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.

```
power.test <- pwr.t.test(d = 0.65,
           sig.level = 0.05,
           power = 0.80,
           type = "one.sample",
           alternative = "two.sided")
(observations <- power.test[[1]])

## [1] 20.58039
```

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`).

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?
   Answer: Yes, looking at table 1, the dopamine levels decrease when the zebra finches sing further away from their adult song.

   (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?
   Answer: Yes, looking at table 1, the dopamine levels slightly increase when the zebra finches sing closer to their adult song.

   (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?
   Answer: Yes, looking at table 1, the dopamine levels increase more when the zebra finches sing closer to their adult song compared to when it is further away.

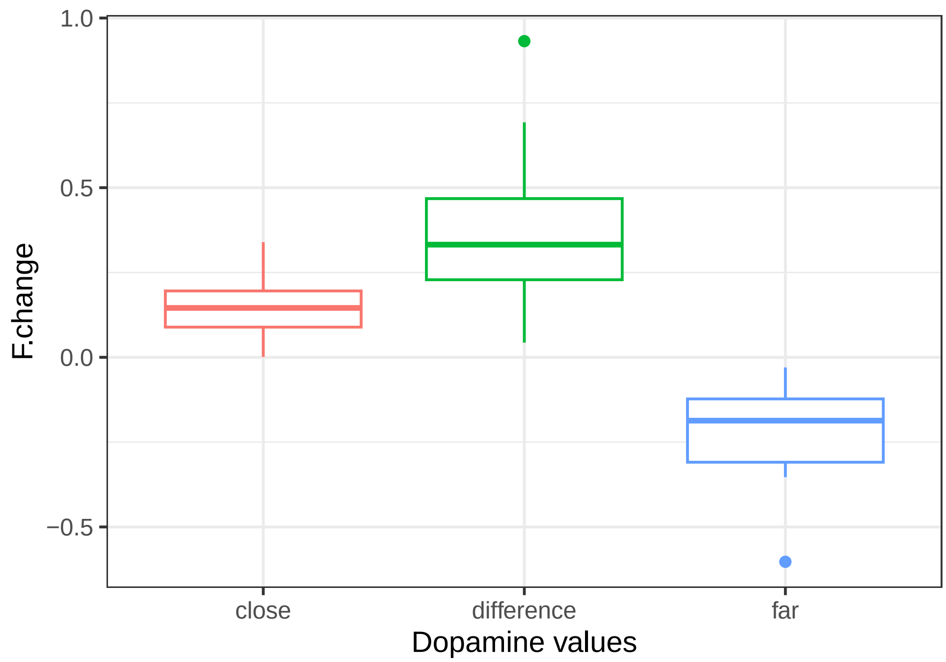


Figure 1: Graphical summary

	type	min	max	mean	sd	median	IQR	skewness	exkurtosis
1	far	-0.60	-0.03	-0.20	0.13	-0.19	0.19	-1.04	1.19
2	close	0.00	0.34	0.16	0.09	0.15	0.11	0.30	-0.86
3	difference	0.04	0.93	0.36	0.21	0.33	0.24	0.77	0.13

Table 1: Numerical summary

(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 ($p = 1.63 \times 10^{-8}$)."

```
closer.test <- t.test(x=close.set, mu = mu0)
t.close <- closer.test[[1]][[1]] #finding the t value
p.close <- closer.test[[3]] #finding the p value
g.close <- interpret_hedges_g(hedges_g(x = close.set, mu = mu0, alternative = "greater"))
```

For a right sided t-test, the close responses differed largely from 0 ($t = 8.30$, $p = 8.13 \times 10^{-9}$; $g = 1.61$; 95% CI: 0.117, 0.195).

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

```
farther.test <- t.test(x=far.set, mu = mu0)
t.far <- farther.test[[1]][[1]] #finding the t value
p.far <- farther.test[[3]] #finding the p value
g.far <- interpret_hedges_g(hedges_g(x = far.set, mu = mu0, alternative = "less"))
```

For a left sided t-test, the far responses differed largely from 0 ($t = -7.78$, $p = 2.59 \times 10^{-8}$; $g = -1.51$; 95% CI: -0.257, -0.149).

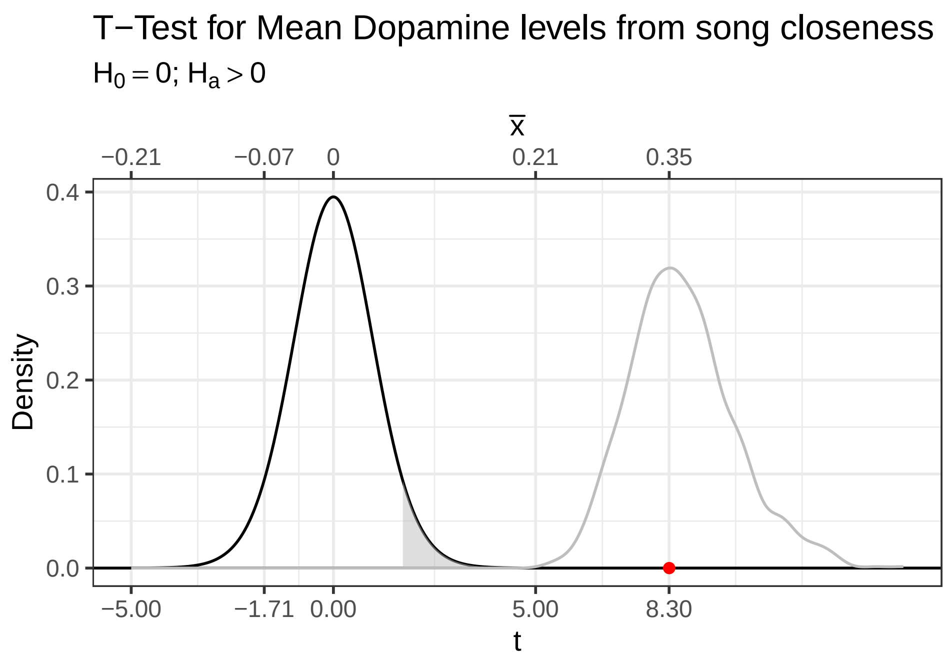
(c) "The difference between populations was significant ($p = 1.04 \times 10^{-8}$)."

```
difference.test <- t.test(x=difference.set, mu = mu0, alternative = "two.sided")
t.difference <- difference.test[[1]][[1]] #finding the t value
p.difference <- difference.test[[3]] #finding the p value
g.diff <- interpret_hedges_g(hedges_g(x = difference.set, mu = mu0, alternative = "two.sided"))
```

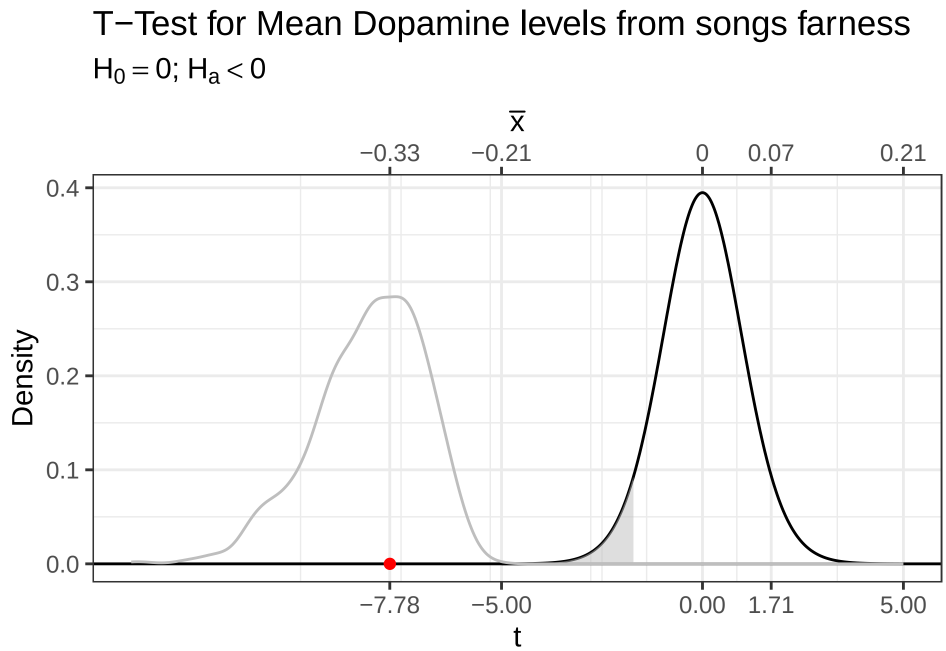
For a two-sided t-test, the difference between populations is significant ($t = 8.51$, $p = 1.04 \times 10^{-8}$; $g = 1.65$; 95% CI:0.272, 0.446).

5. Reverse engineer the hypothesis test plot from Lecture 20 to create accurate hypothesis testing plots for each part of the previous question.

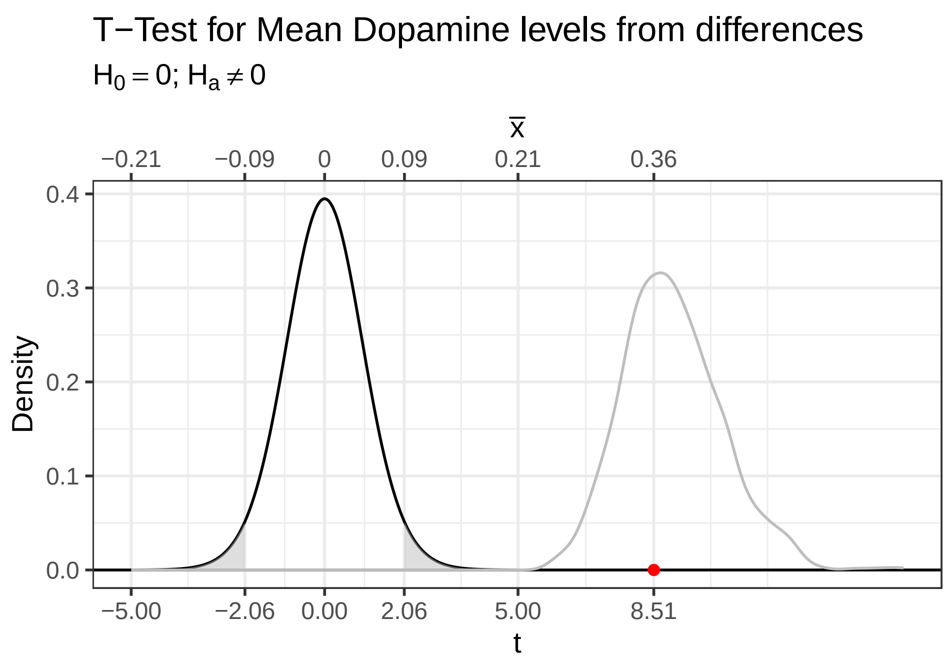
(a) Question 4, part(a).The t statistic is greater than the rejection zone, and the p-value is incredibly small, so the mean is probably not 0.



(b) Question 4, part(b). The t statistic is less than the rejection zone, and the p-value is incredibly small, so the mean is probably not 0.



(c) Question 4, part(c). The t statistic is not within the rejection zone, and the p-value is incredibly small, so the mean is probably not 0.



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.