

Network Dynamics are Associated with Reinforcement Learning

Models

Raphael Gerraty

Behavioral Learning Model

We ran a generalized mixed effects logit model predicting proportion correct with block. Subjects demonstrated significant learning across the task.

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
## Approximation) [glmerMod]
## Family: binomial ( logit )
## Formula: correct ~ block_int + (block_int | subject)
## Data: flex_behav
## Weights: weights
##
##      AIC      BIC   logLik deviance df.resid
##    468.1    480.5   -229.1    458.1      83
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -1.6088 -0.4340  0.1505  0.5624  1.6471
##
## Random effects:
## Groups Name      Variance Std.Dev. Corr
## subject (Intercept) 1.0237   1.0118
##      block_int    0.2195   0.4685   0.81
## Number of obs: 88, groups:  subject, 22
##
## Fixed effects:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)   1.1864     0.2250   5.272 1.35e-07 ***
## block_int     0.2820     0.1136   2.482  0.0131 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##              (Intr)
## block_int  0.748
```

Effect of Flexibility on Reinforcement Learning

Striatal flexibility- REML

We fit a mixed effects generalized linear model using a REML approximation to associate individual learning performance with striatal flexibility across blocks, using lme4.

```

## Generalized linear mixed model fit by maximum likelihood (Laplace
## Approximation) [glmerMod]
## Family: binomial ( logit )
## Formula: correct ~ str_flex + (str_flex || subject)
## Data: flex_behav
## Weights: weights
##
##      AIC      BIC   logLik deviance df.resid
##    494.8    504.7   -243.4   486.8      84
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -2.63858 -0.73581 -0.02002  0.85468  2.43378
##
## Random effects:
## Groups      Name      Variance Std.Dev.
## subject    (Intercept) 2.796e-08 0.0001672
## subject.1 str_flex    6.196e+01 7.8715162
## Number of obs: 88, groups:  subject, 22
##
## Fixed effects:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)  0.04581    0.23683   0.193  0.84662
## str_flex     9.45132    2.74667   3.441  0.00058 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##      (Intr)
## str_flex -0.772

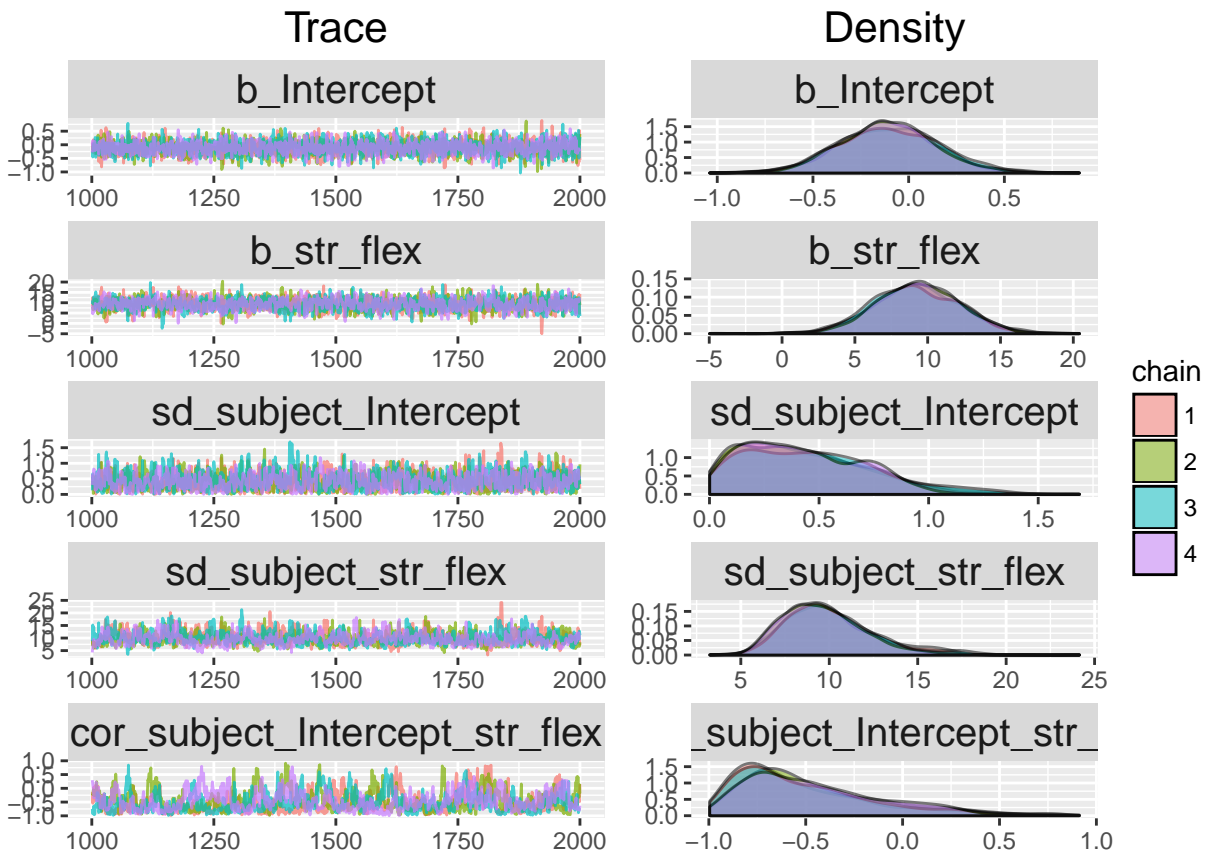
## Generalized linear mixed model fit by maximum likelihood (Laplace
## Approximation) [glmerMod]
## Family: binomial ( logit )
## Formula: correct ~ str_flex + str_flex_mean + (str_flex || subject)
## Data: flex_behav
## Weights: weights
##
##      AIC      BIC   logLik deviance df.resid
##    496.3    508.6   -243.1   486.3      83
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -2.52483 -0.74572 -0.05168  0.81802  2.43855
##
## Random effects:
## Groups      Name      Variance Std.Dev.
## subject    (Intercept)  0.00    0.000
## subject.1 str_flex    66.28    8.141
## Number of obs: 88, groups:  subject, 22
##
## Fixed effects:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)    1.236    1.671   0.740 0.459478

```

```
## str_flex          9.792          2.819    3.473 0.000514 ***
## str_flex_mean   -11.137         15.454   -0.721 0.471150
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##              (Intr) str_fl
## str_flex      0.053
## str_flex_mn  -0.990 -0.162
```

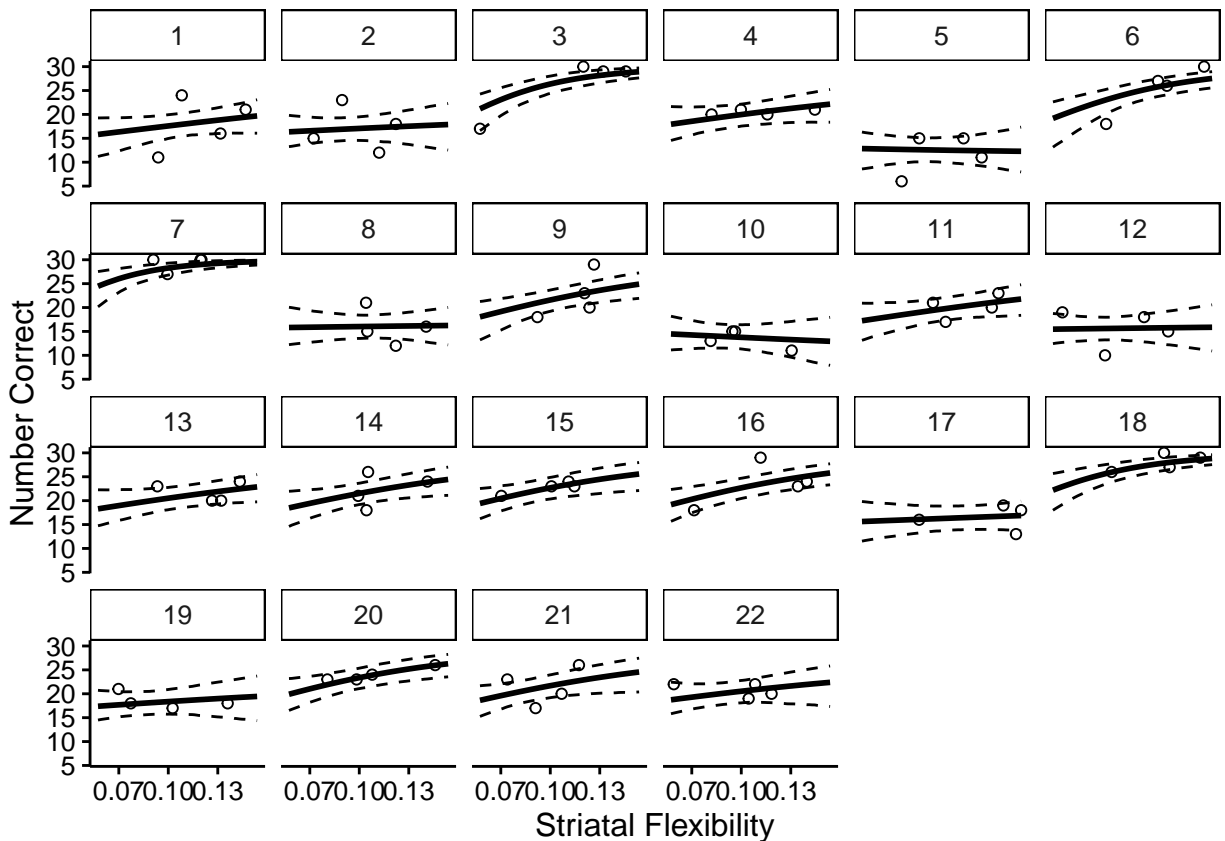
Striatal flexibility- Bayesian model

For appropriate posterior inference, we fit the same model using Hamiltonian Monte Carlo to generate a full posterior distribution for the effect of striatal flexibility on learning performance. We used the ‘brms’ package to build Stan models.



```
## Family: binomial (logit)
## Formula: numcorr ~ str_flex + (str_flex | subject)
## Data: flex_behav (Number of observations: 88)
## Samples: 4 chains, each with iter = 2000; warmup = 1000; thin = 1;
##          total post-warmup samples = 4000
## WAIC: Not computed
##
## Random Effects:
## ~subject (Number of levels: 22)
```

```
##
##          Estimate Est.Error 1-95% CI u-95% CI Eff.Sample
## sd(Intercept)      0.43     0.29    0.02    1.06     1092
## sd(str_flex)       9.92     2.49    6.10   16.00     573
## cor(Intercept,str_flex) -0.48    0.36   -0.93    0.39     197
##
##          Rhat
## sd(Intercept)  1.01
## sd(str_flex)   1.01
## cor(Intercept,str_flex) 1.02
##
## Fixed Effects:
##          Estimate Est.Error 1-95% CI u-95% CI Eff.Sample Rhat
## Intercept    -0.11     0.25   -0.60    0.40     4000    1
## str_flex      9.26     2.94    3.53   14.99     1943    1
##
## Samples were drawn using sampling(NUTS). For each parameter, Eff.Sample
## is a crude measure of effective sample size, and Rhat is the potential
## scale reduction factor on split chains (at convergence, Rhat = 1).
```



Whole-brain flexibility

Because a global measure of flexibility has also been shown to relate to a number of cognitive processes (Bassett et al 2011, Braun et al 2015), we fit another mixed-effects model with this whole-brain metric as a predictor.

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
## Approximation) [glmerMod]
```

```

## Family: binomial ( logit )
## Formula: correct ~ wb_flex + (wb_flex || subject)
## Data: flex_behav
## Weights: weights
##
##      AIC      BIC   logLik deviance df.resid
##    511.5    521.4   -251.8    503.5      84
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -2.67954 -0.71005 -0.01157  0.81079  2.72652
##
## Random effects:
## Groups   Name      Variance Std.Dev.
## subject  (Intercept)  0.00    0.000
## subject.1 wb_flex    64.94    8.058
## Number of obs: 88, groups:  subject, 22
##
## Fixed effects:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)  -0.1104    0.3506  -0.315  0.75287
## wb_flex      11.8486    3.9126   3.028  0.00246 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##      (Intr)
## wb_flex -0.889

```