

Striatal Network Dynamics are Associated with Reinforcement Learning

Models

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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

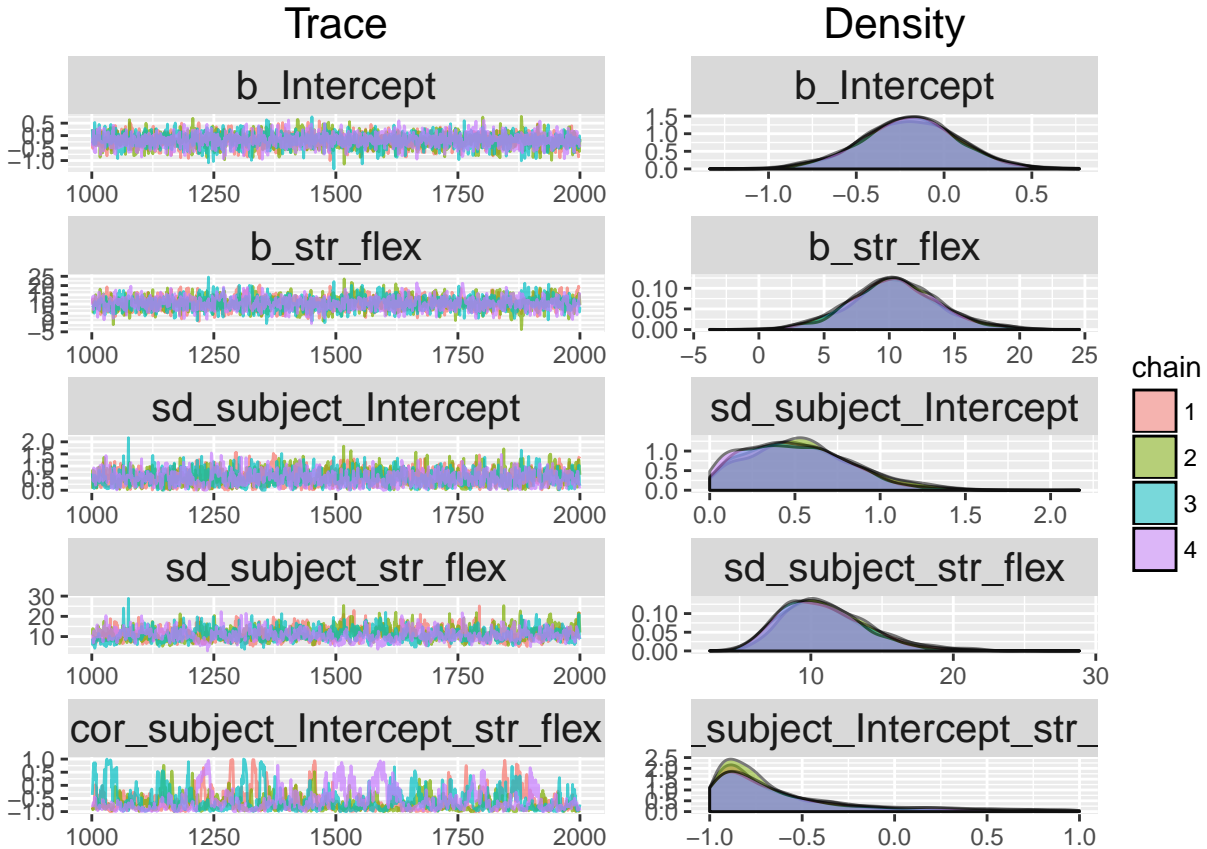
```

```
## 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.

```
## 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)      0.52     0.31    0.04    1.20      1079
## sd(str_flex)      11.03     3.09    6.19   18.23      347
## cor(Intercept,str_flex) -0.62     0.39   -0.99    0.56      176
##      Rhat
## sd(Intercept)      1.01
## sd(str_flex)      1.02
## cor(Intercept,str_flex) 1.03
##
## Fixed Effects:
##      Estimate Est.Error 1-95% CI u-95% CI Eff.Sample Rhat
## Intercept    -0.19     0.28   -0.75    0.35      2489    1
## str_flex     10.42     3.42    3.65   17.56      1628    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

```