

**LO 1.** Define the explanatory variable as the independent variable (predictor), and the response variable as the dependent variable (predicted).

**LO 2.** Plot the explanatory variable ( $x$ ) on the x-axis and the response variable ( $y$ ) on the y-axis, and fit a linear regression model

$$y = \beta_0 + \beta_1 x,$$

where  $\beta_0$  is the intercept, and  $\beta_1$  is the slope.

- Note that the point estimates (estimated from observed data) for  $\beta_0$  and  $\beta_1$  are  $b_0$  and  $b_1$ , respectively.

**LO 3.** When describing the association between two numerical variables, evaluate

- direction: positive ( $x \uparrow, y \uparrow$ ), negative ( $x \downarrow, y \uparrow$ )
- form: linear or not
- strength: determined by the scatter around the underlying relationship

**LO 4.** Define correlation as the linear association between two numerical variables.

- Note that a relationship that is nonlinear is simply called an association.

**LO 5.** Note that correlation coefficient ( $R$ , also called Pearson's  $R$ ) the following properties:

- the magnitude (absolute value) of the correlation coefficient measures the strength of the linear association between two numerical variables
- the sign of the correlation coefficient indicates the direction of association
- the correlation coefficient is always between -1 and 1, -1 indicating perfect negative linear association, +1 indicating perfect positive linear association, and 0 indicating no linear relationship
- the correlation coefficient is unitless
- since the correlation coefficient is unitless, it is not affected by changes in the center or scale of either variable (such as unit conversions)
- the correlation of X with Y is the same as of Y with X
- the correlation coefficient is sensitive to outliers

**LO 6.** Recall that correlation does not imply causation.

**LO 7.** Define residual ( $e$ ) as the difference between the observed ( $y$ ) and predicted ( $\hat{y}$ ) values of the response variable.

$$e_i = y_i - \hat{y}_i$$

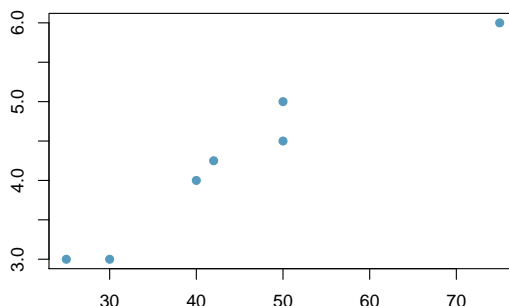
\* *Reading: Section 7.1 of OpenIntro Statistics*

\* *Videos:*

- *Review: Correlation vs. causation, YouTube (2:19)*
- *Intro to Linear Regression, YouTube (5:18) - very slow introduction to linear regression*

\* *Test yourself:*

1. Someone hands you the scatter diagram shown below, but has forgotten to label the axes. Can you calculate the correlation coefficient? Or do you need the labels?



2. A teaching assistant gives a quiz. There are 10 questions on the quiz and no partial credit is given. After grading the papers the TA writes down for each student the number of questions the student got right and the number wrong. What is the correlation of the number of questions right and wrong?

*Hint: Make up some data for number of questions right, calculate number of questions wrong, and plot them against each other.*

3. Suppose you fit a linear regression model predicting score on an exam from number of hours studied. Say you've studied for 4 hours. Would you prefer to be on the line, below the line, or above the line? What would the residual for your score be (0, negative, or positive)?

**LO 8.** Define the least squares line as the line that minimizes the sum of the squared residuals, and list conditions necessary for fitting such line:

- (1) linearity
- (2) nearly normal residuals
- (3) constant variability

**LO 9.** Define an indicator variable as a binary explanatory variable (with two levels).

**LO 10.** Calculate the estimate for the slope ( $b_1$ ) as

$$b_1 = R \frac{s_y}{s_x},$$

where  $R$  is the correlation coefficient,  $s_y$  is the standard deviation of the response variable, and  $s_x$  is the standard deviation of the explanatory variable.

**LO 11.** Interpret the slope as

- “For each unit increase in  $x$ , we would expect  $y$  to increase/decrease on average by  $|b_1|$  units” when  $x$  is numerical.
- “The average increase/decrease in the response variable when between the baseline level and the other level of the explanatory variable is  $|b_1|$ .” when  $x$  is categorical.
- Note that whether the response variable increases or decreases is determined by the sign of  $b_1$ .

**LO 12.** Note that the least squares line always passes through the average of the response and explanatory variables ( $\bar{x}, \bar{y}$ ).

**LO 13.** Use the above property to calculate the estimate for the slope ( $b_0$ ) as

$$b_0 = \bar{y} - b_1 \bar{x},$$

where  $b_1$  is the slope,  $\bar{y}$  is the average of the response variable, and  $\bar{x}$  is the average of explanatory variable.

**LO 14.** Interpret the intercept as

- “When  $x = 0$ , we would expect  $y$  to equal, on average,  $b_0$ .” when  $x$  is numerical.
- “The expected average value of the response variable for the reference level of the explanatory variable is  $b_0$ .” when  $x$  is categorical.

**LO 15.** Predict the value of the response variable for a given value of the explanatory variable,  $x^*$ , by plugging in  $x^*$  in the linear model:

$$\hat{y} = b_0 + b_1 x^*$$

- Only predict for values of  $x^*$  that are in the range of the observed data.
- Do not extrapolate beyond the range of the data, unless you are confident that the linear pattern continues.

**LO 16.** Define  $R^2$  as the percentage of the variability in the response variable explained by the explanatory variable.

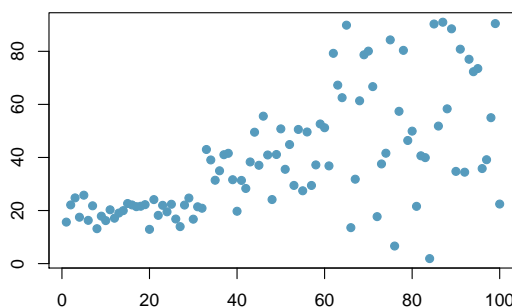
- For a good model, we would like this number to be as close to 100% as possible.
- This value is calculated as the square of the correlation coefficient.

\* *Reading: Section 7.2 of OpenIntro Statistics*

\* *Videos: To be posted*

\* *Test yourself:*

1. We would not want to fit a least squares line to the data shown in the scatterplot below. Which of the conditions does it appear to violate?



2. Derive the formula for  $b_0$  given the fact that the linear model is  $\hat{y} = b_0 + b_1 \times x$  and that the least squares line goes through  $(\bar{x}, \bar{y})$ .
3. One study on male college students found their average height to be 70 inches with a standard deviation of 2 inches. Their average weight was 140 pounds, with a standard deviation of 25 pounds. The correlation between their height and weight was 0.60. Assuming that the two variables are linearly associated, write the linear model for predicting weight from height.
4. Is a male who is 72 inches tall and who weighs 115 pounds on the line, below the line, or above the line?
5. Describe what is an indicator variable, and what levels 0 and 1 mean for such variables.

6. The model below predicts GPA based on an indicator variable (0: not premed, 1: premed). Interpret the intercept and slope estimates in context of the data.

$$\widehat{gpa} = 3.57 - 0.01 \times premed$$

7. If the correlation between two variables  $y$  and  $x$  is 0.6, what percent of the variability in  $y$  does  $x$  explain?

**LO 17.** Define a leverage point as a point that lies away from the center of the data in the horizontal direction.

**LO 18.** Define an influential point as a point that influences (changes) the slope of the regression line.

- This is usually a leverage point that is away from the trajectory of the rest of the data.

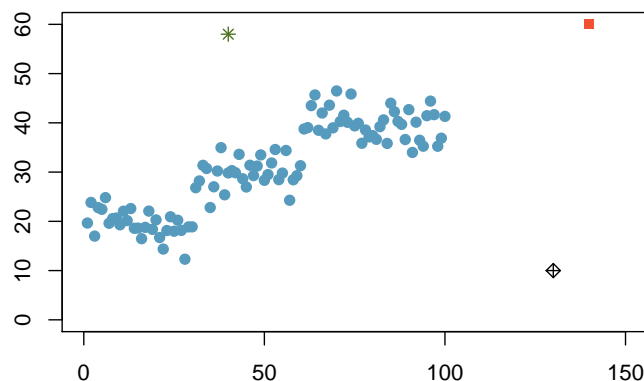
**LO 19.** Do not remove outliers from an analysis without good reason.

**LO 20.** Be cautious about using a categorical explanatory variable when one of the levels has very few observations, as these may act as influential points.

\* *Reading: Section 7.3 of OpenIntro Statistics*

\* *Videos: To be posted*

\* *Test yourself: Determine if each of the three unusual observations in the plot below would be considered just an outlier, a leverage point, or an influential point.*



**LO 21.** Determine whether an explanatory variable is a significant predictor for the response variable using the  $t$ -test and the associated p-value in the regression output.

**LO 22.** Set the null hypothesis testing for the significance of the predictor as  $H_0 : \beta_1 = 0$ , and recognize that the standard software output yields the p-value for the two-sided alternative hypothesis.

- Note that  $\beta_1 = 0$  means the regression line is horizontal, hence suggesting that there is no relationship between the explanatory and the response variables.

**LO 23.** Calculate the T score for the hypothesis test as

$$T_{df} = \frac{b_1 - \text{null value}}{SE_{b_1}}$$

with  $df = n - 2$ .

- Note that the T score has  $n - 2$  degrees of freedom since we lose one degree of freedom for each parameter we estimate, and in this case we estimate the intercept and the slope.

**LO 24.** Note that a hypothesis test for the intercept is often irrelevant since it's usually out of the range of the data, and hence it is usually an extrapolation.

**LO 25.** Calculate a confidence interval for the slope as

$$b_1 \pm t_{df}^* SE_{b_1},$$

where  $df = n - 2$  and  $t_{df}^*$  is the critical score associated with the given confidence level at the desired degrees of freedom.

- Note that the standard error of the slope estimate  $SE_{b_1}$  can be found on the regression output.

\* *Reading: Section 7.4 of OpenIntro Statistics*

\* *Videos: To be posted*

\* *Test yourself:*

1. Given the regression output below for predicting  $y$  from  $x$  where  $n = 100$ , confirm the  $T$  score and the  $p$ -value, determine whether  $x$  is a significant predictor of  $y$ , and interpret the  $p$ -value in context.

	Estimate	Std. Error	t value	Pr(> t )
(Intercept)	19.8581	6.1379	3.24	0.0017
$x$	0.2557	0.1055	2.42	0.0172

2. Calculate a 95% confidence interval for the slope given above.

**LO 26.** Calculate a confidence interval for the average (expected) value of the response variable,  $E(y)$ , for a given  $x^*$  (within the range of the observed data) as

$$\hat{y} \pm t_{n-2}^* s \sqrt{\frac{1}{n} + \frac{(x^* - \bar{x})^2}{\sum (x_i - \bar{x})^2}}$$

where  $s = \sqrt{MSE}$

**LO 27.** Calculate a prediction interval for the predicted value of the response variable,  $\hat{y}$ , for a given  $x^*$  (within the range of the observed data) as

$$\hat{y} \pm t_{n-2}^* s \sqrt{1 + \frac{1}{n} + \frac{(x^* - \bar{x})^2}{\sum (x_i - \bar{x})^2}}$$

where  $s = \sqrt{MSE}$

**LO 28.** A prediction interval is similar in spirit to a confidence interval, except that the prediction interval is designed to cover a “moving target”, the random future value of  $y$ , while the confidence interval is designed to cover the “fixed target”, the average (expected) value of  $y$ ,  $E(y)$ , for a given  $x^*$ .

**LO 29.** Although both are centered at  $\hat{y}$ , the prediction interval is wider than the confidence interval, for a given  $x^*$  and confidence level. This makes sense, since the prediction interval must take account of the tendency of  $y$  to fluctuate from its mean value, while the confidence interval simply needs to account for the uncertainty in estimating the mean value.

**LO 30.** For a given data set, the error in estimating  $E(y)$  and  $\hat{y}$  grows as  $x^*$  moves away from  $\bar{x}$ . Thus, the further  $x^*$  is from  $\bar{x}$ , the wider the confidence and prediction intervals will be.

\* *Video: Prediction and confidence intervals - Dr. Çetinkaya-Rundel, YouTube (10:17)*

- \* *Test yourself: Describe why prediction intervals are wider than confidence intervals, and why both get wider as we move away from the center of the data.*