual(values = c("none", "pch")) +
  guides(color = "none", fill = "none",
         pattern = guide_legend(title = "Setting")) +
  annotate("text", x = 1:4,
           y = c(0.025, 0.0425, 0.045, 0.02),
           label = c("italic(p) == 0.889", "italic(p) == 0.629",
                     "italic(p) == 0.435", "italic(p) == 0.649"),
           parse = T) +
  scale_fill_manual(values = c("CR" = "plum3",
                               "NR" = "mediumslateblue",
                               "IA" = "mediumpurple3",
                               "U" = "orchid4"),
                    limits = c("CR", "NR", "IA", "U"),
                    guide = "none") +
  scale_x_discrete(labels = c("Copying/\nretaliation", "Negative\nreinforcement",
                              "Inequality\naversion", "Unclassified")) +
  scale_y_continuous(limits = c(0, 0.05), expand = c(0, 0)) +
```

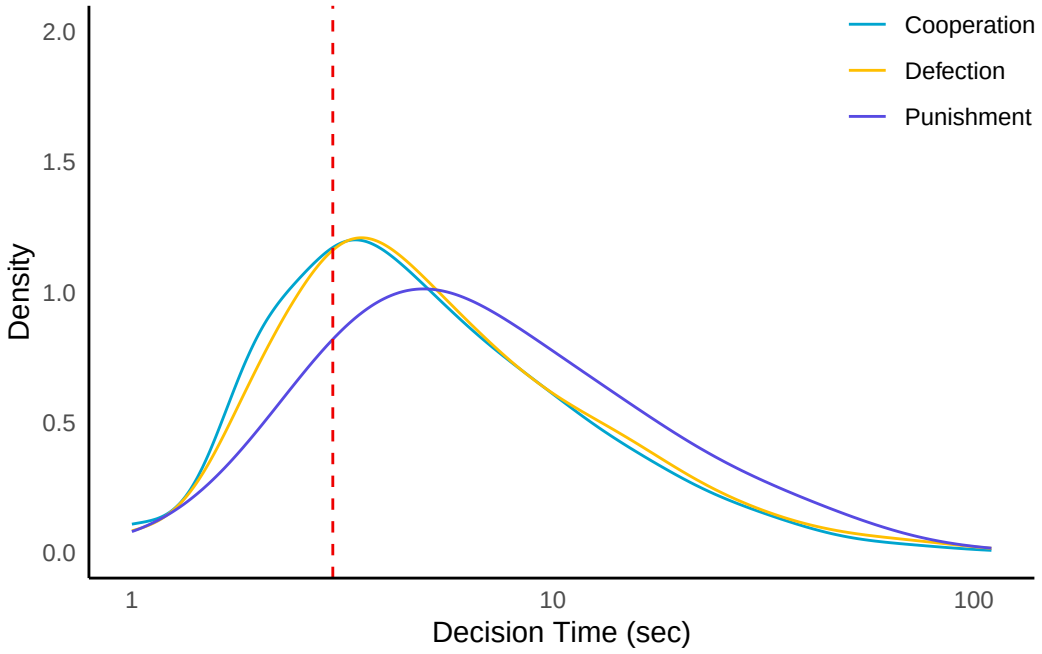
```
  ylab("Proportion") +
  xlab("") +
  theme_classic() +
  theme(panel.grid.minor = element_blank(),
        panel.grid.major = element_blank(),
        legend.position = "bottom",
        legend.key.size = unit(1, "cm"),
        legend.key = element_rect(fill = "#574AE2", color = NA),
        axis.title.x = element_blank(),
        axis.ticks.x = element_blank(),
        axis.ticks.y = element_blank())
```




```
# ggsave(filename = "~/Documents/Projects/harming_esn/figures/fig4.png",
# width = 7, height = 5, units = "in")
```

Figure S2 - Distribution of Decision Times, Experiment 1

```
exp1data %>%
  filter(is.na(behaviorTime_prompt/1000) == 0, behavior %in% c("C", "D", "P")) %>%
  ggplot(aes(x = behaviorTime_prompt/1000, color = behavior)) +
  geom_density(adjust = 2, key_glyph = "path") +
  geom_vline(xintercept = 3, color = "red2", linetype = "dashed") +
  theme_classic() +
  labs(color = "Behavior") +
  xlab("Decision Time (sec)") +
  scale_x_log10(limits = c(1, 110),breaks = c(1, 10, 100),
                name = "Decision Time (sec)") +
  scale_y_continuous(limits = c(0, 2), name = "Density") +
  scale_color_manual(labels = c("Cooperation", "Defection", "Punishment"),
                     values = c("#00A5CF", "#FFBF00", "#574AE2"), guide = "none") +
  guides(colour=guide_legend(title = NULL)) +
  theme(panel.grid.minor = element_blank(),
        panel.grid.major = element_blank(),
        legend.position = c(0.9, 0.9),
        legend.title = element_blank(),
        axis.ticks.x = element_blank(),
        axis.ticks.y = element_blank())
```



```
# ggsave(filename = "~/Documents/Projects/harming_esn/figures/figS2.png",
# width = 7, height = 5, units = "in")
```