Kasdin et al. (2025) show that dopamine in the brains of young zebra finches acts as a learning signal, increasing when they sing closer to their adult song and decreasing when they sing further away, effectively guiding their vocal development through trial-and-error. This suggests that complex natural behaviors, like learning to sing, are shaped by dopamine-driven reinforcement learning, similar to how artificial intelligence learns. You can find the paper at this link: https://www.nature.com/articles/s41586-025-08729-1..

Note they measure dopamine using fibre photometry, changes in the fluorescence indicate dopamine changes in realtime. Their specific measurement considers changes in flourescence in 100-ms windows between 200 and 300 ms from the start of singing, averaged across development.

1. Using the `pwr` package for `R` (Champely, 2020), conduct a power analysis. How many observations would the researchers need to detect a moderate-to-large effect ($d = 0.65$) when using $\alpha = 0.05$ and default power (0.80) for a two-sided one sample t test.

```
library(pwr)
(power <- power.t.test(delta = 0.65, sig.level = 0.05,
             power = 0.8,
             type = "one.sample",
             alternative = "two.sided"))
```

```
##
##      One-sample t test power calculation
##
##               n = 20.58044
##           delta = 0.65
##              sd = 1
##       sig.level = 0.05
##           power = 0.8
##     alternative = two.sided
```

The number of observations that the researchers need to detect a moderate-to-large effect of d = 0.65 is n = 20.58 which is around 21 observations. This was completed using the `pwr` package in `R` (Champely, 2020).

2. Click the link to go to the paper. Find the source data for Figure 2. Download the Excel file. Describe what you needed to do to collect the data for Figure 2(g). Note that you only need the `closer_vals` and `further_vals`. Ensure to `mutate()` the data to get a difference (e.g., `closer_vals - further_vals`).

```
dat.fig2g <- read_csv("fig2gdata.csv")
dat.fig2g <- dat.fig2g |>
  mutate(difference = closer_vals - further_vals)
```

I downloaded excel file called source data for Figure 2g and isolated the columns for the data needed to replicate Figure 2g. Those columns were closer_vals and further_vals. I computed a new variable called difference which quantifies the change in dopamine levels between the closer and farther values. Figure 2g is a scatter plot of averaged delta(F) / F signals for all syllables for closer (blue) and further (red) renditions (Kasdin et al., 2025).

3. Summarize the data.

   (a) Summarize the further data. Do the data suggest that dopamine in the brains of young zebra finches decreases when they sing further away?

```r
library(e1071)
library(xtable)
# Part A: Summarize the Further Data
sum.further <- dat.fig2g |>
  summarize(
    n = n(),
    mean = mean(further_vals, na.rm = T),
    sd = sd(further_vals, na.rm = T),
    skew = skewness(further_vals, na.rm=T)
  )
sum.farther.t1 <- xtable(sum.further,
                         caption = "Summary of Further Data",
                         label = "tab:sumFurther")
```

n	mean	sd	skew
25	-0.20	0.13	-1.04

Table 1: Summary of Further Data

The data suggest that dopamine in the brains of young zebra finches decreases when they sing further away. This is visualized in Figure 1. The further away the finch sings shows lower levels of dopamine with the percent change in fluoresence.

(b) Summarize the closer data. Do the data suggest that dopamine in the brains of young zebra finches increases when they sing closer to their adult song?

```r
# Part B: Summarize the Closer Data
sum.closer <- dat.fig2g |>
  summarize(
    mean = mean(closer_vals, na.rm = T),
    sd = sd(closer_vals, na.rm = T),
    skew = skewness(closer_vals, na.rm=T)
  )
sum.closer.t1 <- xtable(sum.closer,
                         caption = "Summary of Closer Data",
                         label = "tab:sumCloser")
```

mean	sd	skew
0.16	0.09	0.30

Table 2: Summary of Closer Data

The data suggest that dopamine in the brains of young zebra finches increases when they sing closer to their adult song. This is visualized in Figure 1. The closer the finch sings shows higher levels of dopamine with the percent change in fluoresence.

(c) Summarize the paired differences. Do the data suggest that there is a difference between dopamine in the brains of young zebra finches when they sing further away compared to closer to their adult song?

```r
# Part C: Summarize the Paired Differences
sum.dif <- dat.fig2g |>
  summarize(
    mean = mean(difference, na.rm = T),
    sd = sd(difference, na.rm = T),
```

```r
    skew = skewness(difference, na.rm=T)
  )
sum.dif.t1 <- xtable(sum.dif,
                     caption = "Summary of Paired Differences Data",
                     label = "tab:sumDiff")
```

mean	sd	skew
0.36	0.21	0.77

Table 3: Summary of Paired Differences Data

The data suggest that there is a difference between dopamine in the brains of young zebra finches increases when they sing closer to their adult song compared to when they sing farther away. This is visualized in Figure 1.

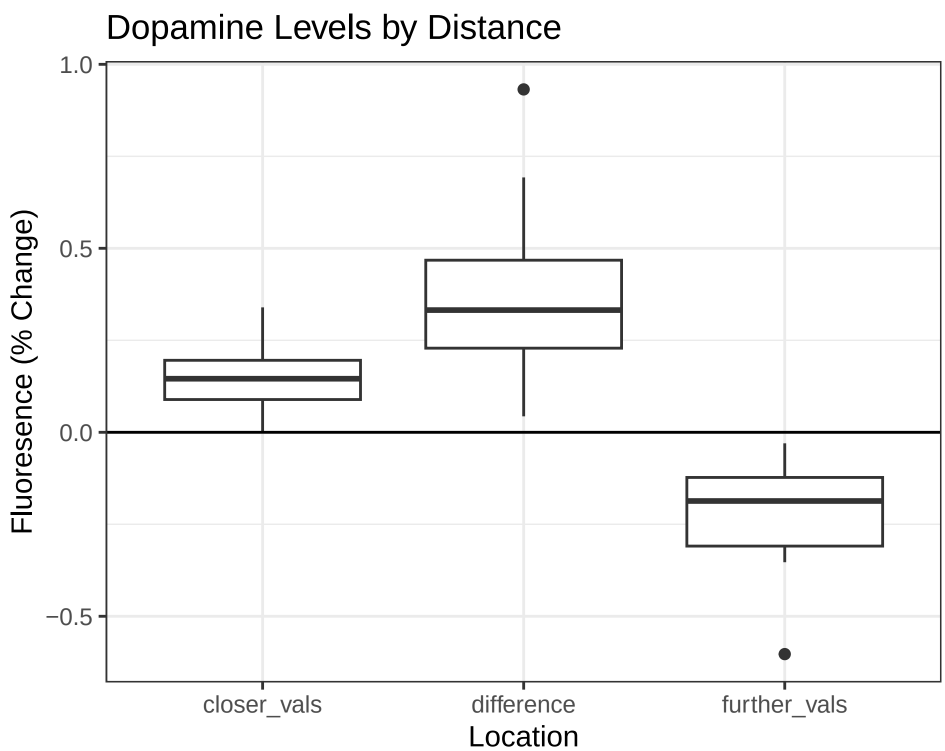

Figure 1: Boxplot of Closer, Further, and Difference Values

Figure 1 shows the three conditions: closer values, farther values, and the paired difference between the first two. For the closer values, the median is above zero which indicates that the percent change in fluorescence is positive. It can be seen that when the young zebra finches sing closer to their adult song, there is an increase in dopamine levels. Controversy, the farther values show a median below zero with majority of the values being negative. This indicates the opposite: that there is a decrease in dopamine levels when they sing farther away. The difference is above zero which shows that the percent change in fluorescence is higher when birds sing closer in comparison to further away.

(d) **Optional Challenge:** Can you reproduce Figure 2(g)? Note that the you can use `geom_errorbar()` to plot the range created by adding the mean $\pm$ one standard deviation.

4. Conduct the inferences they do in the paper. Make sure to report the results a little more comprehensively – that is your parenthetical should look something like: ($t = 23.99$, $p < 0.0001$; $g = 1.34$; 95% CI: 4.43, 4.60).
   Note: Your numbers may vary slightly as they performed some unclear correction of their p-values. I'm waiting to hear back from them via email!

   (a) "The close responses differed significantly from 0 ($p = 1.63 \times 10^{-8}$)."

```
 ### Part A: Close Responses ###
library(effectsize)
mu0 <- 0
x <- dat.fig2g$closer_vals
# Hedges G
g <- hedges_g(x = x, mu = mu0, alternative = "greater")
# T-test
close.stats <- t.test(x=x, mu = mu0, conf.level = 0.95, alternative = "greater") # one tailed
CI <- t.test(x=x, mu = mu0, conf.level = 0.95, alternative = "two.sided")
?t.test
# Report Stats
close.table <- tibble(
  t = close.stats$statistic,
  p = formatC(close.stats$p.value, format = "e", digits = 2),
  g = g$Hedges_g,
  CI.low = CI$conf.int[1],
  CI.high = CI$conf.int[2]
)
close.table <- xtable(close.table,
                      caption = "One-Sided T-Test For Close Values",
                         label = "tab:closetest")
```

t	p	g	CI.low	CI.high
8.30	8.13e-09	1.61	0.12	0.20

Table 4: One-Sided T-Test For Close Values

   (b) "The far responses differed significantly from 0 ($p = 5.17 \times 10^{-8}$)."

```
### Part B: Far Responses ###
# Hedges G
x2 <- dat.fig2g$further_vals
g2 <- hedges_g(x = x2, mu = mu0, alternative = "less")
# T-test
far.stats <- t.test(x=x2, mu = mu0, conf.level = 0.95, alternative = "less") # one tailed t-te
CI2 <- t.test(x=x2, mu = mu0, conf.level = 0.95, alternative = "two.sided")
# Report Stats
far.table <- tibble(
  t = far.stats$statistic,
  p = formatC(far.stats$p.value, format = "e", digits = 2),
  g = g2$Hedges_g,
  CI.low = CI2$conf.int[1],
  CI.high = CI2$conf.int[2]
)
far.table <- xtable(far.table,
                      caption = "One-Sided T-Test For Farther Values",
                         label = "tab:fartest")
```

t	p	g	CI.low	CI.high
-7.78	2.59e-08	-1.51	-0.26	-0.15

Table 5: One-Sided T-Test For Farther Values

(c) "The difference between populations was significant ($p = 1.04 \times 10^{-8}$)."

```
### Part C: Difference ###
# Hedges G
x3 <- dat.fig2g$difference
g3 <- hedges_g(x = x3, mu = mu0, alternative = "two.sided")
# T-test
dif.stats <- t.test(x=x3, mu = mu0, conf.level = 0.95, alternative = "two.sided") # paired t-t
# Report Stats
dif.table <- tibble(
  t = dif.stats$statistic,
  p = formatC(dif.stats$p.value, format = "e", digits = 2),
  g = g3$Hedges_g,
  CI.low = dif.stats$conf.int[1],
  CI.high = dif.stats$conf.int[2],
)
dif.table <- xtable(dif.table,
                      caption = "Two-Tailed T-Test For Paired Difference",
                         label = "tab:diftest")
```

t	p	g	CI.low	CI.high
8.51	1.04e-08	1.65	0.27	0.45

Table 6: Two-Tailed T-Test For Paired Difference

5. Reverse engineer the hypothesis test plot from Lecture 20 to create accurate hypothesis testing plots for each part of the previous question.
   (a) Question 4, part(a).
   (b) Question 4, part(b).
   (c) Question 4, part(c).

References

Champely, S. (2020). *pwr: Basic Functions for Power Analysis*. R package version 1.3-0.

Kasdin, J., Duffy, A., Nadler, N., Raha, A., Fairhall, A. L., Stachenfeld, K. L., and Gadagkar, V. (2025). Natural behaviour is learned through dopamine-mediated reinforcement. *Nature*, pages 1–8.