

Biost 517

Applied Biostatistics I

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Lecture 7: Bivariate Descriptive Statistics

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Lecture Outline

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- Review of univariate descriptive statistics
- Purpose of bivariate descriptive statistics
- Stratified univariate descriptives
- Graphical
 - Stratified histograms, densities, boxplots
 - Scatterplots, least squares lines, smooths
- Correlation

Review of Univariate Descriptive Statistics

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	Binary	Unordered	Ordered		
		Nominal	Categ	Quant	Cens
Distribution					
Frequency	OK	OK	OK	OK	
Cum Freq	boring		OK	OK	KM
Mode	boring	Sample	Sample	Density	
Quantiles	boring		OK	OK	KM
Dichotomize Prop / Odds	OK	OK	OK	OK	KM
Means					
Arithmetic	Prop		***	OK	(?KM)
Geometric				OK	
Std Dev	boring			OK	
Others				OK	

Purpose of Bivariate Descriptive Statistics

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Purpose of Bivariate Description

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- Characterize the relationship between two variables
 - Detecting errors in data collection or data entry
 - Characterizing materials and methods
 - Assessing validity of assumptions
 - Basis for some estimates of association (inference)
 - Hypothesis generation (exploration/inference)

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Detecting Errors

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- Sometimes data measurements are not unusual univariately, but are unusual in combination
 - E.g., 6 foot tall 3 year olds
 - E.g., pregnant males
- Patterns may exist in missing data
 - Minorities may be more likely to be missing data on some medical procedures

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Materials and Methods

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- Describe patterns of sampling
 - E.g., minorities may tend to be younger
 - E.g., older subjects may tend to be women
 - E.g., smokers may tend to drink alcohol more

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Validity of Assumptions

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- Scientific
 - Confounding (ultimately involves 3 variables)
 - Effect modification (involves 3 variables)
- Statistical
 - E.g., assumptions about within group variance
 - E.g., assumptions about linearity of trends
 - E.g., influence of “outliers”

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Evidence of Associations

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- Two variables are said to be associated if the distribution of one variable differs across groups defined by the other variable
 - E.g., if interested in determining whether sex and blood pressure are associated, see if
 - distribution of blood pressure differs between men and women, OR
 - proportion of men varies across groups defined by blood pressure measurements

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Quantify Associations

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- Describe “dose-response”
 - How the effect differs across groups having ever larger differences in the grouping variable
 - E.g., linear response
 - E.g., S-shaped curves
 - E.g., U-shaped trends

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Hypothesis Generation

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- Examine sample to detect associations not previously considered
 - Any such associations suggested by the data should be confirmed in an independent sample

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Stratified Univariate Descriptive Statistics

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Stratified Univariate Descriptives

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- Strata defined by one variable
 - Continuous variables must be divided into categories
- Methods of dividing into categories
 - Scientific basis: Intervals with scientific meaning
 - Statistical basis: Intervals with equal sample sizes
 - Generally such intervals are not evenly spaced, thus detecting linear trends are difficult

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Examining Stratified Descriptives

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- Errors in data:
 - Unusual range by strata
- Materials and methods:
 - Describe central tendency, range by strata
- Validity of assumptions:
 - E.g., missing data by strata
 - E.g., equal variances across strata
 - E.g., linear trends in central tendency
- Evidence of associations:
 - E.g., difference in means, medians across strata

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Choice of Stratified Descriptives

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- By purpose of descriptives
 - Ability to assess errors
 - Ability to describe sample
 - Ability to examine validity of assumptions
 - Scientific relevance as estimates of association
- By type of data
 - Unordered versus ordered
 - Continuous versus discrete
 - Uncensored versus censored

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FEV Ex: Categorizing Age

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- Stata: Create variable containing age categories in two year intervals

```
-g agectg = age
-recode agectg 3/4=3 5/6=5 7/8=7
9/10=9 11/12=11 13/14=13 15/16=15
17/18=17 19/20=19
```

- Alternative approach using arithmetic

```
•g agectg = int ( (age-1) / 2) * 2 + 1
```

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FEV Ex: Stata Commands

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- Stata: Create table of stratified statistics

```
-by agectg: tabstat height, stat(n
mean sd min p25 p50 p75 max)
col(stat) format
```

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FEV Ex: Height by Age Groups

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<u>agectg</u>	<u>N</u>	<u>mean</u>	<u>sd</u>	<u>min</u>	<u>p25</u>	<u>p50</u>	<u>p75</u>	<u>max</u>
3	11.0	48.8	1.8	46.0	48.0	48.0	50.0	52.0
5	65.0	52.5	2.4	46.5	51.0	52.5	54.0	58.0
7	139.0	57.1	3.3	47.0	54.5	57.0	59.5	67.5
9	175.0	61.5	3.3	52.5	59.0	61.0	64.0	70.0
11	147.0	64.7	3.3	57.0	62.0	64.5	67.0	72.0
13	68.0	66.7	3.5	61.0	63.8	67.0	69.0	74.0
15	32.0	66.8	3.4	60.0	64.0	66.8	69.3	73.5
17	14.0	67.7	3.6	60.0	66.0	68.5	70.0	73.0
19	3.0	67.8	3.6	65.5	65.5	66.0	72.0	72.0
Total	654.0	61.1	5.7	46.0	57.0	61.5	65.5	74.0

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FEV Ex: Findings

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- Mean, median height within age strata increases by about 4 inches every two years up until about age 12 then levels off
- Standard deviation of height within age strata much less than standard deviation of entire sample
 - An indication that age predicts height
- Standard deviation of height within age strata increases as the mean increases

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Mean-Variance Relationships

- We often see the variance differ systematically according to group means
 - Differential diagnosis
 - Precision of measurement as a percentage
 - Variability in rates, but measurement of total
 - E.g., different growth per year, height at age 10
 - Confounding
 - E.g., more older kids smoke, which stunts growth?
 - Effect modification
 - E.g, young boys and girls tend to be same height, older boys taller than older girls

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FEV Ex: Age Quantiles

- Stata: Find age quantiles

```
- centile age,c(12 25 37 50 62 75 87)
```

Variable	Obs	Pctile	Centile	[95% Conf. Interval]	
age	654	12	7.0	6.0	7.0
		25	8.0	8.0	8.0
		37	9.0	9.0	9.0
		50	10.0	9.0	10.0
		62	11.0	10.0	11.0
		75	12.0	11.0	12.0
		87	13.0	13.0	14.0

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FEV Ex: Categories by Quantiles

- Stata: Create variable of age categories
 - g agectg=age
 - recode agectg min/7=1 8=2 9=3 10=4 11=5 12=6 13=7 14/max=8
 - tabstat fev, stat(n mean sd min p25 p50 p75 max) col(stat) format by(agectg)

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FEV Ex: Height by Age Octiles

agectg	N	mean	sd	min	p25	p50	p75	max
1	130.0	53.4	3.1	46.0	51.0	53.0	55.5	62.5
2	85.0	58.3	3.2	52.0	56.5	58.5	60.0	67.5
3	94.0	60.6	2.9	53.0	58.5	60.3	62.5	69.0
4	81.0	62.5	3.4	52.5	60.0	62.0	65.0	70.0
5	90.0	64.5	3.2	58.0	62.0	64.5	67.0	72.0
6	57.0	65.2	3.5	57.0	63.0	64.5	68.0	72.0
7	43.0	66.2	3.6	61.0	63.0	66.5	68.5	74.0
8	74.0	67.2	3.4	60.0	64.5	67.0	70.0	73.5
Total	654.0	61.1	5.7	46.0	57.0	61.5	65.5	74.0

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FEV Ex: Findings with Quantiles

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- We were less able to pick out the regions of linearity
 - The lowest octile covered several years, the next few octiles were each 1 year in width
- We were not able to pick out the mean variance relationship
 - The first octile was not as homogeneous with respect to age, and height varied with age within that stratum

Crosstabulation of Categories

.....

- tabulate smoker female, cell column row

smoker	female		Total
	0	1	
	310	279	589
	52.63	47.37	100.00
	92.26	87.74	90.06
0	47.40	42.66	90.06
	26	39	65
	40.00	60.00	100.00
	7.74	12.26	9.94
1	3.98	5.96	9.94
Total	336	318	654
	51.38	48.62	100.00
	100.00	100.00	100.00
	51.38	48.62	100.00

Graphical Bivariate Descriptive Statistics

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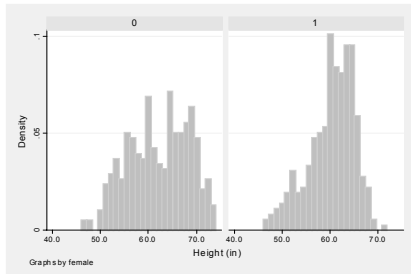
Stratified Univariate Graphs

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- Divide sample into strata based on one variable
- Display for each stratum
 - histograms
 - densities
 - boxplots
- For greatest comparability, the same axes should be used in all plots

Ex: Stratified Histograms

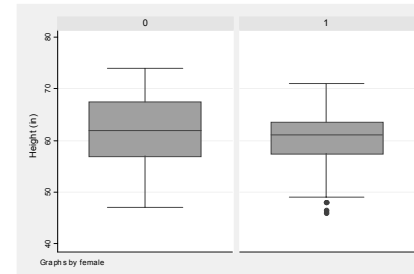
- FEV data: Histograms of height by sex
 - hist height, by(female)
xtitle("Height (in)")



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Ex: Stratified Boxplots

- FEV data: Boxplots of height by sex
 - graph box height, by(female)
ytitle("Height (in)")



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Ex: Stratified Univariate Stats

- FEV data: Univariate description of height by sex
 - tabstat height, by(female) stat(n mean sd min p25 p50 p75 max)
col(stat) format

female	N	mean	sd	min	p25	p50	p75	max
0	336.0	62.0	6.3	47.0	57.0	62.0	67.5	74.0
1	318.0	60.2	4.8	46.0	57.5	61.0	63.5	71.0
Total	654.0	61.1	5.7	46.0	57.0	61.5	65.5	74.0

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Scatterplots

- A graph of Y versus X
 - Most useful for two continuous variables
- Look for
 - Outliers
 - Trends in location across groups
 - First order trends (linear)
 - Second order trends (curves, U-shape, S-shape)
 - Trends in within group spread of data
 - (Looking at range)

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Stata: Scatterplot

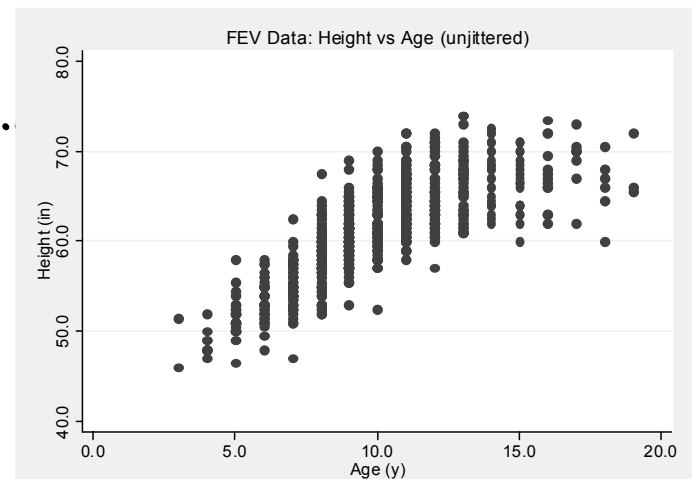
- Stata commands

- “scatter yvar xvar, [options]”

- Example: Height vs Age in FEV Data

```
scatter height age, xtitle("Age (y)")
t1("FEV Data: Height vs Age (unjittered)")
ytitle("Height (in)")
```

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Ex: Interpretation

- No outliers
- Tends to increased height for older ages
 - First order trend is upward
- Hint of curvilinear relationship
 - Height levels off at highest ages
- Suggestion of increasing spread with increased height
 - Must be careful when judging variability from range
 - Need to compare range of equal numbers of data in area with equal slopes

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Jittered Scatterplots

- If variables are discretely measured, jittering can be helpful
 - “jittering”: adding a little noise to the data to break ties
 - I tend to try to jitter to allow visualization of all points, but still try to keep discrete levels separate use a spread of about 40% the separation between categories

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Stata: Jittering

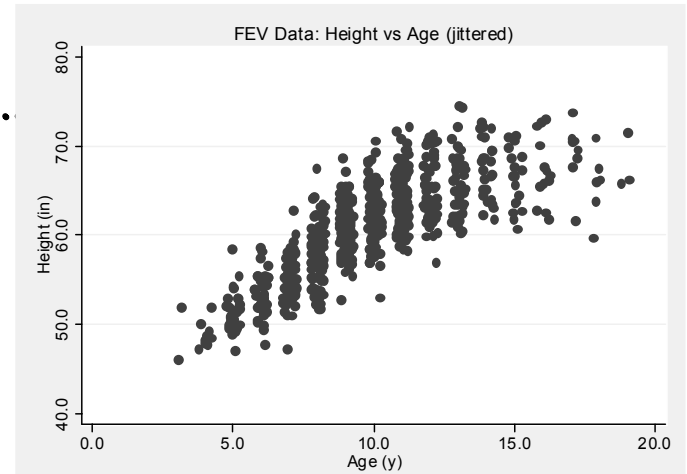
- Stata commands

- `“scatter yvar xvar, jitter(n)”`

- Example: Height vs Age in FEV Data

```
scatter height age, xtitle("Age (y)")
t1("FEV Data: Height vs Age (jittered)")
ytitle("Height (in)") jitter(3)
```

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Variance Within Groups

- On a scatterplot, our eye sees range of data within groups
- We usually want to judge variance
 - Especially how variance might differ with X
- Converting range to variance
 - Consider spread in two regions far apart
 - Need sample sizes approximately equal
 - Need slopes approximately equal

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Superimposed Curves

- It is often helpful to place curves over a scatterplot to help see trends in the data
 - Theoretical relationship
 - If theory prescribes a supposed relationship
 - Least squares line of within group means
 - “Best fitting” line to means, but has to be a line
 - Smooths of measure of location within groups
 - Curve representing approximation to the data
 - E.g., lowess

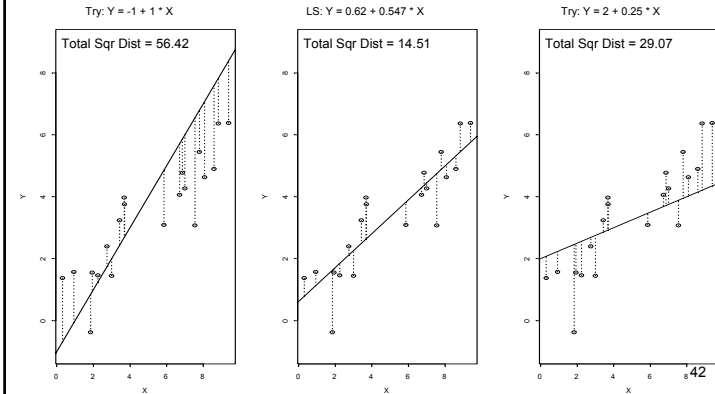
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Least Squares Line

- Find the straight line that minimizes total squared vertical distance from data to line
 - Conceptually: Trial and error search
 - Guess a formula for a line
 - Compute total squared distance from data to line
 - Iterate until smallest number found
 - Calculus:
 - Find a formula based on derivatives
 - Real life:
 - Computers find such estimates easily

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Conceptual Example



Stata: Superimposed Lines

- Basic Stata bivariate graph command
 - “`twoway ...`”
 - Special cases
 - “`twoway scatter ...`” (scatterplot of points)
 - “`twoway line ...`” (connect with lines)
 - “`twoway lfit ...`” (least squares fit)
 - “`twoway lowess ...`” (lowess curve)
- Superimposed graphs
 - `twoway (graphtyp ...) (graphtyp ...) ...`

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Ex: Height vs Age with LS Fit

- Stata commands


```
twoway (scatter height age, jitter(3))
      (lfit height age), xtitle("Age (y)")
      ytitle("Height (in)")
      t1("Least Squares Fit of Height on Age")
```

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Ex: Height vs Age with LS Fit



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Interpretation

- Clearly increasing trend in data
- Our eye tends to like to detect lines, so it takes careful inspection to decide a line is not the best fit
 - Note that at lowest ages and highest ages most data tend to be on one side of line rather than symmetric about line
 - Possible curvilinear association

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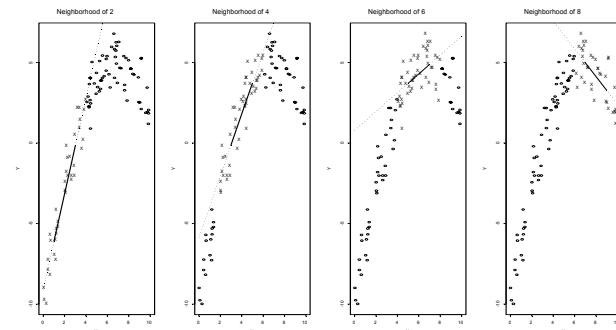
Lowess Smooths

- Locally Weighted Scatterplot Smoother
 - A smoother to find a smooth curve approximating relationship in the data
 - For every value of X, fits straight lines in a neighborhood of that value
 - “Bandwidth” is width of window defining neighborhood
 - Weights closer data more heavily
 - Combines the estimates from different regions to form a smooth curve

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Lowess: Conceptual Algorithm

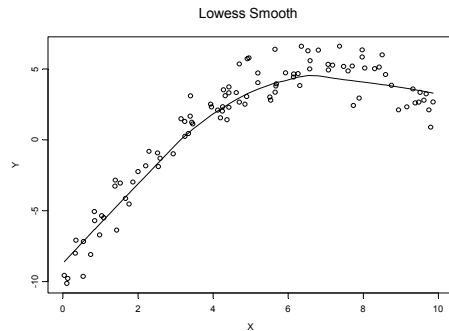
- Least squares lines fit in neighborhoods



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Lowess Smooth

- Combines locally fit least squares lines



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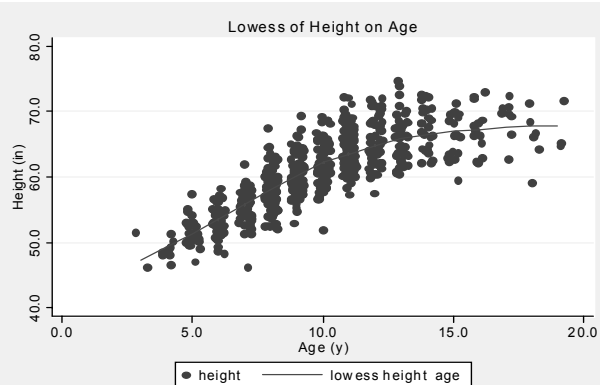
Ex: Height vs Age with Lowess

- Stata commands

```
twoway (scatter height age, jitter(3))
(lowess height age),
xtitle("Age (y)") ytitle("Height (in)")
t1("Lowess of Height on Age")
```

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Ex: Height vs Age with Lowess



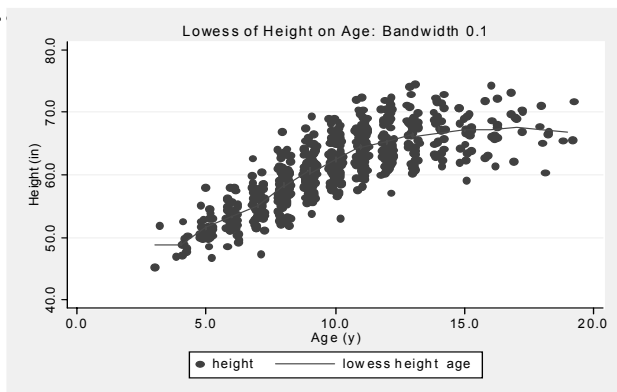
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Changing the Bandwidth

- Default bandwidth is 0.8 (80% of data)
 - I typically use the default of whatever program I am using
 - Stata commands for less smoothing
- ```
twoway (scatter height age, jitter(3))
(lowess height age, bwidth(.1)),
xtitle("Age (y)") ytitle("Height (in)")
t1("Lowess of Height on Age: Bandwidth 0.1")
```

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## Changing the Bandwidth



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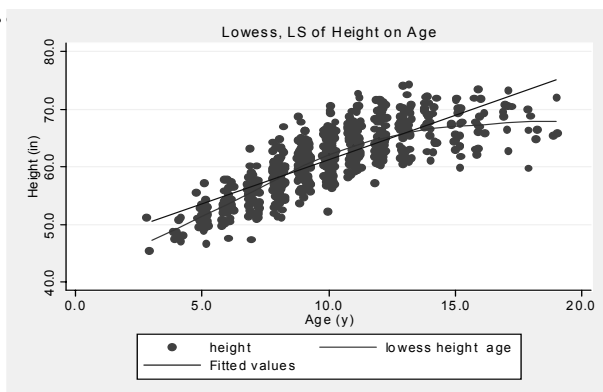
## Ex: Showing Both LS, Lowess

### • Stata commands

```
twoway (scatter height age, jitter(3))
(lowess height age, col("red"))
(lfit height age, col("blue"),
xtitle("Age (y)") ytitle("Height (in)")
t1("Lowess, LS of Height on Age"))
```

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## Ex: Showing Both LS, Lowess



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## Interpretation

- Lowess smooth shows that height tends to increase pretty linearly with age up until about age 11 or 12
- Height levels off in late teens with little change in mean height

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## Other Smoothers

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- Many different methods of smoothing data have been proposed
  - Lowess is often criticized due to the way it can accentuate data near the end of its range
    - One should not make too much of the way the estimate curve wiggles at the extremes of the data
  - For my purposes, almost any smoother will do
    - I just want to have something that is not forced to be a line, and something that I did not draw
      - I can be just as biased as anyone

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## Correlation

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## Correlation Coefficient

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- A measure of the tendency of the largest measurements for one variable to be associated with the largest measurements of the other variable
  - Dimensionless
  - The sample correlation  $r$  estimates the population correlation  $\rho$  (rho)

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## Pearson's Correlation Coefficient

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- Definition of correlation between  $X$  and  $Y$ :

$$\begin{aligned} r &= \frac{\text{Cov}(X, Y)}{\sqrt{\text{Var}(X) \text{Var}(Y)}} = \frac{\sum_{i=1}^n (X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^n (X_i - \bar{X})^2} \sqrt{\sum_{i=1}^n (Y_i - \bar{Y})^2}} \\ &= \frac{\sum_{i=1}^n X_i Y_i - n\bar{X}\bar{Y}}{\sqrt{\sum_{i=1}^n X_i^2 - n\bar{X}^2} \sqrt{\sum_{i=1}^n Y_i^2 - n\bar{Y}^2}} \end{aligned}$$

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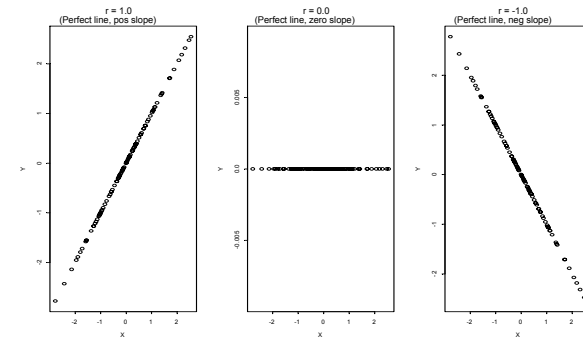
## Possible Values of r

- Range of r :  $-1 \leq r \leq 1$ 
  - $r = 1$  : perfect positive correlation
    - a graph of X vs Y will be a straight line with positive slope
  - $r = -1$  : perfect negative correlation
    - a graph of X vs Y will be a straight line with negative slope
  - $r = 0$  : no correlation

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## Straight Line Relationships

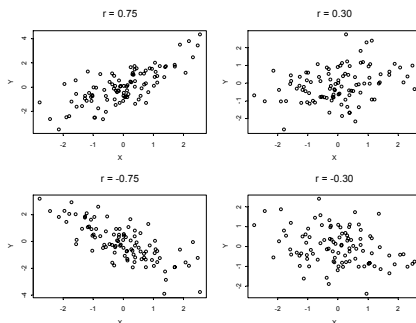
- Pearson's correlation coefficient with linear data



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## Linear Trends in Data

- Pearson's correlation coefficient with variable data



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## Correlation and Independence

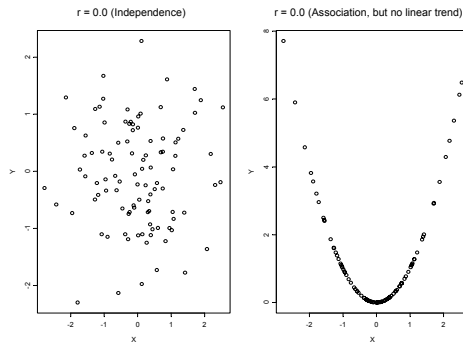
- Independent variables will have  $\rho = 0$ 
  - (and r tending to be close to 0)
- However, uncorrelated variables are not necessarily independent
  - Correlation measures linear trend in the mean of one variable in groups defined by the other
  - It is possible that a nonlinear association exists between two variables, and that the first order trend is a zero slope

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## Uncorrelated Variables

- No linear trend between the variables



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## Stata Commands

- "correlate varlist"
  - Correlation of all pairs of variables
  - Missing data deleted on a casewise basis
- "pwcorr varlist"
  - Correlation of all pairs of variables
  - Missing data deleted on a pairwise basis

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## Ex: Correlation in FEV Data

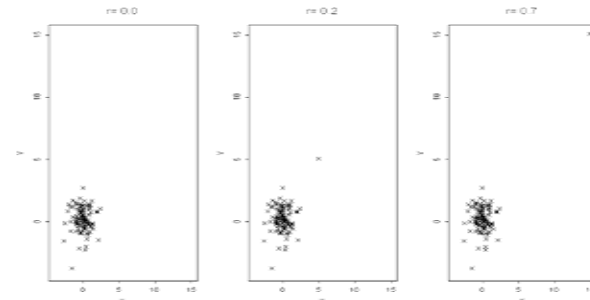
```
. corr subjid age fev height sex smoke
(obs=654)
+-----+-----+
| subjid age fev height sex smoke
+-----+-----+
subjid | 1.0000
age |-0.0112 1.0000
fev |-0.0147 0.7565 1.0000
height |-0.0317 0.7919 0.8681 1.0000
sex | 0.0407 -0.0291 -0.2084 -0.1590 1.0000
smoke |-0.0601 -0.4043 -0.2454 -0.2804 -0.0756 1.0000
```

- Some of these correlations don't make much sense
  - subjid is a nominal variable
  - sex, smoke are binary variables

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## Effect of Outliers on r

- Pearson's correlation coefficient can be greatly affected by outliers



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## Spearman's Rank Correlation

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- To decrease the influence of outliers, Spearman's rank correlation coefficient computes the correlation of the ranks of the data

– In the previous example, the rank correlation is always the same: approximately 0.07

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## Stata: Spearman's Correlation

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– “`spearman var1 var2`”

- Correlation of one pair of variables
- Cases with missing data for either variable are deleted, and then ranks are computed

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## Ex: Correlation in PSA Data

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```
corr nadir pretx
```

```
(obs=43)
```

```
-----+-----
nadir| nadir pretx
-----+-----
nadir| 1.0000
pretx| 0.5371 1.0000
```

```
spearman nadir pretx
```

```
Number of obs = 43
```

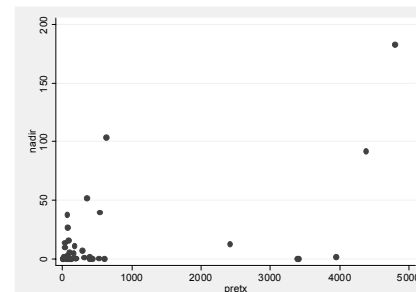
```
Spearman's rho = 0.1489
```

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## Ex: Nadir vs Pretreatment PSA

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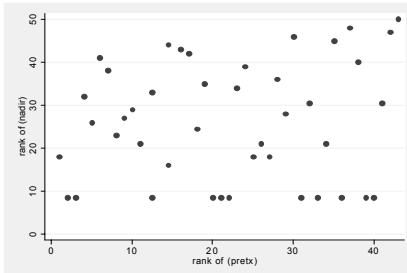
- Scatterplot of nadir versus pretx  
– `scatter nadir pretx`



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## Ex: Nadir vs Pretx Ranks

- `egen mnknadir = rank(nadir)`
- `egen mknpretx = rank(pretx)`
- `scatter mnknadir mknpretx`



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## Ex: Spearman's Corr vs r

- Possible explanation for lower rank correlation with Spearman's
  - Perhaps outliers in distribution of nadir and/or pretx unduly inflate  $r$
  - Perhaps transforming to ranks masks true linear association in skewed variables

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## Uses of Correlation

- By type of variable
  - Correlation is a mean, thus only makes sense when a mean does
    - Limited interpretability with categorical data
    - Of no scientific relevance with censored data
- By scientific question
  - Greatest relevance when looking for associations between variables
    - But not particularly generalizable across studies

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## Correlation and Regression

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## More Interpretable Formula for r

$$r \approx \beta \sqrt{\frac{\text{Var}(X)}{\beta^2 \text{Var}(X) + \text{Var}(Y | X = x)}}$$

$\beta$  = (LS) slope between Y and X

$\text{Var}(X)$  = variance of X in sample

$\text{Var}(Y | X = x)$  = variance of Y in groups that have same value of X

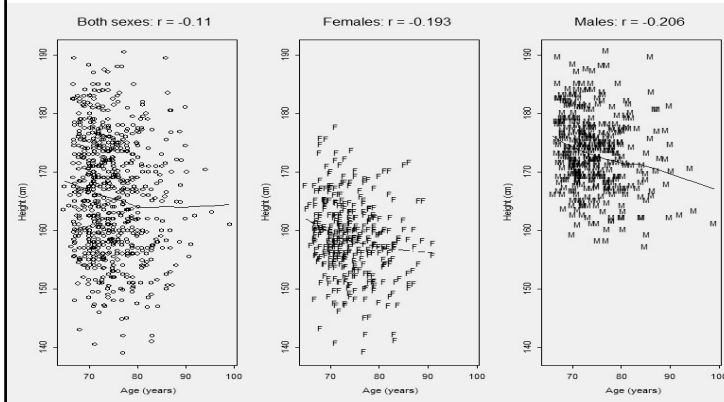
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## Properties of Correlation

- Correlation tends to increase in absolute value as
  - The absolute value of the slope of the line increases
  - The variance of data decreases within groups that share a common value of X
  - The variance of X increases
  - (Sample size is unimportant in tendencies toward lower or higher correlation)

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## Ex: Height vs Age (by Sex)

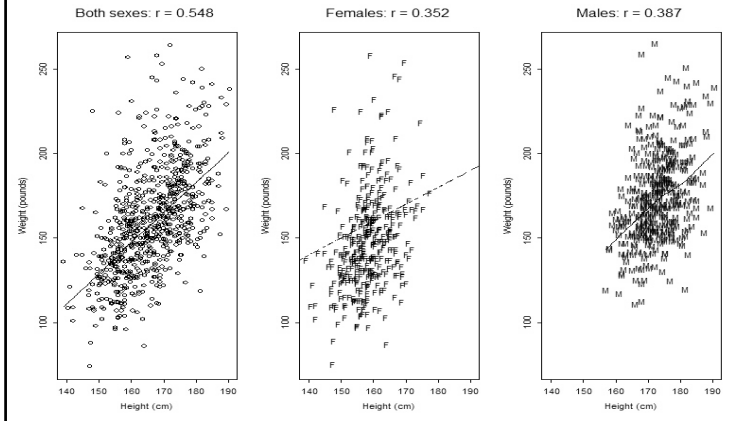


## Ex: Height vs Age (by Sex)

- Correlation between Height and Age
  - Males:  $r = -0.206$ ; Females:  $r = -0.193$
  - Combined:  $r = -0.110$
- Less extreme r in combined sexes
  - Approximately same slope in each sex and overall
  - Approximately same variance of age in each sex and overall
  - Combined group has higher within group variance of height by age (due to sex effect)

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## Ex: Weight vs Height (by Sex)



## Ex: Weight vs Height (by Sex)

- Correlation between Height and Weight
  - Males:  $r = .387$ ; Females:  $r = 0.352$
  - Combined:  $r = 0.548$
- More extreme  $r$  in combined sexes
  - Approximately same slope in each sex and overall
  - Approximately same within group variance (by height) for each sex and overall
  - Combined group has higher variance of height

## Scientific Relevance of $r$

- Correlation as a scientific measure
  - It should be noted that
    - the slope between  $X$  and  $Y$  is of scientific interest
    - the variance of  $Y|X=x$  is partly of scientific interest, but it can be affected by restricting sampling to certain values of another variable
      - E.g.,  $\text{var}(\text{Height} | \text{Age})$  is less in males than when both sexes are included
    - the variance of  $X$  is often set by study design
      - This is often not of scientific interest