A meta-analysis of mental rotation ability in the first years of life

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Commit f320c65

Results

Effect sizes of individual experiments:

```r
# Add columns to the table of included experiments
included %>%
  mutate(
    # Add difference between condition means
    mean_diff = case_when(
      !is.na(mean_diff) ~ mean_diff,
      TRUE ~ mean_novel - mean_familiar
    ),
    # Add d_z from paired t test of condition means (Rosenthal, 1991)
    d_z_t = t / sqrt(sample_size),
    # Add d_z from mean and standard deviation of the difference
    d_z_diff = mean_diff / sd_diff,
    # Add d_av from mean difference and standard devations (assumes r = 0)
    # (Cumming, 2012)
    sd_av = (sd_novel + sd_familiar) / 2,
    d_av = mean_diff / sd_av,
    # Add d from one-sample t test of novelty preference scores
    d_nov_pref = (nov_pref - 0.5) / sd_nov_pref,
    # Choose one type of outcome variable for each experiment
    yi = case_when(
      # 1. If d was reported directed
      !is.na(d) ~ d,
      # 2. If a paired sample t test was reported
      !is.na(d_z_t) ~ d_z_t,
      # 3. If the difference between means and its SD were reported
      !is.na(d_z_diff) ~ d_z_diff,
      # 4. If the individual condition means and their SDs were reported
      !is.na(d_av) ~ d_av,
      # 5. If a novelty preference score and its SD were reported
      !is.na(d_nov_pref) ~ d_nov_pref
    ),
    # Keep track which type of outcome measure was chosen for each article
    yi_type = case_when(
      !is.na(d) ~ "d",
      !is.na(d_z_t) ~ "d_z_t",
      !is.na(d_z_diff) ~ "d_z_diff",
      !is.na(d_av) ~ "d_av",
      !is.na(d_nov_pref) ~ "d_nov_pref",
```

```
      TRUE ~ "none"
    ) %>%
      factor(levels = c(
        "d", "d_z_t", "d_z_diff", "d_av", "d_nov_pref", "none"
      )),
    # Find studies with any value of d_z (from t test or mean / SD of the diff.)
    d_z = case_when(
      !is.na(d_z_t) ~ d_z_t,
      !is.na(d_z_diff) ~ d_z_diff
    ),
    # Compute SD of the difference based on d_z
    sd_z = mean_diff / d_z,
    # Compute correlation based on sd_z and condition SDs
    ri = (sd_z^2 - sd_novel^2 - sd_familiar^2) / (-2 * sd_novel * sd_familiar)
  ) %>%
  # Exclude experiments with redundant samples, missing stats, or age > 2 years
  filter(!redundant & !is.na(yi) & age_mean < 730) -> dat

# Overview of the different effect sizes
dat %>%
  select(id, group, yi_type, yi, d, d_z_t, d_z_diff, d_av, d_nov_pref, ri) %>%
  print(n = Inf)
```

```
## # A tibble: 59 x 10
##    id          group yi_type       yi     d   d_z_t d_z_diff     d_av d_nov_pref
##    <chr>       <chr> <fct>      <dbl> <dbl>   <dbl>    <dbl>    <dbl>      <dbl>
##  1 antrilli20~ vert~ d        1.05     1.05 NA         0.727   1.06        NA
##  2 antrilli20~ hori~ d       -0.21    -0.21 NA        -0.219  -0.223       NA
##  3 christodou~ all   d_av    -0.428   NA    NA        NA      -0.428       NA
##  4 constantin~ males d        0.85     0.85  0.661    NA      NA            0.605
##  5 constantin~ fema~ d       -0.2     -0.2  -0.0189   NA      NA           -0.0515
##  6 erdmann2018 male~ d_z_t   -0.194   NA    -0.194    NA      -0.146       NA
##  7 erdmann2018 fema~ d_z_t   -0.170   NA    -0.170    NA      -0.153       NA
##  8 erdmann2018 male~ d_av    -0.00285 NA    NA        NA      -0.00285     NA
##  9 erdmann2018 fema~ d_av     0.0160  NA    NA        NA       0.0160      NA
## 10 frick_2013  8m    d_av     0.0902  NA    NA        NA       0.0902      NA
## 11 frick_2013  10m   d_av     1.03    NA    NA        NA       1.03        NA
## 12 frick_2014  exp1~ d       -0.48    -0.48 -0.484    NA      -0.714       NA
## 13 frick_2014  exp1~ d        0.75     0.75  0.754    NA       0.831       NA
## 14 frick_2014  exp2~ d        0.18     0.18  0.179    NA       0.239       NA
## 15 frick_2014  exp2~ d        0.72     0.72  0.716    NA       0.848       NA
## 16 frick_2014  exp3~ d        0.79     0.79  0.788    NA       0.533       NA
## 17 frick_2014  exp3~ d       -0.13    -0.13 -0.128    NA      -0.172       NA
## 18 gerhard_20~ nonc~ d       -0.55    -0.55 -0.409    NA      NA           -0.553
## 19 gerhard_20~ craw~ d_nov_~  0.163   NA    NA        NA      NA            0.163
## 20 gerhardsam~ vert~ d        0.66     0.66  0.657    NA      NA            0.657
## 21 gerhardsam~ vert~ d_nov_~  0.0517  NA    NA        NA      NA            0.0517
## 22 gerhardsam~ hori~ d       -0.73    -0.73 -0.730    NA      NA           -0.730
## 23 gerhardsam~ hori~ d_nov_~  0.179   NA    NA        NA      NA            0.179
## 24 kaaz_2020   exp1~ d_z_t    0.0144  NA     0.0144   NA      NA            0.0139
## 25 kaaz_2020   exp1~ d_z_t   -0.128   NA    -0.128    NA      NA           -0.128
## 26 kaaz_2020   exp1~ d_z_t   -0.240   NA    -0.240    NA      NA           -0.240
## 27 kaaz_2020   exp1~ d_z_t   -0.118   NA    -0.118    NA      NA           -0.118
## 28 kaaz_2020   exp1~ d_z_t   -0.0318  NA    -0.0318   NA      NA           -0.0313
```

```
## 29 kaaz_2020   exp1~ d_z_t    0.0794  NA     0.0794  NA      NA            0.0791
## 30 kaaz_2020   exp2~ d_z_t   -0.0823  NA    -0.0823  NA      NA           -0.0820
## 31 kaaz_2020   exp2~ d_z_t    0.357   NA     0.357   NA      NA            0.356
## 32 kelch_2021  exp1~ d       -0.91    -0.91 -0.911   NA      -1.00        -0.910
## 33 kelch_2021  exp1~ d_av     0.0706  NA    NA       NA       0.0706       0.148
## 34 kelch_2021  exp2~ d_av    -0.233   NA    NA       NA      -0.233       -0.225
## 35 kelch_2021  exp2~ d_av     0.232   NA    NA       NA       0.232        0.244
## 36 kellman_19~ kine~ d_z_t    0.837   NA     0.837   NA      NA           NA
## 37 kellman_19~ kine~ d_z_t    0.826   NA     0.826   NA      NA           NA
## 38 lauer_2015  fema~ d        1.15     1.15  1.14    NA      NA            1.17
## 39 lauer_2015  males d        0.59     0.59  0.584   NA      NA            0.667
## 40 moehring_2~ expl~ d_av     0.934   NA    NA       NA       0.934       NA
## 41 moehring_2~ obse~ d_av     1.09    NA    NA       NA       1.09        NA
## 42 moore_2008  males d        0.61     0.61  0.910   NA      NA           NA
## 43 moore_2008  fema~ d       -0.06    -0.06 -0.0783  NA      NA           NA
## 44 moore_2011  males d_z_t    0.635   NA     0.635   NA      NA           NA
## 45 moore_2011  fema~ d_z_t    0.179   NA     0.179   NA      NA           NA
## 46 quinn_2008  fema~ d_z_t    0.0173  NA     0.0173  NA      NA            0.0168
## 47 quinn_2008  males d_z_t    2.08    NA     2.08    NA      NA            2.08
## 48 quinn_2014  exp2~ d_z_t   -0.196   NA    -0.196   NA      NA           -0.197
## 49 quinn_2014  exp2~ d_z_t   -0.0635  NA    -0.0635  NA      NA           -0.0631
## 50 quinn_2014  exp2~ d_z_t    1.33    NA     1.33    NA      NA            1.33
## 51 quinn_2014  exp2~ d_z_t    1.02    NA     1.02    NA      NA            1.02
## 52 schwarzer_~ craw~ d_av     0.502   NA    NA       NA       0.502       NA
## 53 schwarzer_~ nonc~ d_av    -0.261   NA    NA       NA      -0.261       NA
## 54 schwarzer_~ craw~ d_z_di~  0.711   NA    NA        0.711  NA           NA
## 55 schwarzer_~ nonc~ d_z_di~  0.0981  NA    NA        0.0981 NA           NA
## 56 slone_2018  mitt~ d_z_di~  0.114   NA    NA        0.114  NA           NA
## 57 slone_2018  mitt~ d_z_di~  0.0403  NA    NA        0.0403 NA           NA
## 58 slone_2018  mitt~ d_z_di~ -0.435   NA    NA       -0.435  NA           NA
## 59 slone_2018  mitt~ d_z_di~  0.0672  NA    NA        0.0672 NA           NA
## # ... with 1 more variable: ri <dbl>
```

```r
# Correlations between dependent samples
summary(dat$ri)
```

```
##     Min.  1st Qu.   Median     Mean  3rd Qu.     Max.     NA's
## -0.04149  0.17710  0.50674  0.43527  0.67061  0.79924       48
```

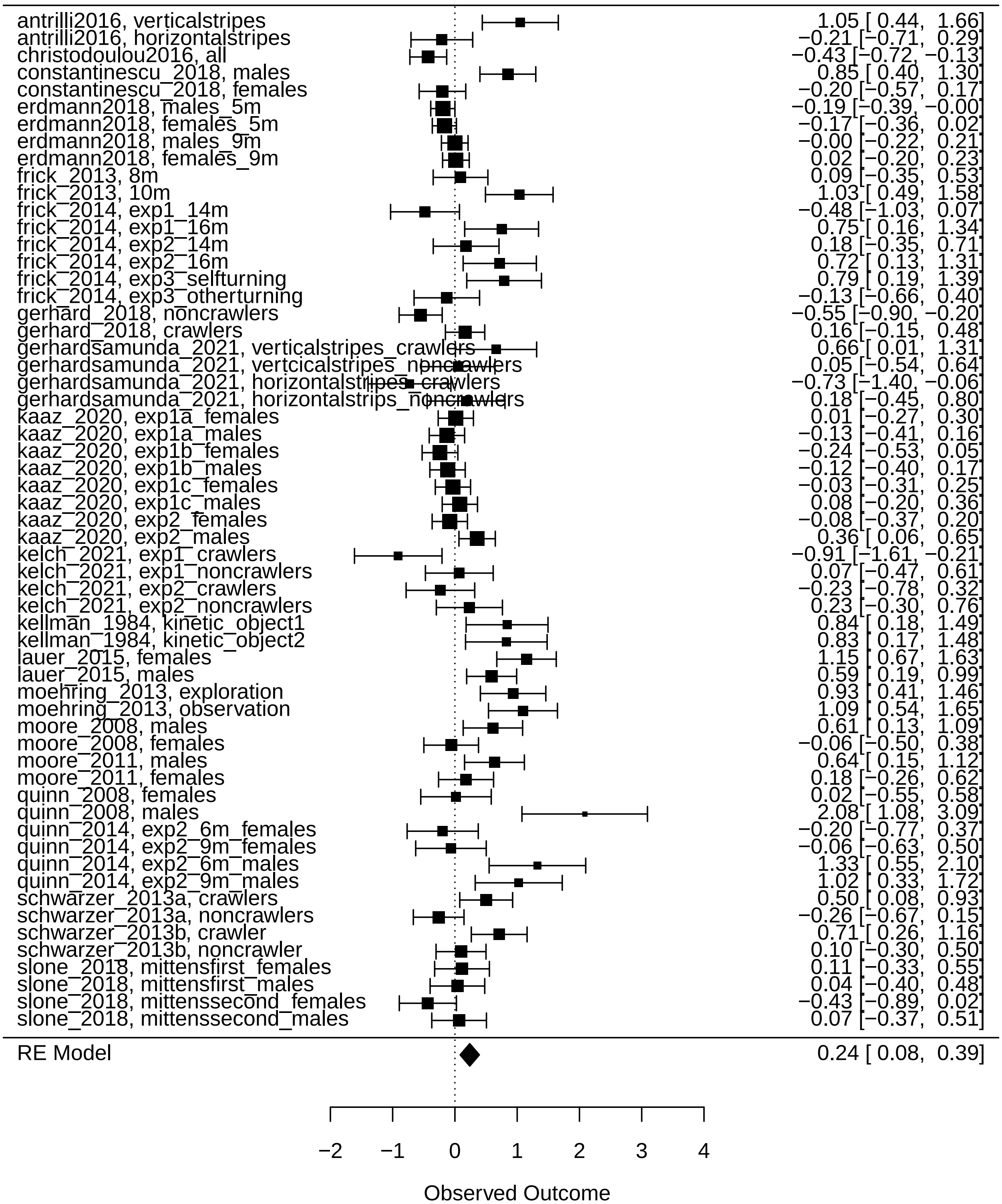
Actual meta-analysis:

```r
# Compute standard error of Cohen's d based on assumed correlation
# This will need a sensitivity analysis
r_assumed <- 0.5
dat %>%
  mutate(
    ni = sample_size,
    sei = sqrt(((2 * (1 - r_assumed)) / ni) + (yi^2 / (2 * ni))),
    age_months = age_mean / 30.417
  ) %>%
  select(id, group, age_months, female_percent, ni, yi, sei) %>%
  # Compute sampling variance from standard errors
  escalc(yi = yi, sei = sei, ni = ni, data = .) %>%
  tibble() -> dat_r

# Create vector of experiment IDs for plotting
```

```r
experiment_ids <- with(dat_r, paste(id, group, sep = ", "))

# # Two-level model
# res <- rma(
#   yi, vi,
#   data = dat_r,
#   slab = experiment_ids
# )
# print(res)
# forest(res)

# Three-level model
res_mv <- rma.mv(
  yi, vi,
  random = ~ group | id,
  data = dat_r,
  slab = experiment_ids
)
print(res_mv)
```

```
##
## Multivariate Meta-Analysis Model (k = 59; method: REML)
##
## Variance Components:
##
## outer factor: id    (nlvls = 20)
## inner factor: group (nlvls = 49)
##
##             estim    sqrt  fixed
## tau^2      0.1857  0.4309     no
## rho        0.2556             no
##
## Test for Heterogeneity:
## Q(df = 58) = 248.7957, p-val < .0001
##
## Model Results:
##
## estimate      se    zval    pval   ci.lb   ci.ub
##   0.2381  0.0784  3.0368  0.0024  0.0844  0.3917  **
##
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
forest(res_mv)
```

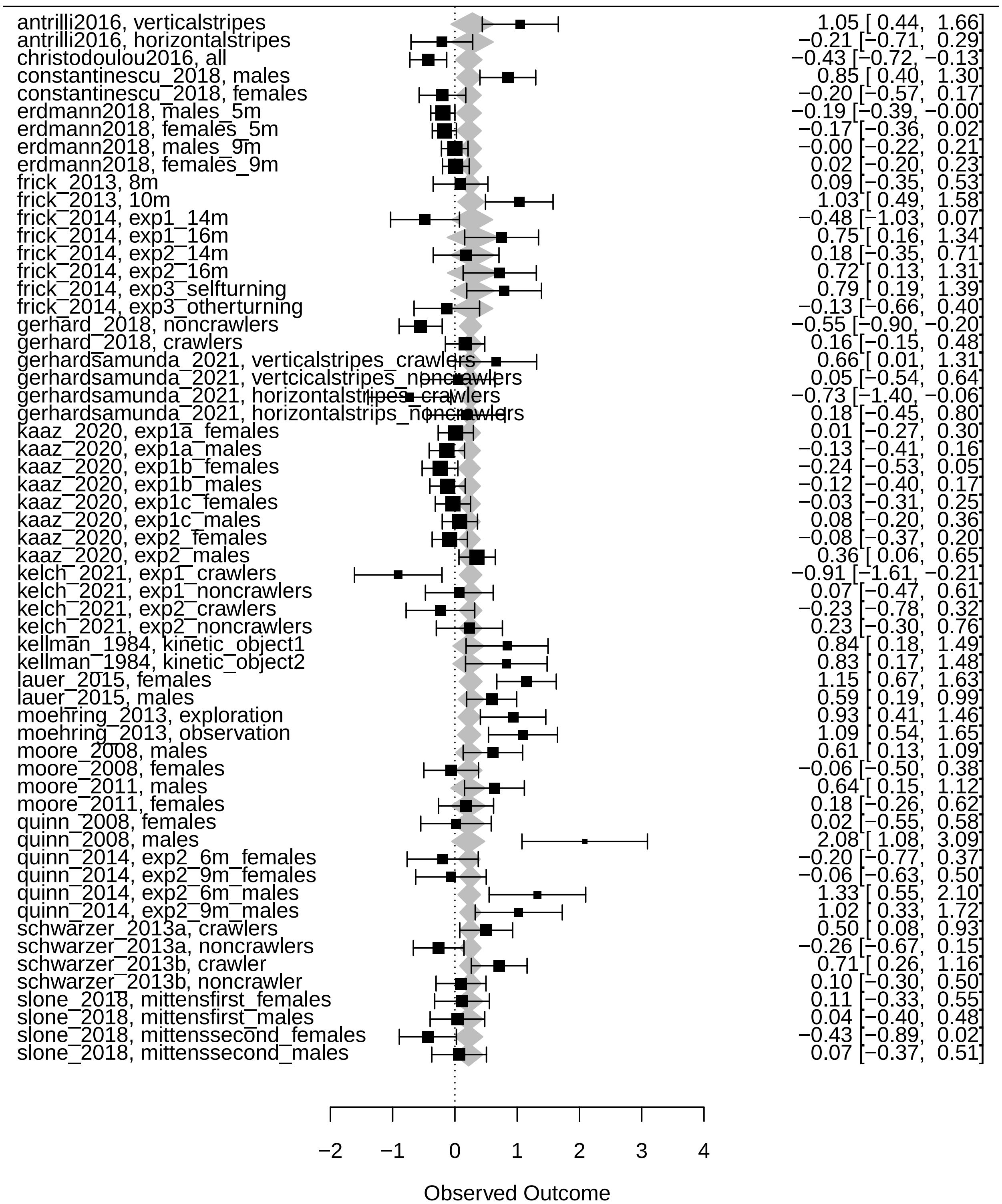



```
# # Saving the forest plot
# pdf("forest.pdf", width = 12, height = 12)
# forest(res_mv)
# dev.off()

# # Profile likelihodd plots
```

```r
# profile(res_mv, sigma2 = 1)
# profile(res_mv, sigma2 = 2)

# Meta-regression with age
res_age <- rma.mv(
  yi, vi,
  mods = ~age_months,
  random = ~ group | id,
  data = dat_r,
  slab = experiment_ids
)
print(res_age)
```

```
##
## Multivariate Meta-Analysis Model (k = 59; method: REML)
##
## Variance Components:
##
## outer factor: id    (nlvls = 20)
## inner factor: group (nlvls = 49)
##
##             estim    sqrt  fixed
## tau^2      0.1922  0.4384     no
## rho        0.2853             no
##
## Test for Residual Heterogeneity:
## QE(df = 57) = 242.1270, p-val < .0001
##
## Test of Moderators (coefficient 2):
## QM(df = 1) = 0.0651, p-val = 0.7986
##
## Model Results:
##
##             estimate      se    zval    pval    ci.lb   ci.ub
## intrcpt       0.1919  0.2093  0.9169  0.3592  -0.2183  0.6021
## age_months    0.0063  0.0246  0.2552  0.7986  -0.0419  0.0544
##
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
forest(res_age)
```




```
# Meta-regression with gender
res_gender <- rma.mv(
  yi, vi,
  mods = ~female_percent,
  random = ~ group | id,
  data = dat_r,
```

```r
  slab = experiment_ids
)
```

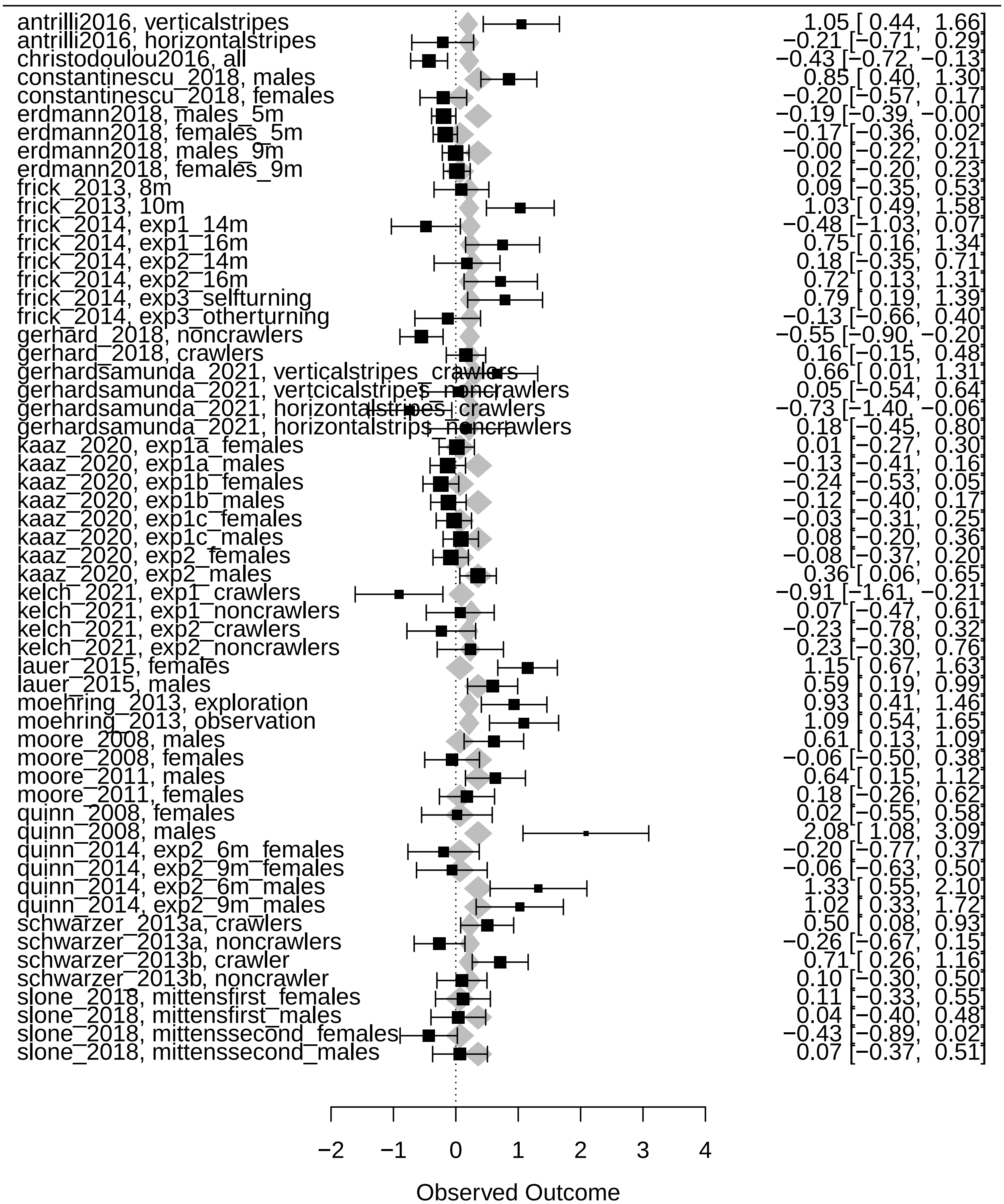
```
## Warning: Rows with NAs omitted from model fitting.
```

```
## Warning: One or more levels of inner factor (i.e., kinetic_object1,
## kinetic_object2) removed due to NAs.
```

```r
print(res_gender)
```

```
##
## Multivariate Meta-Analysis Model (k = 57; method: REML)
##
## Variance Components:
##
## outer factor: id    (nlvls = 19)
## inner factor: group (nlvls = 49)
##
##             estim    sqrt  fixed
## tau^2      0.1774  0.4212     no
## rho        0.2342             no
##
## Test for Residual Heterogeneity:
## QE(df = 55) = 233.1638, p-val < .0001
##
## Test of Moderators (coefficient 2):
## QM(df = 1) = 3.6465, p-val = 0.0562
##
## Model Results:
##
##                 estimate      se     zval    pval    ci.lb   ci.ub
## intrcpt           0.3572  0.1079   3.3095  0.0009   0.1457  0.5687  ***
## female_percent   -0.2915  0.1527  -1.9096  0.0562  -0.5907  0.0077    .
##
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
forest(res_gender)
```




```
# Meta-regression with age, gender, and their interaction
res_full <- rma.mv(
  yi, vi,
  mods = ~ age_months * female_percent,
  random = ~ group | id,
  data = dat_r,
```

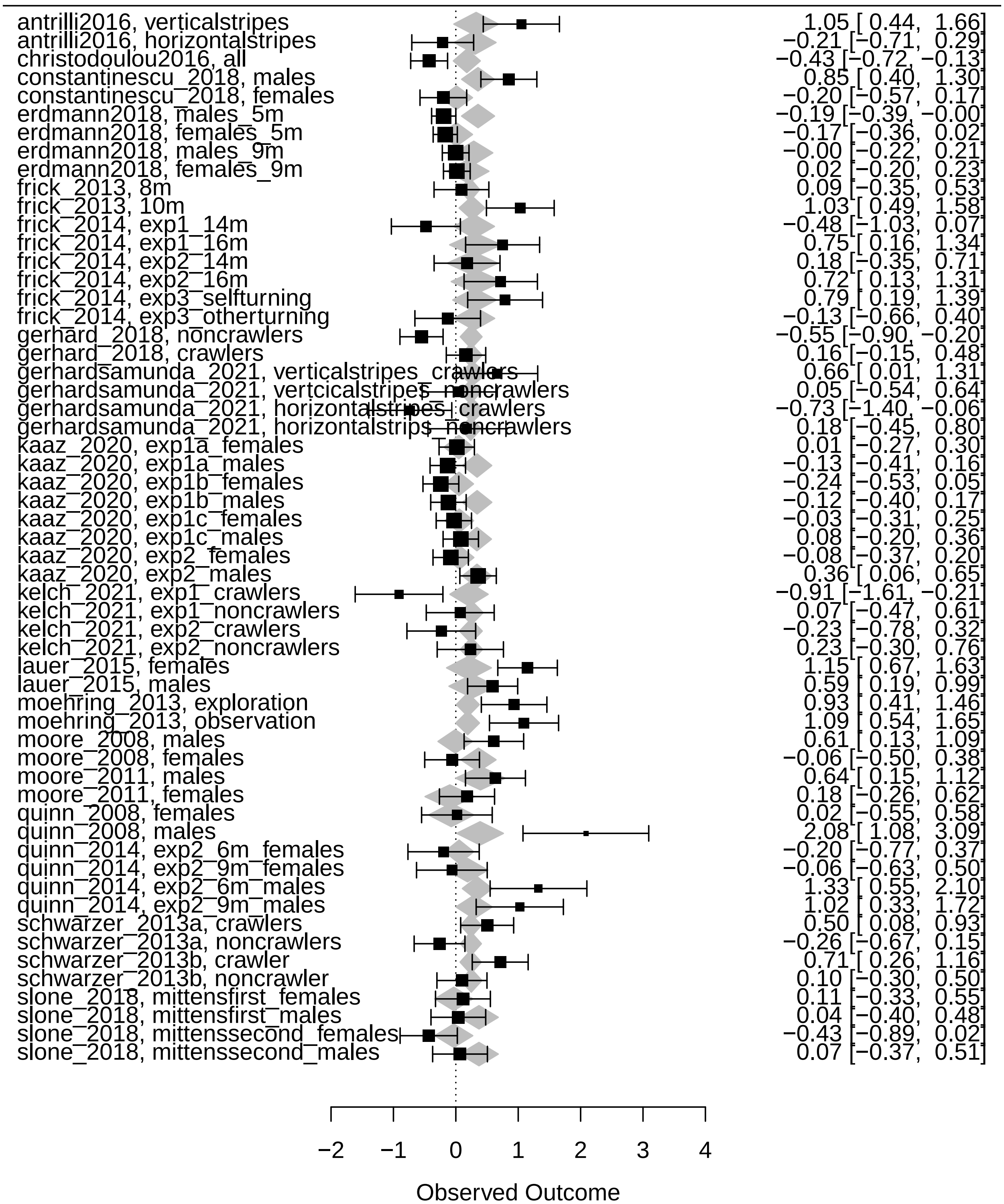
```r
  slab = experiment_ids
)
```

```
## Warning: Rows with NAs omitted from model fitting.

## Warning: One or more levels of inner factor (i.e., kinetic_object1,
## kinetic_object2) removed due to NAs.
```

```r
print(res_full)
```

```
##
## Multivariate Meta-Analysis Model (k = 57; method: REML)
##
## Variance Components:
##
## outer factor: id    (nlvls = 19)
## inner factor: group (nlvls = 49)
##
##             estim    sqrt  fixed
## tau^2      0.1853  0.4304     no
## rho        0.2728             no
##
## Test for Residual Heterogeneity:
## QE(df = 53) = 223.3541, p-val < .0001
##
## Test of Moderators (coefficients 2:4):
## QM(df = 3) = 4.6842, p-val = 0.1964
##
## Model Results:
##
##                           estimate      se     zval    pval    ci.lb   ci.ub
## intrcpt                     0.4501  0.3239   1.3897  0.1646  -0.1847  1.0850
## age_months                 -0.0173  0.0433  -0.4003  0.6889  -0.1022  0.0675
## female_percent             -0.6970  0.5014  -1.3901  0.1645  -1.6796  0.2857
## age_months:female_percent   0.0645  0.0753   0.8558  0.3921  -0.0832  0.2121
##
## intrcpt
## age_months
## female_percent
## age_months:female_percent
##
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
forest(res_full)
```



Methods

Information sources and search strategy

Article sources:

```
##
##    database   reference      review review_done
##        1954          49          11          23
```

Selection process

Interrater agreement

Percent agreement for binary decision (include/exclude):

```
## [1] 0.9852725
```

Cohen's kappa for binary decision (include/exclude):

```
## Call: cohen.kappa1(x = x, w = w, n.obs = n.obs, alpha = alpha, levels = levels)
##
## Cohen Kappa and Weighted Kappa correlation coefficients and confidence boundaries
##                  lower estimate upper
## unweighted kappa  0.55     0.67  0.78
## weighted kappa    0.55     0.67  0.78
##
##  Number of subjects = 2037
```

Correlation (phi) for binary decision (include/exclude):

```
##
##  Pearson's product-moment correlation
##
## data:  bin_1 and bin_2
## t = 40.336, df = 2035, p-value < 2.2e-16
## alternative hypothesis: true correlation is not equal to 0
## 95 percent confidence interval:
##  0.6416930 0.6900038
## sample estimates:
##       cor
## 0.6665477
```

Percent agreement for exclusion codes:

```
## [1] 0.8821797
```

Cohen's kappa for exclusion codes:

```
## Warning in cohen.kappa1(x, w = w, n.obs = n.obs, alpha = alpha, levels =
## levels): upper or lower confidence interval exceed abs(1) and set to +/- 1.
```

```
## Call: cohen.kappa1(x = x, w = w, n.obs = n.obs, alpha = alpha, levels = levels)
##
## Cohen Kappa and Weighted Kappa correlation coefficients and confidence boundaries
##                  lower estimate upper
## unweighted kappa  0.69     0.72  0.75
## weighted kappa    0.40     0.72  1.00
##
##  Number of subjects = 2037
```

Final decisions

Exlucsion codes:

```
## 1 = not in english
```

```
## 2 = not a group study
## 3 = not infants
## 4 = not typically developing
## 5 = no mental rotation
## 6 = no within-group statistics
## 7 = include paper
## 8 = no access or insufficient statistics
```

```
##
##    1    2    3    4    5    7    8
##   49  320 1545    4   89   27    3
```

Included experiments

Total number of articles (according to `screening` table):

```
## [1] 27
```

Total number of articles (according to `included` table):

```
## [1] 27
```

Total number of experiments:

```
## [1] 99
```

Number of non-redundant experiments:

```
## [1] 79
```

Number of experiments per type of effect size:

```
## Warning: Unknown or uninitialised column: `yi_type`.
```

```
## < table of extent 0 >
```

Total number of infants across experiments:

```
## [1] NA
```

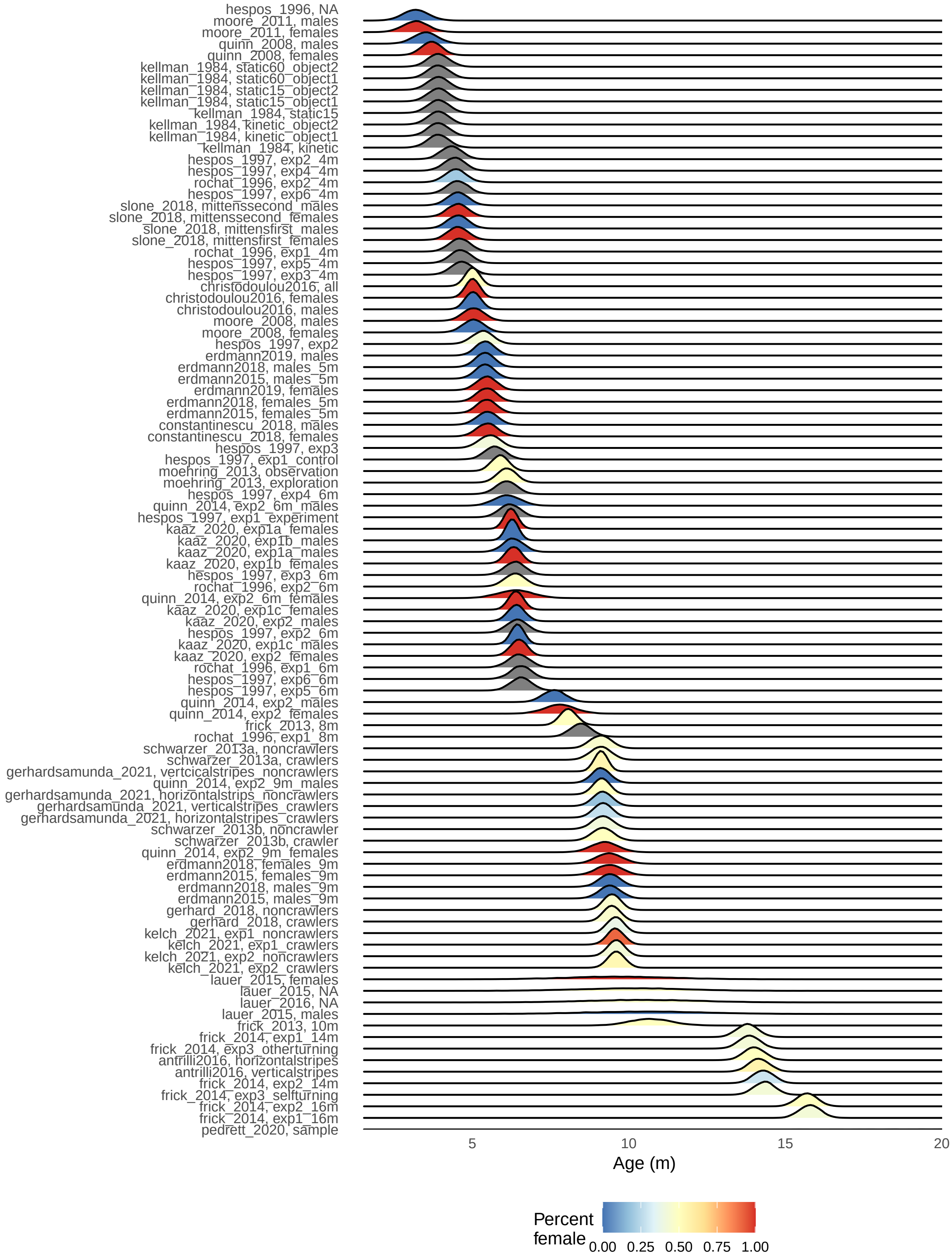
Descriptive information about the infant samples:

```
##   sample_size        age_mean         age_sd           age_min
##  Min.   :  7.00   Min.   : 97.1   Min.   :  5.80   Min.   : 98.0
##  1st Qu.: 12.00   1st Qu.:152.2   1st Qu.:  7.97   1st Qu.:123.7
##  Median : 20.00   Median :192.8   Median :  9.51   Median :180.2
##  Mean   : 28.26   Mean   :225.5   Mean   : 15.14   Mean   :210.7
##  3rd Qu.: 28.00   3rd Qu.:280.2   3rd Qu.: 11.39   3rd Qu.:273.9
##  Max.   :104.00   Max.   :935.0   Max.   :153.41   Max.   :669.2
##  NA's   :1        NA's   :1       NA's   :41       NA's   :46
##     age_max       female_percent
##  Min.   : 138.0   Min.   :0.0000
##  1st Qu.: 154.1   1st Qu.:0.0000
##  Median : 210.6   Median :0.4600
##  Mean   : 275.3   Mean   :0.4805
##  3rd Qu.: 348.6   3rd Qu.:1.0000
##  Max.   :1155.8   Max.   :1.0000
##  NA's   :46       NA's   :25
```

Age and gender distributions of all experiments:

```
## Warning in rnorm(n(), age_mean, age_sd): NAs produced
```

```
## Warning: Removed 10000 rows containing non-finite values (stat_density_ridges).
```



Sample sizes and ages of all experiments:

```
## Warning: Removed 1 rows containing missing values (geom_point).
```