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)

alpha = 0.05

pwr.testing <- pwr.t.test(d=0.65, sig.level = alpha, power = 0.80,
                          type = "one.sample", alternative = "two.sided")
(pwr.testing$n)

## [1] 20.58039
```

   Solution: The number of observations needed to achieve the defined parameters is $n = 20.58039$. To obtain this value of n, I used the `pwr.t.test()` function from the **pwr** package. I was able to plug in all the given parameters into this function to calculate the number of observations needed.

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`).

```
library(xtable)
library(tidyverse)

closer.vals <- read_csv("Closer_vals.csv")

farther.vals <- read_csv("Farther_vals.csv")

figure2G.data <- tibble(closer_vals = closer.vals$Closer_vals,
                        farther_vals = farther.vals$Farther_vals) |>
  mutate(difference = closer_vals - farther_vals)

xtable(figure2G.data)
```

   Information: This information was tablulated through the **R xtable** package.

observation	closer_vals	farther_vals	difference
1	0.28	-0.19	0.47
2	0.08	-0.03	0.11
3	0.13	-0.19	0.32
4	0.04	-0.07	0.11
5	0.15	-0.09	0.23
6	0.20	-0.16	0.36
7	0.16	-0.31	0.47
8	0.18	-0.16	0.34
9	0.13	-0.13	0.26
10	0.10	-0.05	0.15
11	0.33	-0.60	0.93
12	0.17	-0.24	0.41
13	0.07	-0.12	0.20
14	0.00	-0.13	0.13
15	0.00	-0.04	0.04
16	0.09	-0.24	0.33
17	0.26	-0.34	0.61
18	0.28	-0.31	0.59
19	0.07	-0.18	0.25
20	0.15	-0.07	0.23
21	0.27	-0.34	0.61
22	0.15	-0.19	0.34
23	0.10	-0.20	0.30
24	0.19	-0.31	0.50
25	0.34	-0.35	0.69

Table 1: Table of `closer_vals`, `farther_vals`, and `difference` for each observation.

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?

```
farther.summary <- summarize(figure2G.data,
                             mean = mean(farther_vals),
                             variance = var(farther_vals),
                             median = median(farther_vals),
                             IQR = IQR(farther_vals),
                             skew = skewness(farther_vals),
                             e.kurt = kurtosis(farther_vals),
                             min = min(farther_vals),
                             max = max(farther_vals))
xtable(farther.summary)
```

   As can be seen in Table 2, both the mean and median statistics are negative which suggests that as young zebra finches are further away from the adult songs they experience a decrease in dopamine levels. Both the minimum and maximum values being negative also suggests that in all cases young zebra finches experience a decrease in dopamine levels.

mean	variance	median	IQR	skew	e.kurt	min	max
-0.20	0.02	-0.19	0.19	-1.04	1.19	-0.60	-0.03

Table 2: Summary Statistics Regarding Farther Data.

(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?

```
closer.summary <- summarize(figure2G.data,
                             mean = mean(closer_vals),
                             variance = var(closer_vals),
                             median = median(closer_vals),
                             IQR = IQR(closer_vals),
                             skew = skewness(closer_vals),
                             e.kurt = kurtosis(closer_vals),
                             min = min(closer_vals),
                             max = max(closer_vals))
xtable(closer.summary)
```

As can be seen in Table 3, both the mean and median statistics are positive which suggests that as young zebra finches are closer to the adult songs they experience an increase in dopamine levels. The minimum and maximum values also supplement the idea that as young zebra finches sing closer to the adult songs they experience an increase in dopamine levels because both statistics are postive.

mean	variance	median	IQR	skew	e.kurt	min	max
0.16	0.01	0.15	0.11	0.30	-0.86	0.00	0.34

Table 3: Summary Statistics Regarding Closer Data.

(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?

```
difference.summary <- summarize(figure2G.data,
                             mean = mean(difference),
                             variance = var(difference),
                             median = median(difference),
                             IQR = IQR(difference),
                             skew = skewness(difference),
                             e.kurt = kurtosis(difference),
                             min = min(difference),
                             max = max(difference))
xtable(difference.summary)
```

mean	variance	median	IQR	skew	e.kurt	min	max
0.36	0.04	0.33	0.24	0.77	0.13	0.04	0.93

Table 4: Summary Statistics Regarding The Difference Between Closer Data and Farther Data.

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!

NOTE: To accomplish the tasks in part 4, we used the `hedges_g(), t.test(), and interpret_hedges_g()` from the `effectsize` (?)effectsize) package.

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

```r
mu0 <- 0
x.close <- figure2G.data$closer_vals

hedges_g(x = x.close, mu = mu0, alternative = "greater")
```

```
## Hedges' g |      95% CI
## ------------------------
## 1.61      | [1.10, Inf]
##
## - One-sided CIs: upper bound fixed at [Inf].
```

```r
interpret_hedges_g(1.61)
```

```
## [1] "large"
## (Rules: cohen1988)
```

```r
t.test(x = x.close, mu = mu0, alternative = "greater")
```

```
##
##  One Sample t-test
##
## data:  x.close
## t = 8.3024, df = 24, p-value = 8.132e-09
## alternative hypothesis: true mean is greater than 0
## 95 percent confidence interval:
##  0.1240301       Inf
## sample estimates:
## mean of x
## 0.1562231
```

```r
(CI.upper <- t.test(x = x.close,
                    mu = mu0,
                    alternative = "two.sided")$conf.int[2])
```

```
## [1] 0.1950586
```

Solution: ($t = 8.3024$, $p < 0.0001$; $g = 1.61$; 95% CI: 0.1240, 0.1951)

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

```r
mu0 <- 0
x.far <- figure2G.data$farther_vals

hedges_g(x = x.far, mu = mu0, alternative = "less")
```

```
## Hedges' g |        95% CI
## -------------------------
## -1.51     | [-Inf, -1.02]
##
## - One-sided CIs: lower bound fixed at [-Inf].
```

```r
interpret_hedges_g(-1.51)
```

```
## [1] "large"
## (Rules: cohen1988)
```

```r
t.test(x = x.far, mu = mu0, alternative = "less")
```

```
##
```

```
##  One Sample t-test
##
## data:  x.far
## t = -7.778, df = 24, p-value = 2.587e-08
## alternative hypothesis: true mean is less than 0
## 95 percent confidence interval:
##        -Inf -0.1581322
## sample estimates:
##  mean of x
## -0.2027244
```

```
(CI.lower <- t.test(x = x.far,
                    mu = mu0,
                    alternative = "two.sided")$conf.int[1])
```

```
## [1] -0.2565176
```

Solution: ($t = -7.778$, $p < 0.0001$; $g = -1.51$; 95% CI: -0.2565, -0.1581)

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

```
mu0 <- 0
x.difference <- figure2G.data$difference

hedges_g(x = x.difference, mu = mu0, alternative = "two.sided")
```

```
## Hedges' g |       95% CI
## ------------------------
## 1.65      | [1.04, 2.24]
```

```
interpret_hedges_g(1.65)
```

```
## [1] "large"
## (Rules: cohen1988)
```

```
t.test(x=x.difference, mu = mu0, alternative = "two.sided")
```

```
##
##  One Sample t-test
##
## data:  x.difference
## t = 8.5109, df = 24, p-value = 1.037e-08
## alternative hypothesis: true mean is not equal to 0
## 95 percent confidence interval:
##  0.2719028 0.4459921
## sample estimates:
## mean of x
## 0.3589475
```

Solution: ($t = 8.5109$, $p < 0.0001$; $g = 1.65$; 95% CI: 0.272, 0.446)

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).

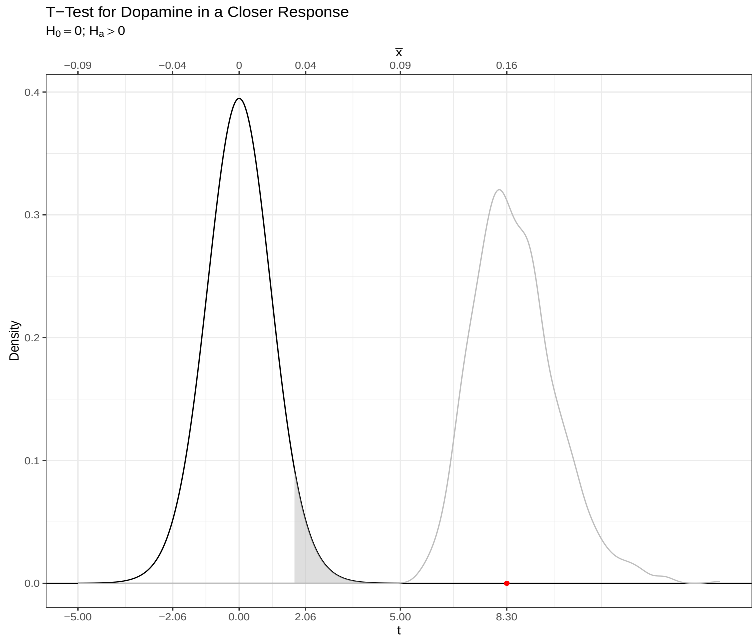

Figure 1: A figure for T-Test for Dopamine in a Closer Response.

(b) Question 4, part(b).

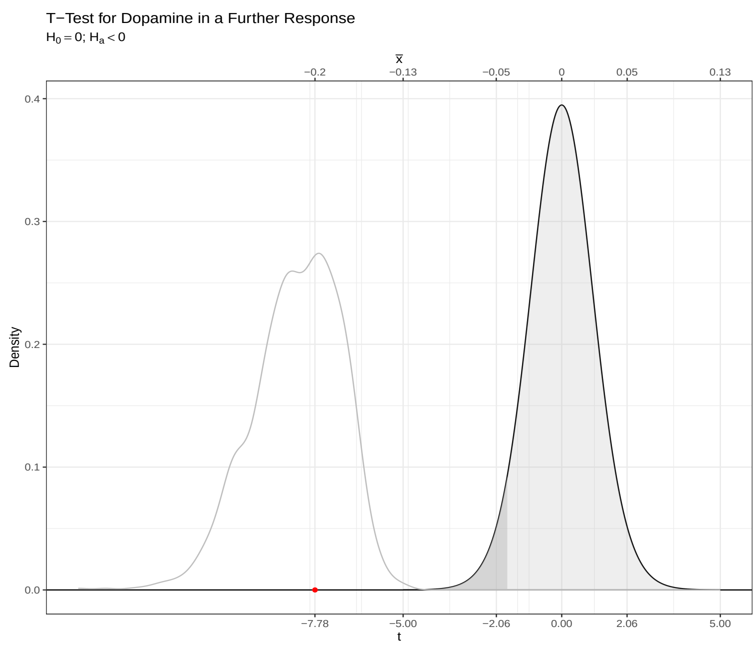

Figure 2: A figure for T-Test for Dopamine in a Further Response.

(c) Question 4, part(c).

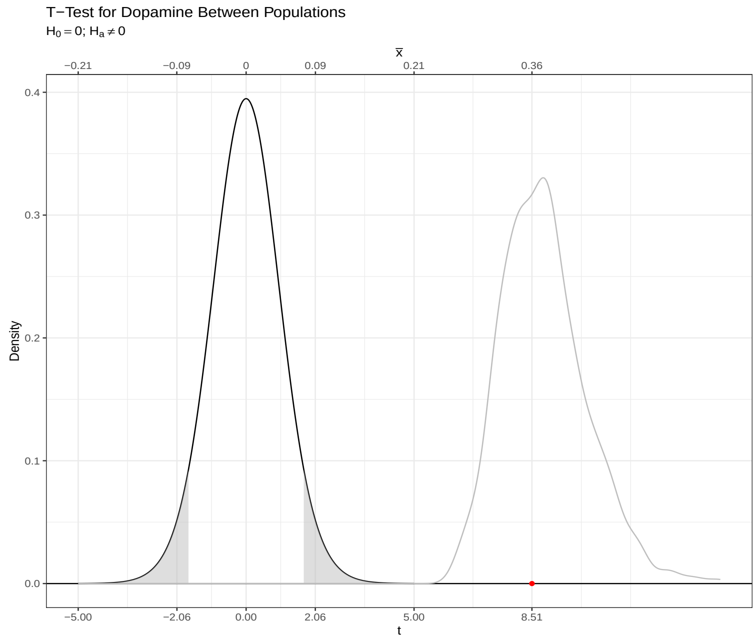

Figure 3: A figure for T-Test for Dopamine Between Populations.

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.