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.

```
pwr.t.test(d = 0.65, # large effect
           power = 0.80,
           sig.level = 0.05,
           alternative = "two.sided",
           type = "one.sample")


##
##      One-sample t test power calculation
##
##               n = 20.58039
##               d = 0.65
##       sig.level = 0.05
##           power = 0.8
##     alternative = two.sided


n = 21
```

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`).

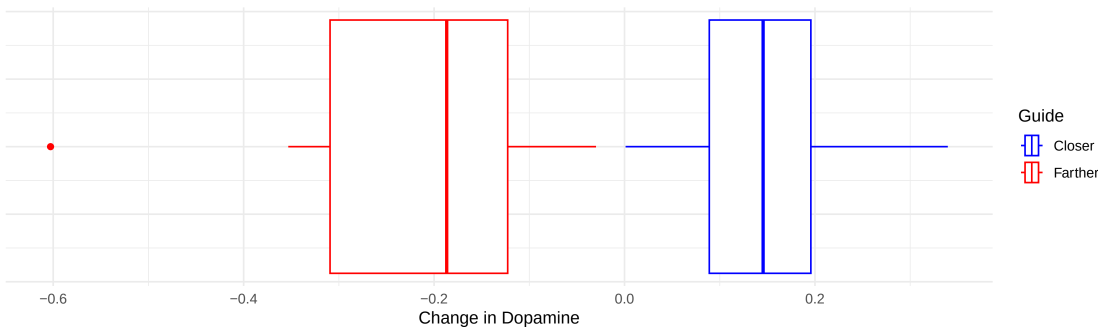
```
closer = read_csv("closer.csv") |>
  select(1)


## New names:
## Rows:  25 Columns:  5
## -- Column specification
## -------------------------------------------------------- Delimiter:  "," dbl
## (1):  Values lgl (4):  ...2, ...3, ...4, ...5
## i Use `spec()` to retrieve the full column specification for this data.  i
## Specify the column types or set `show_col_types = FALSE` to quiet this message.
## * `` -> `...2`
## * `` -> `...3`
## * `` -> `...4`
## * `` -> `...5`


farther = read_csv("farther.csv") |>
  select(1)


## New names:
## Rows:  25 Columns:  5
## -- Column specification
## -------------------------------------------------------- Delimiter:  "," dbl
## (1):  Values lgl (4):  ...2, ...3, ...4, ...5
## i Use `spec()` to retrieve the full column specification for this data.  i
## Specify the column types or set `show_col_types = FALSE` to quiet this message.
## * `` -> `...2`
## * `` -> `...3`
## * `` -> `...4`
## * `` -> `...5`


closer.v = closer$Values
farther.v = farther$Values

differences = c()
```

```
for(i in 1:length(closer.v)){
  differences[i] = closer.v[i] -farther.v[i]
}

data = tibble(closer = closer.v, farther = farther.v, difference = differences)
```

3. Summarize the data.

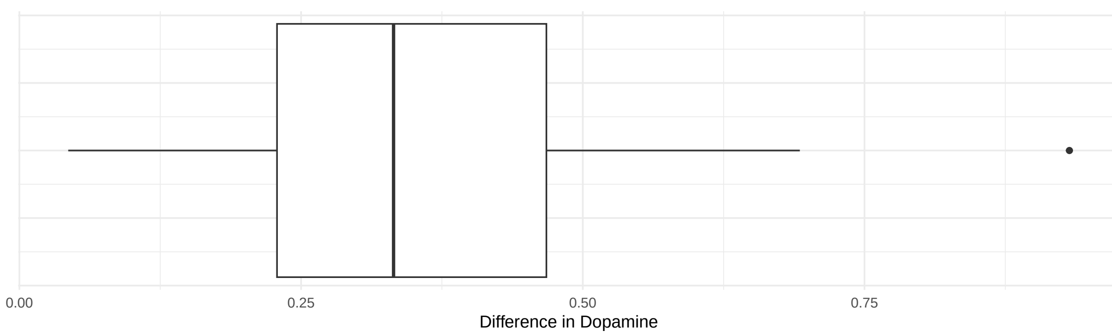
   (a) Summarize the further data. Do the data suggest that dopamine in the brains of young zebra finches decreases when they sing further away? The data suggests that it does decrease because as we can see in the red boxplot below almost all of the data is less than 0 showing that there was a decrease in dopamine for every bird.

   (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?



Similar to the far data, the close data shows that there is an increase in dopamine because every birds dopamine increased when they were closer.

   (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?



It suggests that there is a significant difference in the dopamine of their brains because all of the data is not near 0. This shows that there is a difference between the dopamine change when the birds are close and far is very significant.

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

```r
t.test(data$closer, alternative = "greater")
hedges_g(x = data$closer, alternative = "greater")
t.test(data$closer)

(t = 8.3024, p < 0.0001; g = 1.61; 95% CI: 0.1173875, 0.1950586)
```

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

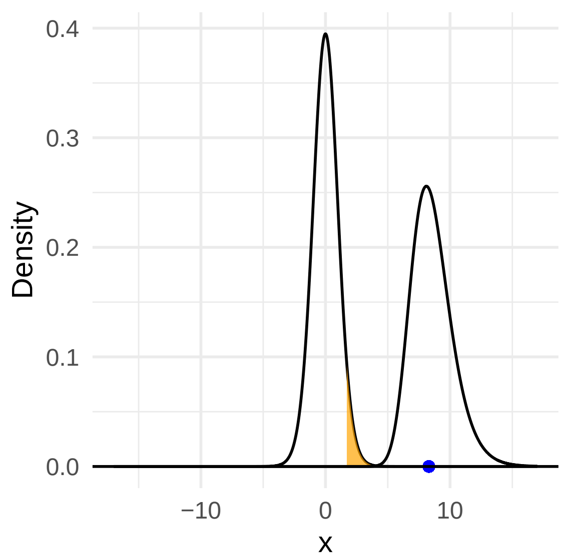
```r
t.test(data$farther, alternative = "less")
hedges_g(x = data$farther, alternative = "less")
t.test(data$farther)

(t = -7.778, p < 0.0001; g = -1.51; 95% CI: -0.2565176, -0.1489313)
```

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

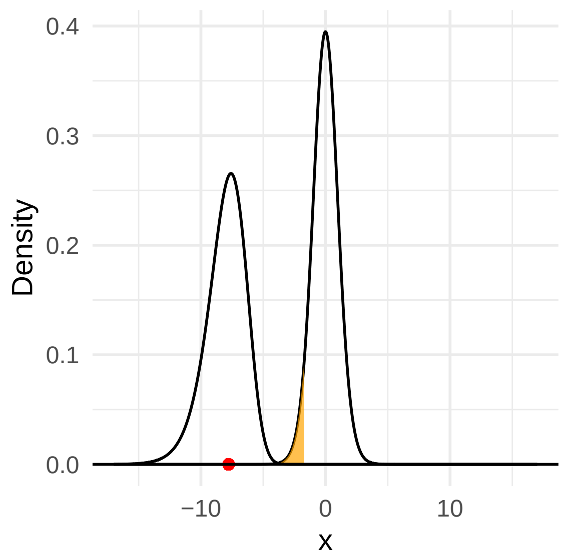
```r
t.test(data$difference)
hedges_g(x = data$difference)

(t = 8.5109, p < 0.0001; g = 1.65; 95% CI: 0.2719028, 0.4459921)
```

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

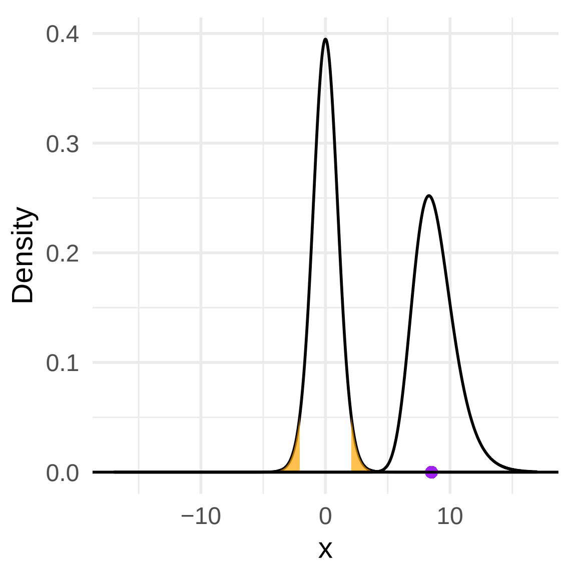
   (a) Question 4, part(a).



   (b) Question 4, part(b).



(c) Question 4, part(c).



This lab used the packages `tidyverse`, `pwr` and `effectsize` to calculate some of hte values above and organize the data (Wickham et al., 2019) (Champely, 2020) (Ben-Shachar et al., 2020).

References

Ben-Shachar, M. S., Lüdecke, D., and Makowski, D. (2020). effectsize: Estimation of effect size indices and standardized parameters. *Journal of Open Source Software*, 5(56):2815.

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.

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L. D., François, R., Grolemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., Pedersen, T. L., Miller, E., Bache, S. M., Müller, K., Ooms, J., Robinson, D., Seidel, D. P., Spinu, V., Takahashi, K., Vaughan, D., Wilke, C., Woo, K., and Yutani, H. (2019). Welcome to the tidyverse. *Journal of Open Source Software*, 4(43):1686.