University of Colorado
Boulder

Human-Robot Interaction

Descriptive & Inferential Statistics

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Statistical Analysis

So you've got some data, now what?

Statistics

- Descriptive
  - Summarizes data quantitatively without employing a probabilistic formulation
  - Enables people to "get a sense" of the data
  - Can be useful in exploratory analysis
  - Often provided alongside inferential or Bayesian statistics
  - Does not enable any conclusions to be drawn from data
- Inferential (frequentist) statistics
  - Draw conclusions from data that are subject to random variation
  - Focuses on *P(Data | Hypothesis)*
- Bayesian statistics
  - Focuses on *P(Hypothesis | Data)* using Bayes's rule

Inferential vs Bayesian

Example: What is the average height *h* in inches of all adult males in the U.S.?

Bayesian approach

- Begin with a prior distribution: *h* is between 60 and 84 inches, most likely somewhere in the middle
- Collect data (random sample of U.S. adult males)
- Update the prior to create posterior distribution: $P(70 \leq h \leq 74) = .95$

Inferential approach

- *h* is an unknown constant that either is in the range [70,74] or not (i.e., statement that $P(70 \leq h \leq 74) = .95$ is meaningless)
- Only allow probability statements about sampling, *not* about the world
- Could make statement that $P(70 \leq H \leq 74) = .95$ where *H* = random sampling from U.S. population of adult males

Today

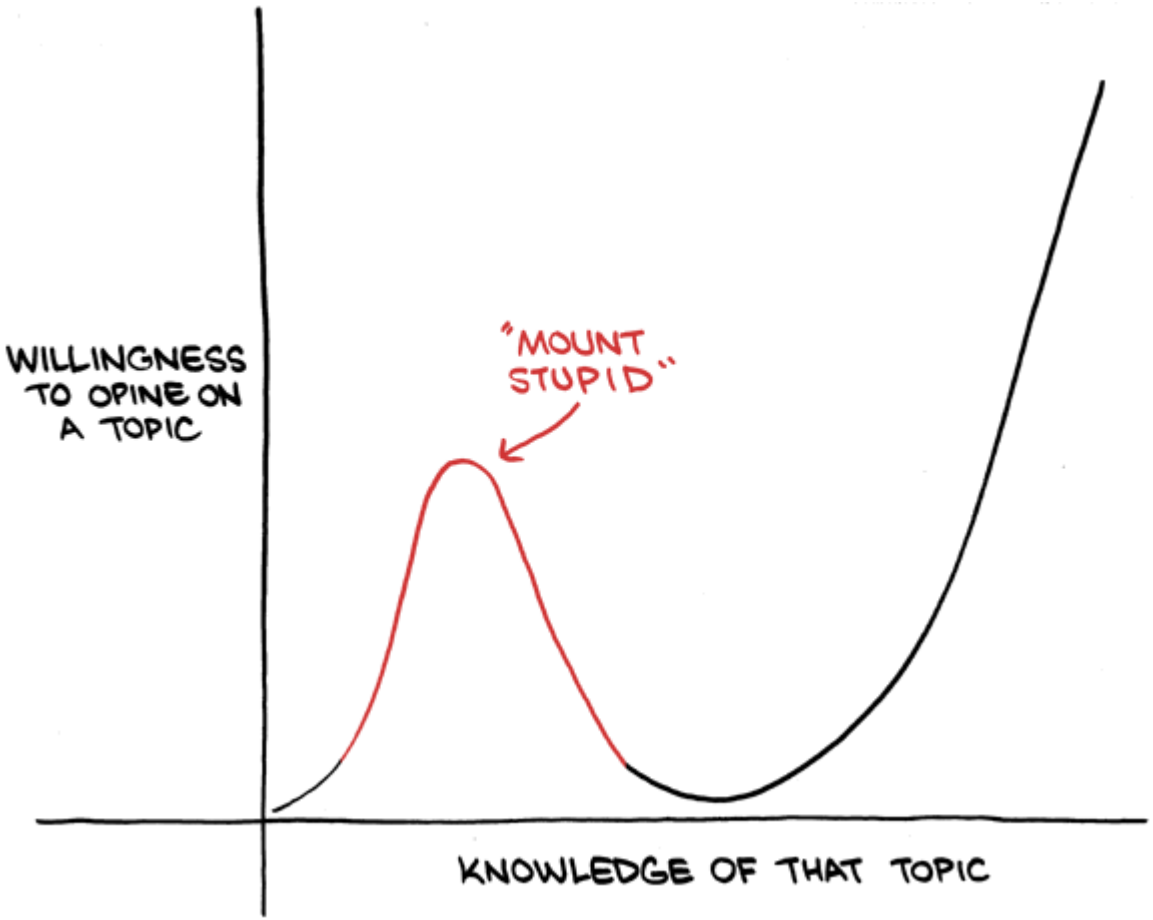
We will cover descriptive and inferential statistics

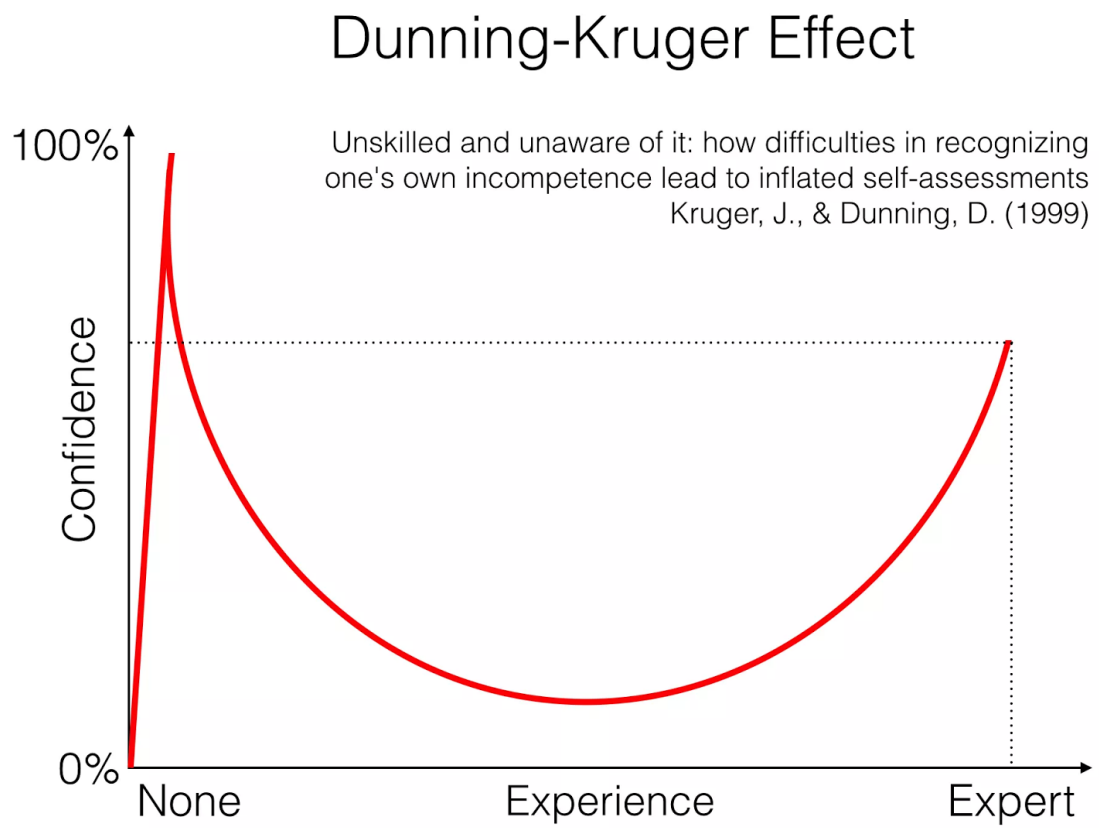
- These are currently the major approaches for HRI research

Bayesian approaches are gaining popularity in related fields

- See http://www.aviz.fr/badstats for discussion of statistical reform

Proceed with Caution!





Questions?

Descriptive Statistics

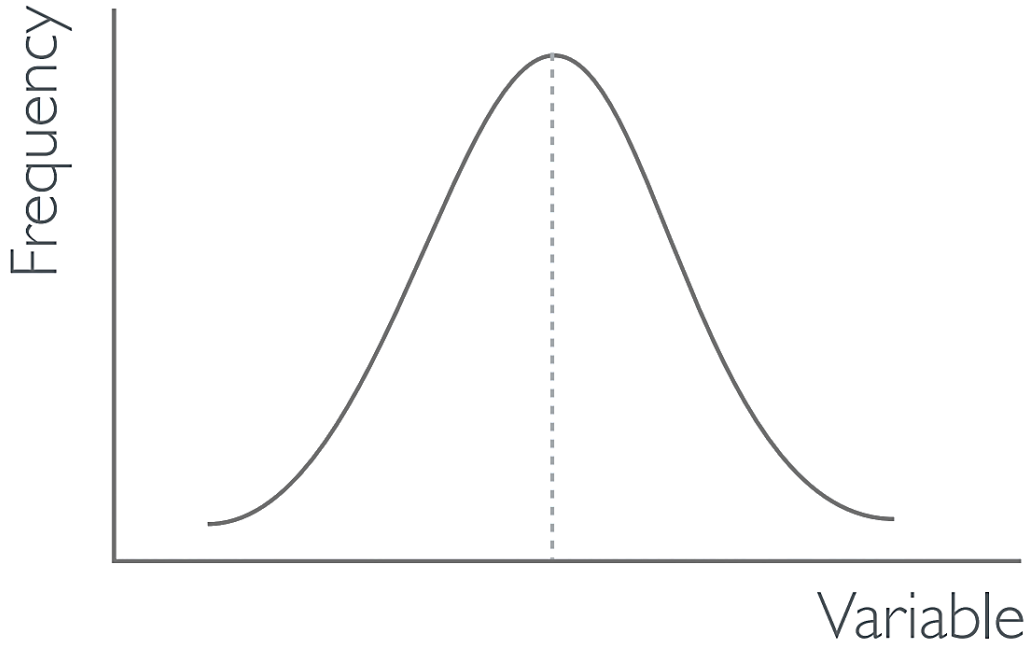
Descriptive Statistics

Human-interpretable computed quantities that **describe** your data

Some describe overall distribution
- Range
- Sample size (N)

Some describe central tendency
- Mean
- Median
- Mode

Some describe variation/dispersion
- Standard Deviation
- Confidence Intervals

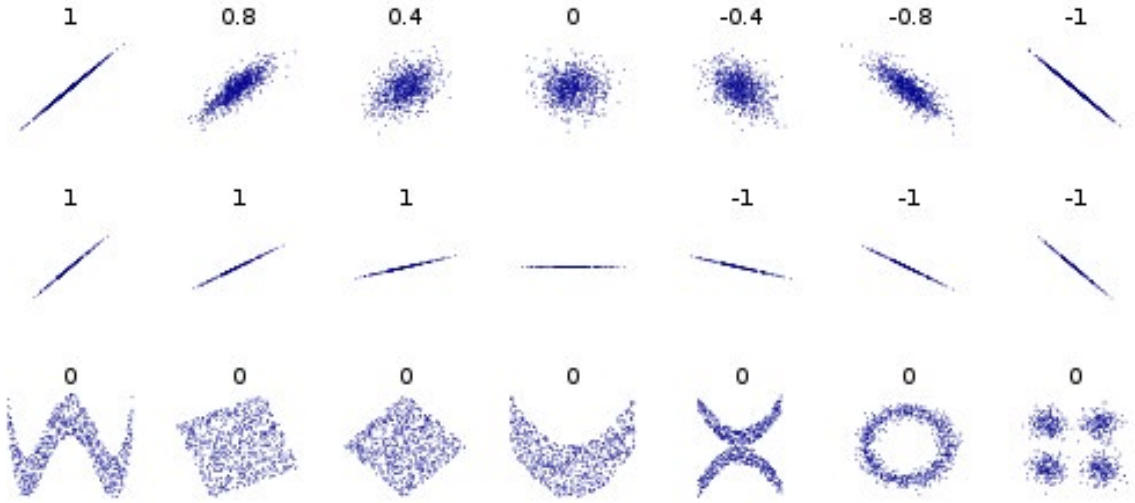


Performance Statistics

Mean: The average value of the dependent measure

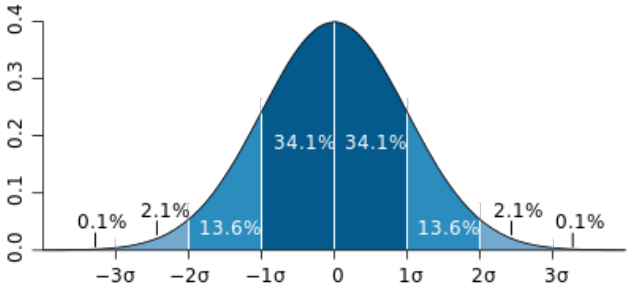
Median: The middle value of the dependent measure

Correlation: How well one variable explains the other



Variance Statistics

Standard Deviation: The overall variation of individual values from the sample mean



Confidence Intervals: The predicted range you'd expect the true value to fall into if you collected all of the possible samples for some level of certainty

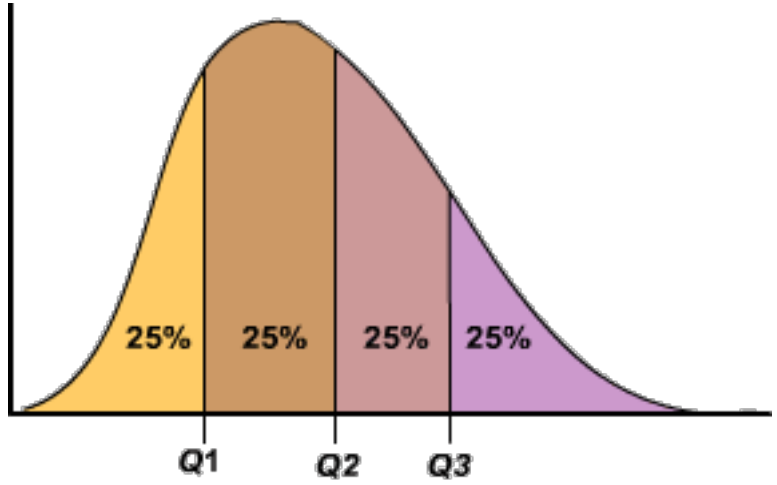
- e.g., 95% confidence interval of [0 - 0.7] seconds means if we collected infinite samples, 95% of the time the mean of those samples would fall within the range [0 - 0.7] seconds

Variance Statistics

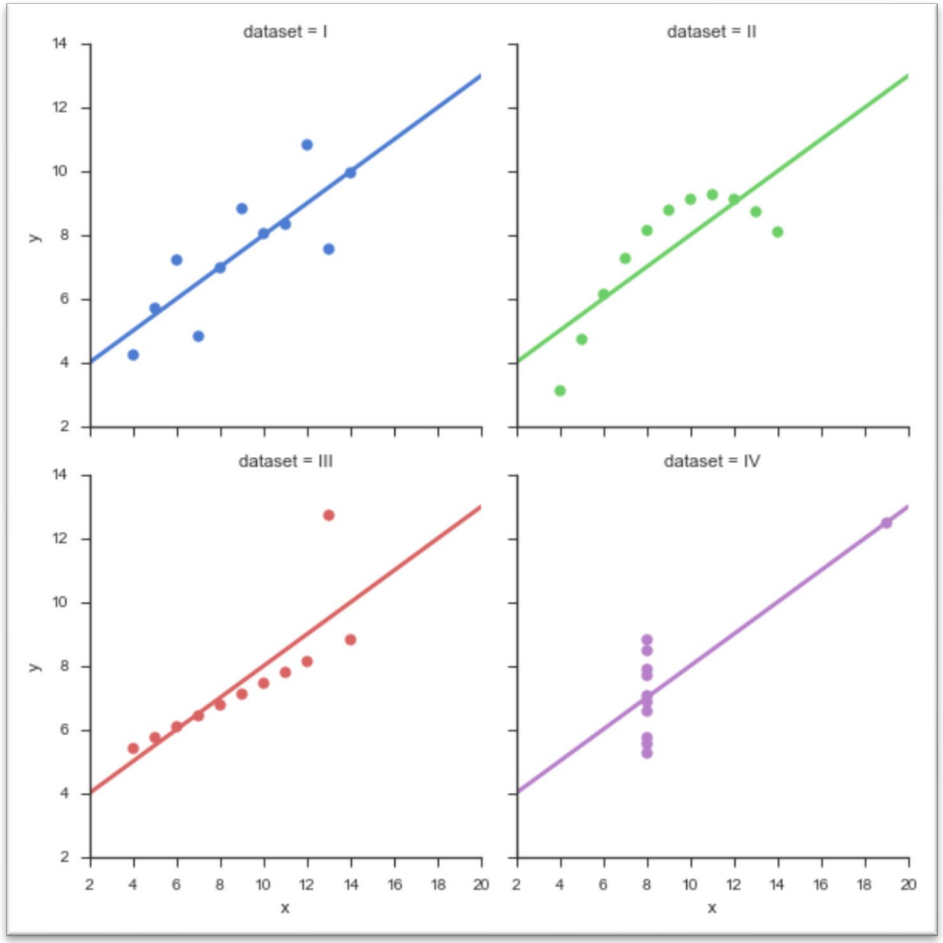
Percentiles: The bounds within which X% of your measured samples fall into (the median is the 50th percentile)

Quartiles: The 25th, 50th, & 75th percentiles

Interquartile Range (IQR): The span from the 25th to 75th percentile

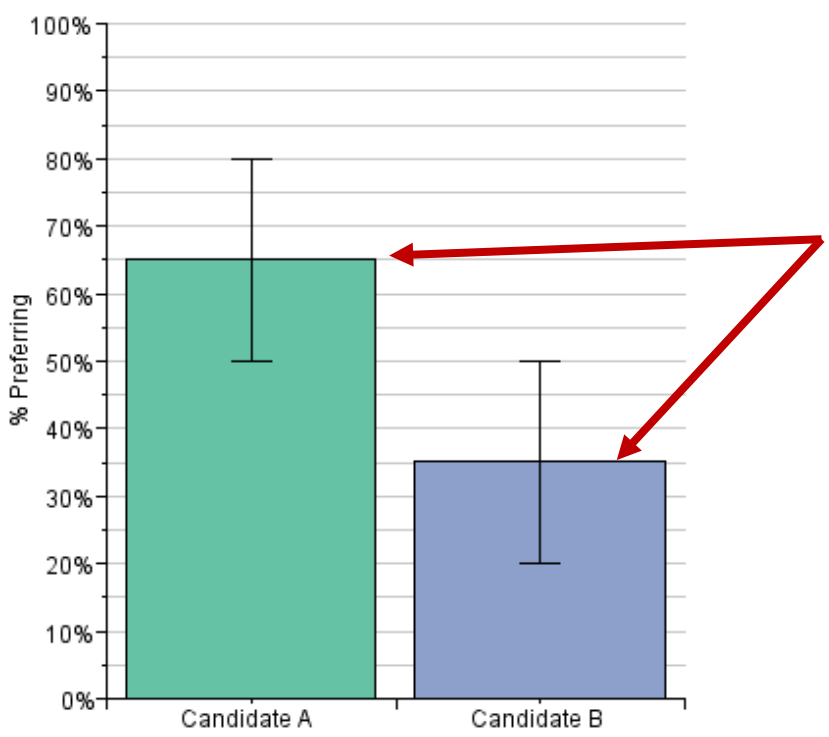


Make sure to visually explore your data!

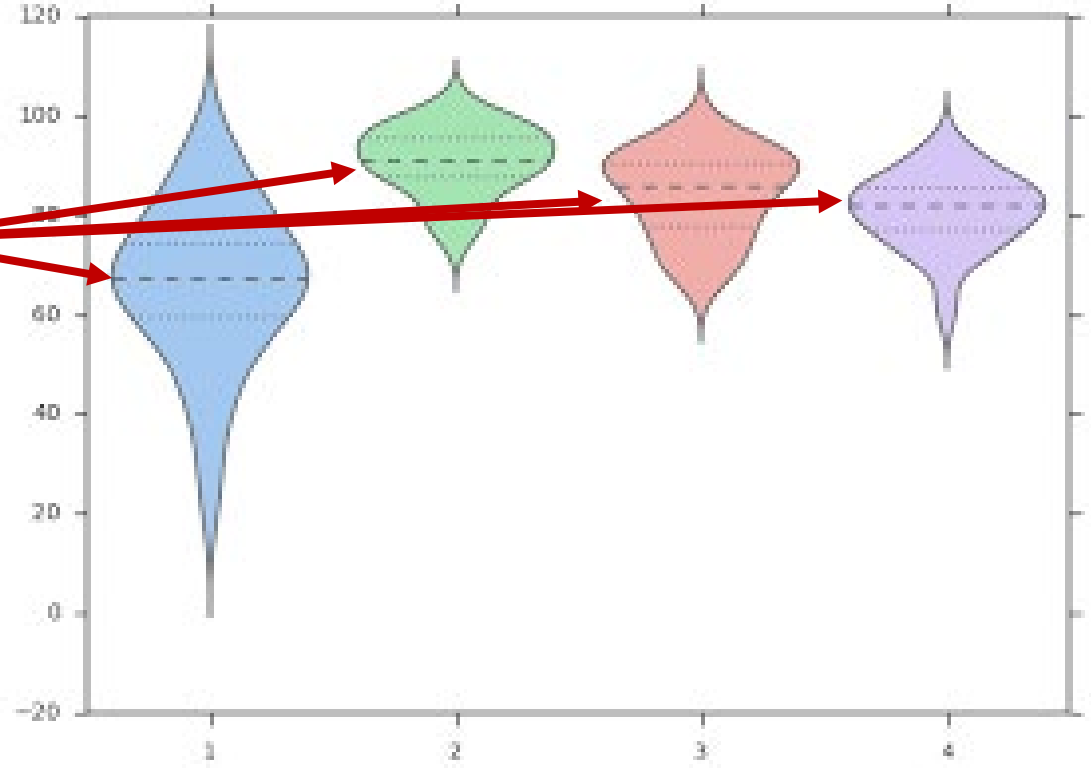


Presenting Descriptive Statistics

If you're reporting results of an experiment, descriptive statistics provide meaningful ways of doing so



Means



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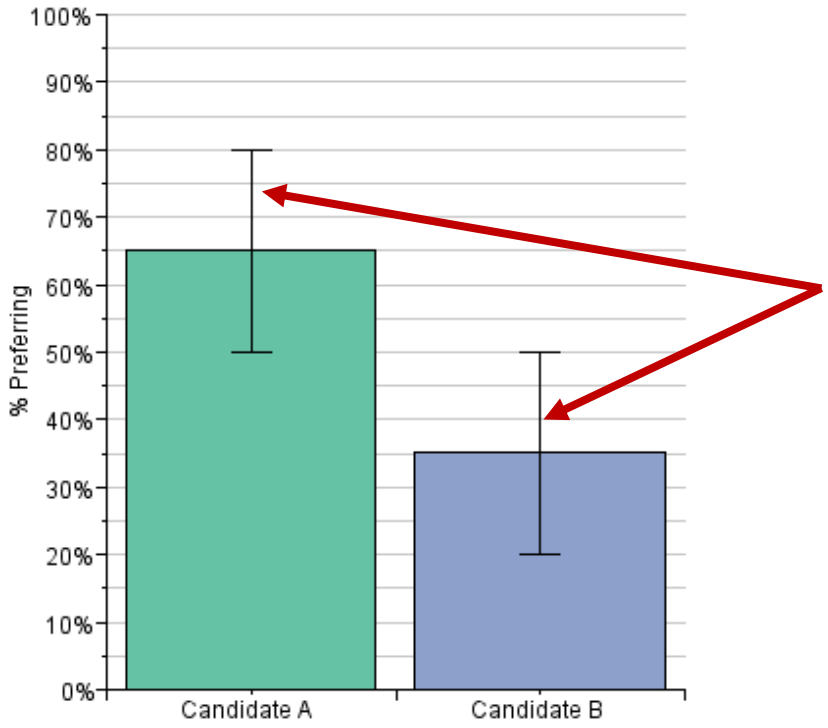
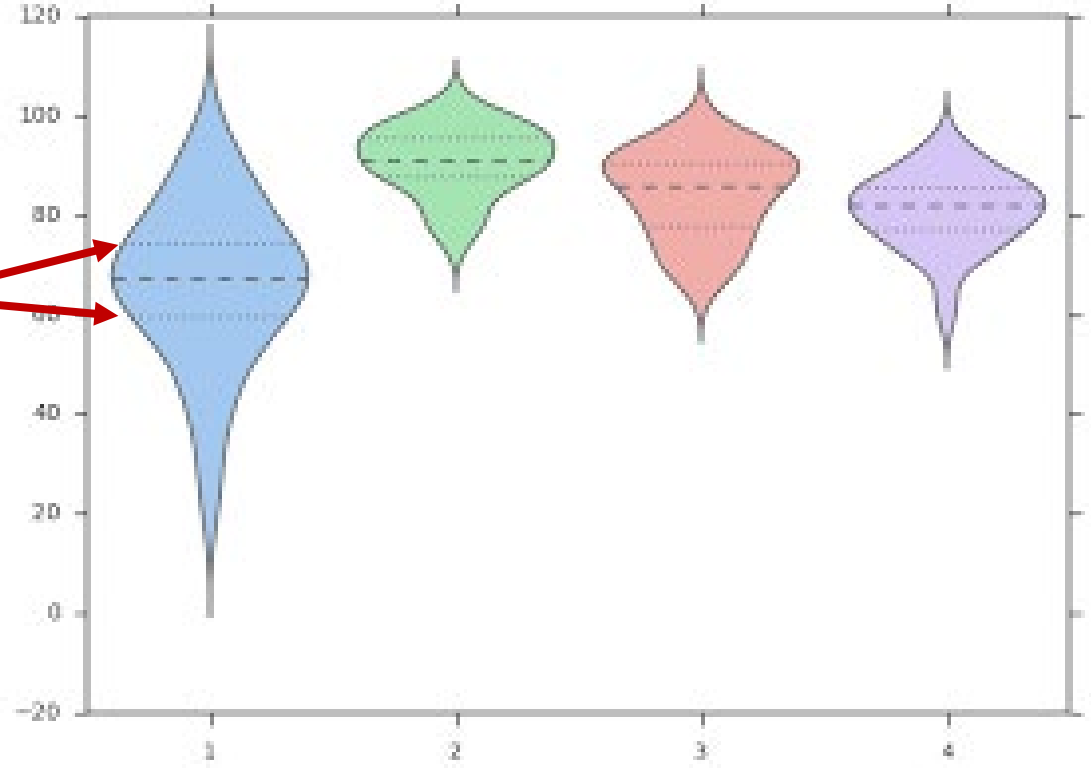


Standard Deviation (or SE)



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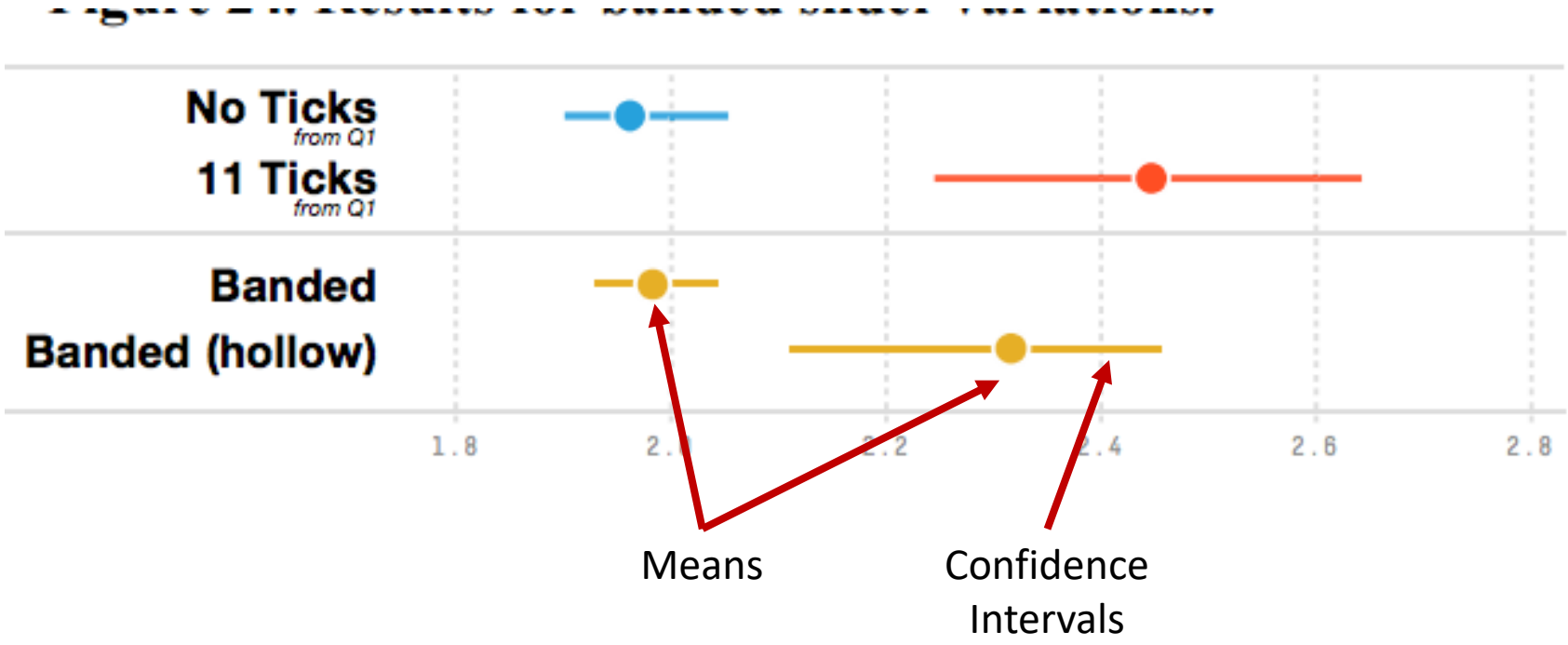

Presenting Descriptive Statistics

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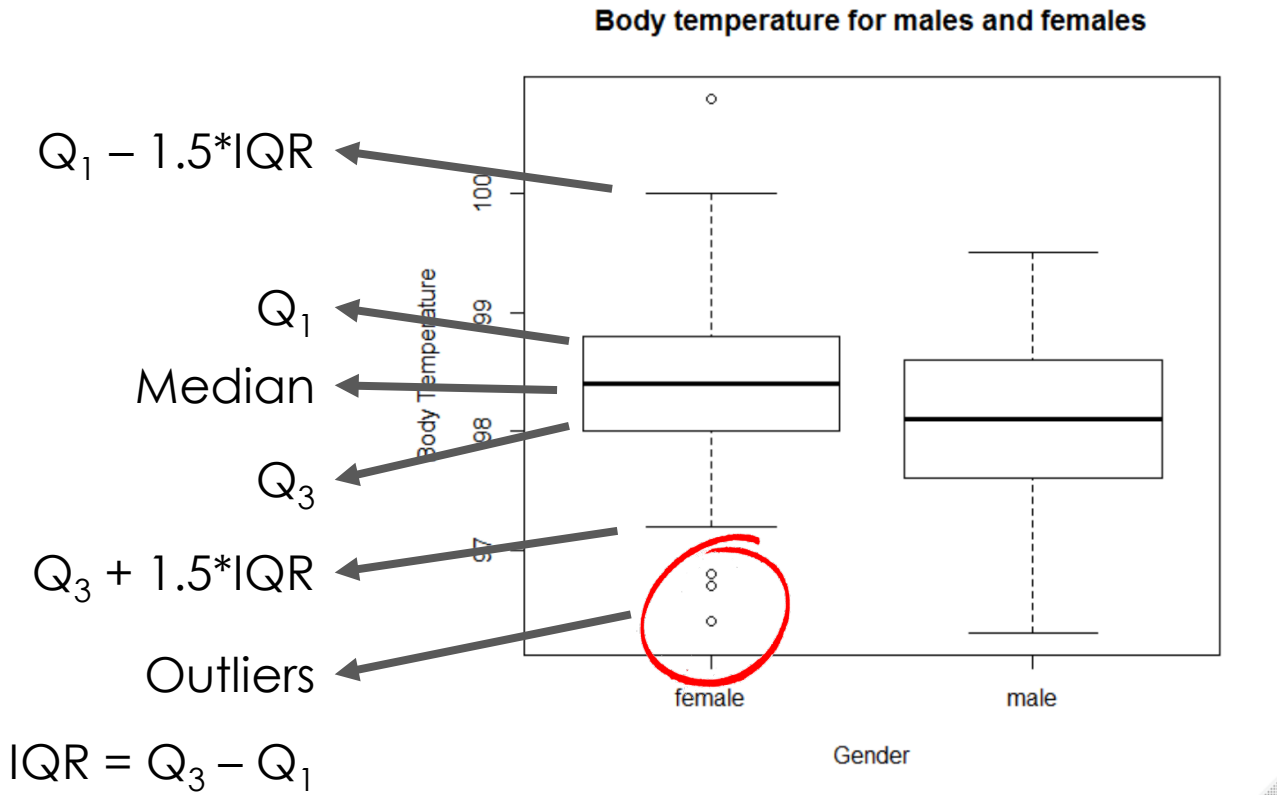


Examples using R and JMP

Download the datasets from Moodle:

- FactorAnalysis_Data.csv (same example data from scale construction)
- Temps.txt
- RepeatedMeasures.csv

Packages needed for R:

```
install.packages("Hmisc")
install.packages("corrgram")
install.packages("sciplot")
```

Example: R Descriptive Statistics

R Basics

Calculate min, max, mean, stdev, quartiles

```
summary(data)
```

```
sapply(data, mean, na.rm=TRUE)
```

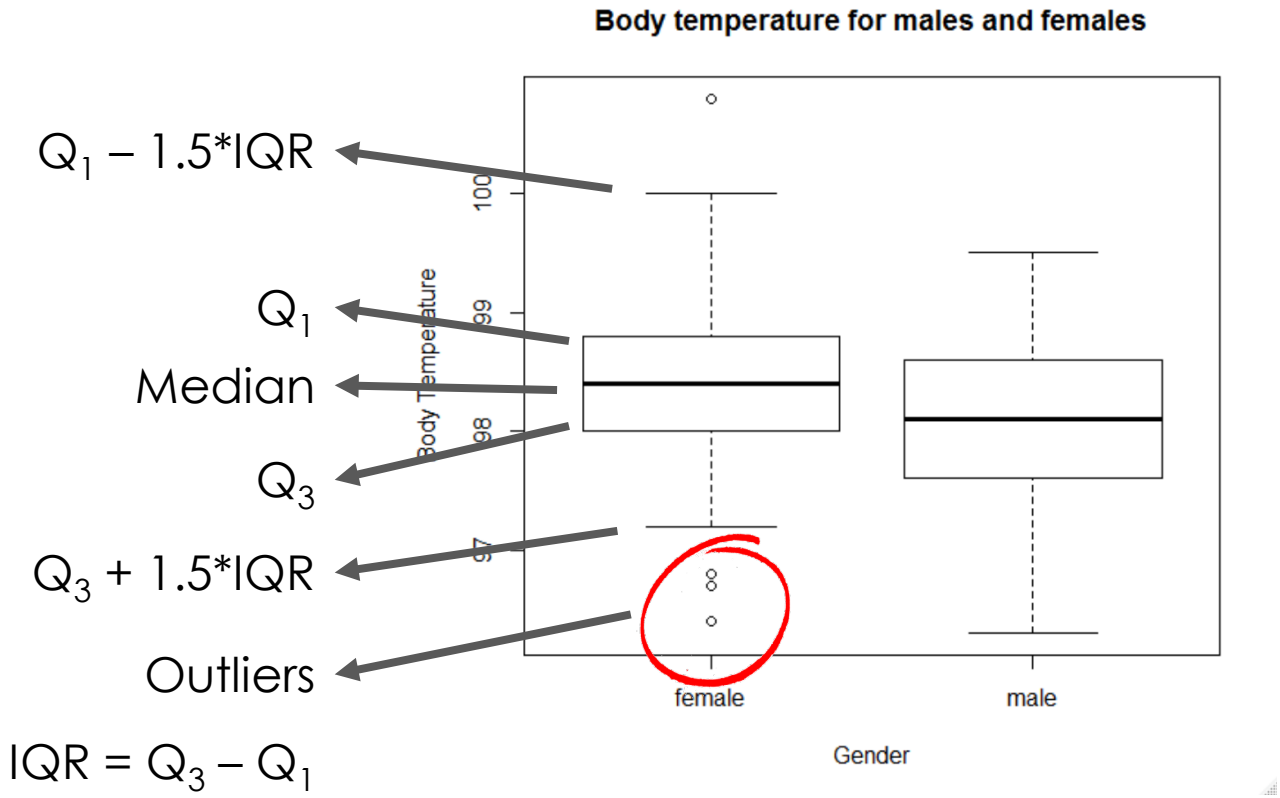
(sapply calculates mean, sd, var, min, max, med, range, and quantile)

```
> setwd("C:\\Users\\Dan\\OneDrive\\Teaching\\HRI Spring 2016\\Lecture 19")
> data <- read.csv("FactorAnalysis_Data.csv")
> summary(data)
 Participant.ID   Condition  Looks_humanlike Behaves_humanlike   Attractive        Cute          Cheerful     Friendly       Optimistic          Warm            Happy
 p01    : 1     Control:14   Min.   :3.000   Min.   :2.000     Min.   :5.000   Min.   :1.00   Min.   :1   Min.   :2.000   Min.   :2.000   Min.   :2.000   Min.   :1.000
 p02    : 1     Cue    :15   1st Qu.:6.000   1st Qu.:3.000     1st Qu.:6.000   1st Qu.:2.00   1st Qu.:2   1st Qu.:3.000   1st Qu.:3.000   1st Qu.:3.000   1st Qu.:3.000
 p03    : 1                  Median :6.000   Median :4.000     Median :6.000   Median :2.00   Median :3   Median :4.000   Median :4.000   Median :3.000   Median :4.000
 p04    : 1                  Mean   :5.931   Mean   :4.034     Mean   :6.207   Mean   :2.69   Mean   :3   Mean   :3.931   Mean   :3.897   Mean   :3.517   Mean   :3.655
 p05    : 1                  3rd Qu.:7.000   3rd Qu.:5.000     3rd Qu.:7.000   3rd Qu.:4.00   3rd Qu.:4   3rd Qu.:5.000   3rd Qu.:5.000   3rd Qu.:5.000   3rd Qu.:4.000
 p06    : 1                  Max.   :7.000   Max.   :6.000     Max.   :7.000   Max.   :7.00   Max.   :5   Max.   :6.000   Max.   :6.000   Max.   :6.000   Max.   :7.000
 (Other):23
 Knowledgeable    Responsible     Intelligent       Sensible         Loyal          Honest       Cooperative      Attentive     You_like_the_robot Robot_likes_you
 Min.   :2.000   Min.   :3.000   Min.   :2.000   Min.   :2.000   Min.   :3.000   Min.   :3.000   Min.   :3.000   Min.   :1.000   Min.   :2          Min.   :2.000
 1st Qu.:5.000   1st Qu.:4.000   1st Qu.:5.000   1st Qu.:4.000   1st Qu.:5.000   1st Qu.:5.000   1st Qu.:5.000   1st Qu.:3.000   1st Qu.:4          1st Qu.:3.000
 Median :5.000   Median :5.000   Median :6.000   Median :5.000   Median :6.000   Median :6.000   Median :6.000   Median :4.000   Median :5          Median :4.000
 Mean   :4.966   Mean   :5.069   Mean   :5.448   Mean   :4.793   Mean   :5.759   Mean   :5.655   Mean   :5.862   Mean   :4.103   Mean   :5          Mean   :3.724
 3rd Qu.:6.000   3rd Qu.:6.000   3rd Qu.:6.000   3rd Qu.:6.000   3rd Qu.:7.000   3rd Qu.:7.000   3rd Qu.:7.000   3rd Qu.:5.000   3rd Qu.:6          3rd Qu.:5.000
 Max.   :7.000   Max.   :7.000   Max.   :7.000   Max.   :7.000   Max.   :7.000   Max.   :7.000   Max.   :7.000   Max.   :7.000   Max.   :7          Max.   :6.000

> sapply(data, mean, na.rm=TRUE)
    Participant.ID          Condition    Looks_humanlike  Behaves_humanlike        Attractive               Cute          Cheerful          Friendly        Optimistic
                NA                 NA           5.931034           4.034483          6.206897           2.689655          3.000000          3.931034          3.896552
              Warm              Happy      Knowledgeable       Responsible       Intelligent          Sensible             Loyal            Honest       Cooperative
          3.517241           3.655172           4.965517           5.068966          5.448276          4.793103          5.758621          5.655172          5.862069
         Attentive You_like_the_robot     Robot_likes_you
          4.103448           5.000000           3.724138
```

Visual Exploration

```
> data <- read.delim("Temps.txt")
> bodytemp <- data$bodytemp
> gender <- data$gender
> boxplot(bodytemp~gender, main="Body temperature for males and females", xlab="Gender",
ylab="Body Temperature")
```



Questions?

Example: JMP Descriptive Statistics

FactorAnalysis_Data - JMP Pro

File Edit Tables Rows Cols DOE Analyze Graph Tools View Window Help

FactorAnalysis_Data
Source

Columns (21/2)
- Participant ID
- Condition
- Looks_humanlike
- Behaves_humanlike
- Attractive
- Cute
- Cheerful
- Friendly
- Optimistic
- Warm
- Happy
- Knowledgeable
- Responsible
- Intelligent
- Sensible
- Loyal
- Honest
- Cooperative
- Attentive
- You_like_the_robot
- Robot_likes_you

Rows

All rows	29
Selected	0
Excluded	0
Hidden	0
Labelled	0

	Participant ID	Condition	Looks_humanlike	Behaves_humanlike	Attractive	Cute	Cheerful	Friendly	Optimistic	Warm	Happy	Knowledgeable	Responsible	Intelligent	Sensible	Lo
1	p01	Control	6	4	7	1	1	2	3	2	2	4	6	6	6	
2	p02	Control	6	5	7	3	4	6	5	6	7	7	7	7	7	
3	p03	Control	5	3	5	1	1	5	4	4	4	5	5	5	2	
4	p04	Control	7	4	7	4	4	6	4	5	4	6	6	5	5	
5	p05	Cue	7	5	6	3	3	4	4	3	5	6	4	6	5	
6	p06	Cue	6	5	6	2	4	5	3	3	4	5	5	6	5	
7	p07	Cue	7	5	7	2	4	5	4	3	4	5	5	4	4	
8	p08	Cue	6	2	6	3	2	5	5	5	5	7	7	7	7	
9	p09	Cue	6	4	7	4	3	5	5	5	5	5	6	6	6	
10	p10	Control	6	6	6	2	5	3	4	4	4	6	5	6	5	
11	p11	Control	6	4	6	2	2	3	6	3	4	5	6	5	6	
12	p12	Cue	6	4	7	2	2	2	4	2	2	6	3	6	5	
13	p13	Cue	5	3	5	1	2	3	4	3	2	3	3	3	5	
14	p14	Control	6	4	6	2	3	5	4	4	5	6	4	7	6	
15	p15	Control	6	6	7	5	4	3	3	5	2	4	5	5	6	
16	p16	Cue	6	5	6	2	5	5	5	5	6	5	6	6	4	
17	p17	Cue	6	3	7	7	2	3	3	3	2	5	5	6	5	
18	p18	Control	7	5	6	3	2	3	2	3	4	3	5	6	4	
19	p19	Control	6	3	5	1	3	3	5	3	2	5	3	5	5	
20	p20	Cue	7	5	7	5	3	4	4	2	3	5	4	4	5	
21	p21	Control	6	6	7	4	3	3	4	4	3	5	5	7	5	
22	p22	Cue	3	4	7	1	2	3	5	3	1	5	6	4	2	
23	p23	Control	6	2	6	1	4	5	2	3	4	6	6	6	4	
24	p24	Cue	5	2	6	4	1	2	4	2	4	2	7	2	2	
25	p25	Control	7	5	7	2	4	5	3	5	3	5	5	6	6	
26	p26	Cue	7	4	5	2	2	3	5	3	4	6	7	7	6	
27	p27	Control	4	2	6	5	4	6	4	5	5	3	5	5	4	
28	p28	Cue	7	4	5	2	5	5	2	2	3	5	3	6	3	
29	p29	Cue	4	3	5	2	3	2	3	2	3	4	3	4	4	

FactorAnalysis_Data - JMP Pro

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Distribution
Fit Y by X
Matched Pairs
Tabulate
Fit Model
Modeling
Multivariate Methods
Quality and Process
Reliability and Survival
Consumer Research

Distribution of a batch of values. Frequencies if categorical. Means and quantiles if continuous. Histograms, Box Plots, Quantile Plots. Tests on means, Fitting distributions. Capability.

FactorAna
Source

Columns (
Participan
Condition
Looks_hur
Behaves_h
Attractive
Cute
Cheerful
Friendly
Optimistic
Warm
Happy
Knowledgeable
Responsible
Intelligent
Sensible
Loyal
Honest
Cooperative
Attentive
You_like_the_robot
Robot_likes_you

Rows
All rows 29
Selected 0
Excluded 0
Hidden 0
Labelled 0

				Behaves_humanlike	Attractive	Cute	Cheerful	Friendly	Optimistic	Warm	Happy	Knowledgeable	Responsible	Intelligent	Sensible	Lo
				4	7	1	1	2	3	2	2	4	6	6	6	
				5	7	3	4	6	5	6	7	7	7	7	7	
				3	5	1	1	5	4	4	4	5	5	5	2	
		Control	7	4	7	4	4	6	4	5	4	6	6	5	5	
		Cue	7	5	6	3	3	4	4	3	5	6	4	6	5	
		Cue	6	5	6	2	4	5	3	3	4	5	5	6	5	
		Cue	7	5	7	2	4	5	4	3	4	5	5	4	4	
		Cue	6	2	6	3	2	5	5	5	5	7	7	7	7	
		Cue	6	4	7	4	3	5	5	5	5	5	6	6	6	
		Control	6	6	6	2	5	3	4	4	4	6	5	6	5	
		Control	6	4	6	2	2	3	6	3	4	5	6	5	6	
12	p12	Cue	6	4	7	2	2	2	4	2	2	6	3	6	5	
13	p13	Cue	5	3	5	1	2	3	4	3	2	3	3	3	5	
14	p14	Control	6	4	6	2	3	5	4	4	5	6	4	7	6	
15	p15	Control	6	6	7	5	4	3	3	5	2	4	5	5	6	
16	p16	Cue	6	5	6	2	5	5	5	5	6	5	6	6	4	
17	p17	Cue	6	3	7	7	2	3	3	3	2	5	5	6	5	
18	p18	Control	7	5	6	3	2	3	2	3	4	3	5	6	4	
19	p19	Control	6	3	5	1	3	3	5	3	2	5	3	5	5	
20	p20	Cue	7	5	7	5	3	4	4	2	3	5	4	4	5	
21	p21	Control	6	6	7	4	3	3	4	4	3	5	5	7	5	
22	p22	Cue	3	4	7	1	2	3	5	3	1	5	6	4	2	
23	p23	Control	6	2	6	1	4	5	2	3	4	6	6	6	4	
24	p24	Cue	5	2	6	4	1	2	4	2	4	2	7	2	2	
25	p25	Control	7	5	7	2	4	5	3	5	3	5	5	6	6	
26	p26	Cue	7	4	5	2	2	3	5	3	4	6	7	7	6	
27	p27	Control	4	2	6	5	4	6	4	5	5	3	5	5	4	
28	p28	Cue	7	4	5	2	5	5	2	2	3	5	3	6	3	
29	p29	Cue	4	3	5	2	3	2	3	2	3	4	3	4	4	

FactorAnalysis_Data - JMP Pro

File Edit Tables Rows Cols DOE Analyze Graph Tools View Window Help

FactorAnalysis_Data
Source

Columns (21/2)
Participant ID
Condition
Looks_humanlik
Behaves_human
Attractive
Cute
Cheerful
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You_like_the_robot
Robot_likes_you

Rows
All rows 29
Selected 0
Excluded 0
Hidden 0
Labelled 0

Distribution - JMP Pro

The distribution of values in each column

Select Columns
21 Columns
Participant ID
Condition
Looks_humanlike
Behaves_humanlike
Attractive
Cute
Cheerful
Friendly
Optimistic
Warm
Happy
Knowledgeable
Responsible
Intelligent
Sensible

Cast Selected Columns into Roles
Y, Columns: Looks_humanlike, Behaves_humanlike
optional
Weight: optional numeric
Freq: optional numeric
By: optional

Action
OK
Cancel
Remove
Recall
Help

Histograms Only

	Participant ID	Condition	Looks_humanlike	Behaves_humanlike	Attractive	Cute	Cheerful	Friendly	Optimistic	Warm	Happy	Knowledgeable	Responsible	Intelligent	Sensible	Lo
					7	1	1	2	3	2	2	4	6	6	6	
					7	3	4	6	5	6	7	7	7	7	7	
					5	1	1	5	4	4	4	5	5	5	2	
					7	4	4	6	4	5	4	6	6	5	5	
					6	3	3	4	4	3	5	6	4	6	5	
					6	2	4	5	3	3	4	5	5	6	5	
					7	2	4	5	4	3	4	5	5	4	4	
					6	3	2	5	5	5	5	7	7	7	7	
					7	4	3	5	5	5	5	5	6	6	6	
					6	2	5	3	4	4	4	6	5	6	5	
					6	2	2	3	6	3	4	5	6	5	6	
					7	2	2	2	4	2	2	6	3	6	5	
					5	1	2	3	4	3	2	3	3	3	5	
					6	2	3	5	4	4	5	6	4	7	6	
					7	5	4	3	3	5	2	4	5	5	6	
					6	2	5	5	5	5	6	5	6	6	4	
					7	7	2	3	3	3	2	5	5	6	5	
					6	3	2	3	2	3	4	3	5	6	4	
					5	1	3	3	5	3	2	5	3	5	5	
					7	5	3	4	4	2	3	5	4	4	5	
					7	4	3	3	4	4	3	5	5	7	5	
22	p22	Cue	3	4	7	1	2	3	5	3	1	5	6	4	2	
23	p23	Control	6	2	6	1	4	5	2	3	4	6	6	6	4	
24	p24	Cue	5	2	6	4	1	2	4	2	4	2	7	2	2	
25	p25	Control	7	5	7	2	4	5	3	5	3	5	5	6	6	
26	p26	Cue	7	4	5	2	2	3	5	3	4	6	7	7	6	
27	p27	Control	4	2	6	5	4	6	4	5	5	3	5	5	4	
28	p28	Cue	7	4	5	2	5	5	2	2	3	5	3	6	3	
29	p29	Cue	4	3	5	2	3	2	3	2	3	4	3	4	4	

FactorAnalysis_Data - JMP Pro

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Columns (21/2)

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- Warm
- Happy
- Knowledgeable
- Responsible
- Intelligent
- Sensible
- Loyal
- Honest
- Cooperative
- Attentive
- You_like_the_robot
- Robot_likes_you

Rows

All rows	29
Selected	0
Excluded	0
Hidden	0
Labelled	0

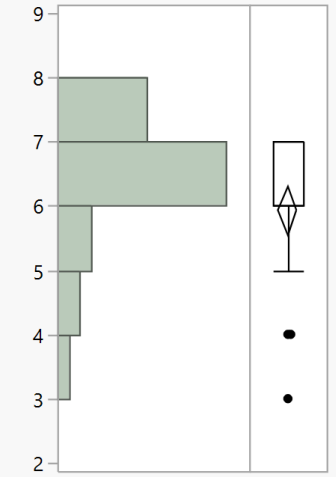
	Participant ID	Condition	Looks_humanlike	Behaves_humanlike	Attractive	Intelligent	Sensible	Lo
1	p01	Control	6	4	7	6	6	
2	p02	Control	6	5	7	7	7	
3	p03	Control	5	3	5	5	2	
4	p04	Control	7	4	7	5	5	
5	p05	Cue	7	5	6	6	5	
6	p06	Cue	6	5	6	6	5	
7	p07	Cue	7	5	7	4	4	
8	p08	Cue	6	2	6	7	7	
9	p09	Cue	6	4	7	6	6	
10	p10	Control	6	6	6	6	5	
11	p11	Control	6	4	6	5	6	
12	p12	Cue	6	4	7	6	5	
13	p13	Cue	5	3	5	3	5	
14	p14	Control	6	4	6	7	6	
15	p15	Control	6	6	7	5	6	
16	p16	Cue	6	5	6	6	4	
17	p17	Cue	6	3	7	6	5	
18	p18	Control	7	5	6	6	4	
19	p19	Control	6	3	5	5	5	
20	p20	Cue	7	5	7	4	5	
21	p21	Control	6	6	7	7	5	
22	p22	Cue	3	4	7	4	2	
23	p23	Control	6	2	6	6	4	
24	p24	Cue	5	2	6	2	2	
25	p25	Control	7	5	7	6	6	
26	p26	Cue	7	4	5	7	6	
27	p27	Control	4	2	6	5	4	
28	p28	Cue	7	4	5	6	3	
29	p29	Cue	4	3	5	4	4	

FactorAnalysis_Data - Distribution of Looks_humanlike, Behaves_...

File Edit Tables Rows Cols DOE Analyze Graph Tools View Window Help

Distributions

Looks_humanlike



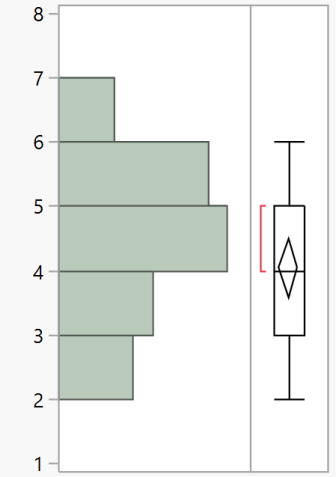
Quantiles

100.0%	maximum	7
99.5%		7
97.5%		7
90.0%		7
75.0%	quartile	7
50.0%	median	6
25.0%	quartile	6
10.0%		4
2.5%		3
0.5%		3
0.0%	minimum	3

Summary Statistics

Mean	5.9310345
Std Dev	0.9975339
Std Err Mean	0.1852374
Upper 95% Mean	6.3104761
Lower 95% Mean	5.5515929
N	29

Behaves_humanlike



Quantiles

100.0%	maximum	6
99.5%		6
97.5%		6
90.0%		6
75.0%	quartile	5
50.0%	median	4
25.0%	quartile	3
10.0%		2
2.5%		2
0.5%		2
0.0%	minimum	2

Summary Statistics

Mean	4.0344828
Std Dev	1.2095678
Std Err Mean	0.2246111
Upper 95% Mean	4.4945777
Lower 95% Mean	3.5743878
N	29

FactorAnalysis_Data - JMP Pro

File Edit Tables Rows Cols DOE Analyze Graph Tools View Window Help

FactorAnalysis_Data
Source

Columns (21/2)
- Participant ID
- Condition
- Looks_humanlike
- Behaves_humanlike
- Attractive
- Cute
- Cheerful
- Friendly
- Optimistic
- Warm
- Happy
- Knowledgeable
- Responsible
- Intelligent
- Sensible
- Loyal
- Honest
- Cooperative
- Attentive
- You_like_the_robot
- Robot_likes_you

Rows
All rows	29
Selected	0
Excluded	0
Hidden	0
Labelled	0

	Participant ID	Condition	Looks_humanlike	Behaves_humanlike	Attractive	Intelligent	Sensible	Lo
1	p01	Control	6	4	7	6	6	
2	p02	Control	6			7	7	
3	p03	Control	5			5	2	
4	p04	Control	7			5	5	
5	p05	Cue	7			6	5	
6	p06	Cue	6			6	5	
7	p07	Cue	7			4	4	
8	p08	Cue	6			7	7	
9	p09	Cue	6			6	6	
10	p10	Control	6			6	5	
11	p11	Control	6			5	6	
12	p12	Cue	6			6	5	
13	p13	Cue	5			3	5	
14	p14	Control	6			7	6	
15	p15	Control	6			5	6	
16	p16	Cue	6			6	4	
17	p17	Cue	6			6	5	
18	p18	Control	7			6	4	
19	p19					5	5	
20	p20					4	5	
21	p21					7	5	
22	p22					4	2	
23	p23					6	4	
24	p24			2	6	2	2	
25	p25			5	7	6	6	
26	p26			4	5	7	6	
27	p27			2	6	5	4	
28	p28			4	5	6	3	
29	p29			3	5	4	4	

Display Options
Histogram Options
Normal Quantile Plot
✓ Outlier Box Plot
Quantile Box Plot
Stem and Leaf
CDF Plot
Test Mean
Test Std Dev
Confidence Interval
Prediction Interval
Tolerance Interval
Capability Analysis
Continuous Fit
Discrete Fit
Save
Remove

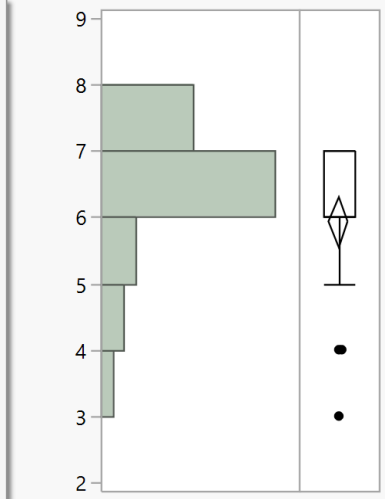
Normal
LogNormal
Weibull
Weibull with threshold
Extreme Value
Exponential
Gamma
Beta
Normal Mixtures
Smooth Curve
Johnson Su
Johnson Sb
Johnson Sl
GLog
All

FactorAnalysis_Data - Distribution of Looks_humanlike, Behaves_...

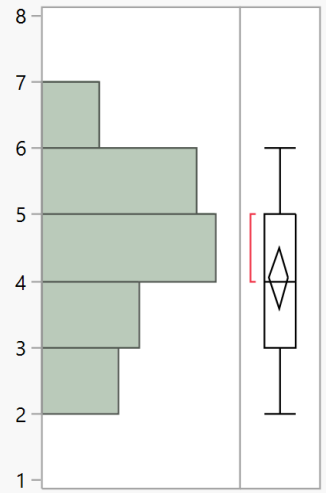
File Edit Tables Rows Cols DOE Analyze Graph Tools View Window Help

Distributions

Looks_humanlike



Behaves_humanlike



Quantiles

100.0%	maximum	7
99.5%		7
97.5%		7
90.0%		7
75.0%	quartile	7
50.0%	median	6
25.0%	quartile	6
10.0%		4
2.5%		3
0.5%		3
0.0%	minimum	3

Quantiles

100.0%	maximum	6
99.5%		6
97.5%		6
90.0%		6
75.0%	quartile	5
50.0%	median	4
25.0%	quartile	3
10.0%		2
2.5%		2
0.5%		2
0.0%	minimum	2

Summary Statistics

Mean	5.9310345
Std Dev	0.9975339
Std Err Mean	0.1852374
Upper 95% Mean	6.3104761
Lower 95% Mean	5.5515929
N	29

Summary Statistics

Mean	4.0344828
Std Dev	1.2095678
Std Err Mean	0.2246111
Upper 95% Mean	4.4945777
Lower 95% Mean	3.5743878
N	29

FactorAnalysis_Data - JMP Pro

File Edit Tables Rows Cols DOE Analyze Graph Tools View Window Help

FactorAnalysis_Data
Source

Columns (21/2)
- Participant ID
- Condition
- Looks_humanlike
- Behaves_humanlike
- Attractive
- Cute
- Cheerful
- Friendly
- Optimistic
- Warm
- Happy
- Knowledgeable
- Responsible
- Intelligent
- Sensible
- Loyal
- Honest
- Cooperative
- Attentive
- You_like_the_robot
- Robot_likes_you

Rows

All rows	29
Selected	0
Excluded	0
Hidden	0
Labelled	0

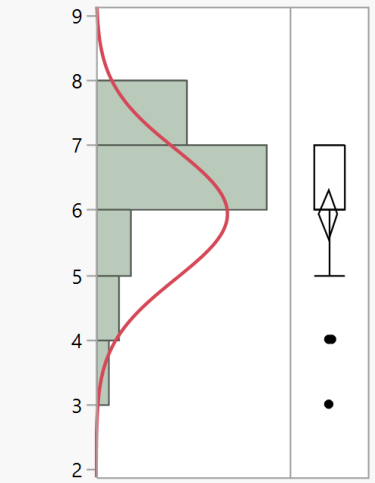
	Participant ID	Condition	Looks_humanlike
1	p01	Control	6
2	p02	Control	6
3	p03	Control	5
4	p04	Control	7
5	p05	Cue	7
6	p06	Cue	6
7	p07	Cue	7
8	p08	Cue	6
9	p09	Cue	6
10	p10	Control	6
11	p11	Control	6
12	p12	Cue	6
13	p13	Cue	5
14	p14	Control	6
15	p15	Control	6
16	p16	Cue	6
17	p17	Cue	6
18	p18	Control	7
19	p19	Control	6
20	p20	Cue	7
21	p21	Control	6
22	p22	Cue	3
23	p23	Control	6
24	p24	Cue	5
25	p25	Control	7
26	p26	Cue	7
27	p27	Control	4
28	p28	Cue	7
29	p29	Cue	4

FactorAnalysis_Data - Distribution of Looks_humanlike, Behaves_humanlike - JMP Pro

File Edit Tables Rows Cols DOE Analyze Graph Tools View Window Help

Distributions

Looks_humanlike



Normal(5.93103,0.99753)

Quantiles

100.0%	maximum	7
99.5%		7
97.5%		7
90.0%		7
75.0%	quartile	7
50.0%	median	6
25.0%	quartile	6
10.0%		4
2.5%		3
0.5%		3
0.0%	minimum	3

Summary Statistics

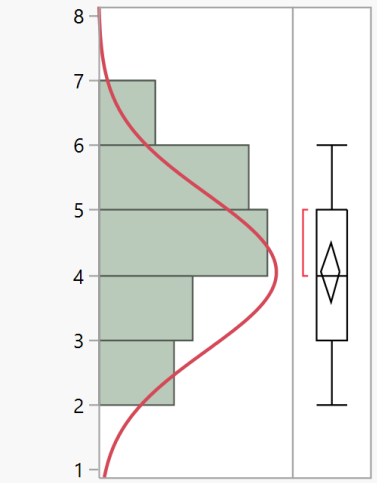
Mean	5.9310345
Std Dev	0.9975339
Std Err Mean	0.1852374
Upper 95% Mean	6.3104761
Lower 95% Mean	5.5515929
N	29

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%

Behaves_humanlike



Normal(4.03448,1.20957)

Quantiles

100.0%	maximum	6
99.5%		6
97.5%		6
90.0%		6
75.0%	quartile	5
50.0%	median	4
25.0%	quartile	3
10.0%		2
2.5%		2
0.5%		2
0.0%	minimum	2

Summary Statistics

Mean	4.0344828
Std Dev	1.2095678
Std Err Mean	0.2246111
Upper 95% Mean	4.4945777
Lower 95% Mean	3.5743878
N	29

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%

FactorAnalysis_Data - JMP Pro

File Edit Tables Rows Cols DOE Analyze Graph Tools View Window Help

FactorAnalysis_Data

Source

Columns (21/2)

- Participant ID
- Condition
- Looks_humanlike
- Behaves_humanlike
- Attractive
- Cute
- Cheerful
- Friendly
- Optimistic
- Warm
- Happy
- Knowledgeable
- Responsible
- Intelligent
- Sensible
- Loyal
- Honest
- Cooperative
- Attentive
- You_like_the_robot
- Robot_likes_you

Rows

All rows	29
Selected	0
Excluded	0
Hidden	0
Labelled	0

	Participant ID	Condition	Looks_humanlike
1	p01	Control	6
2	p02	Control	6
3	p03	Control	5
4	p04	Control	7
5	p05	Cue	7
6	p06	Cue	6
7	p07	Cue	7
8	p08	Cue	6
9	p09	Cue	6
10	p10	Control	6
11	p11	Control	6
12	p12	Cue	6
13	p13	Cue	5
14	p14	Control	6
15	p15	Control	6
16	p16	Cue	6
17	p17	Cue	6
18	p18	Control	7
19	p19	Control	6
20	p20	Cue	7
21	p21	Control	6
22	p22	Cue	3
23	p23	Control	6
24	p24	Cue	5
25	p25	Control	7
26	p26		
27	p27		

- Diagnostic Plot
- ✔ Density Curve
- Goodness of Fit
- Fix Parameters
- Quantiles
- Set Spec Limits for K Sigma
- Spec Limits
- Save Fitted Quantiles
- Save Density Formula
- Save Spec Limits
- Remove Fit

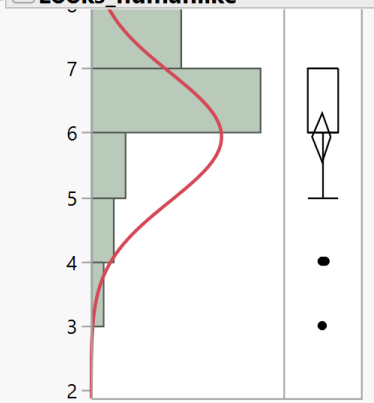
Tests the goodness of fit for this distribution against the data.

FactorAnalysis_Data - Distribution of Looks_humanlike, Behaves_humanlike - JMP Pro

File Edit Tables Rows Cols DOE Analyze Graph Tools View Window Help

Distributions

Looks_humanlike



Normal(5.93103,0.99753)

Quantiles

100.0%	maximum	7
99.5%		7
97.5%		7
90.0%		7
75.0%	quartile	7
50.0%	median	6
25.0%	quartile	6
10.0%		4
2.5%		3
0.5%		3
0.0%	minimum	3

Summary Statistics

Mean	5.9310345
Std Dev	0.9975339
Std Err Mean	0.1852374
Upper 95% Mean	6.3104761
Lower 95% Mean	5.5515929
N	29

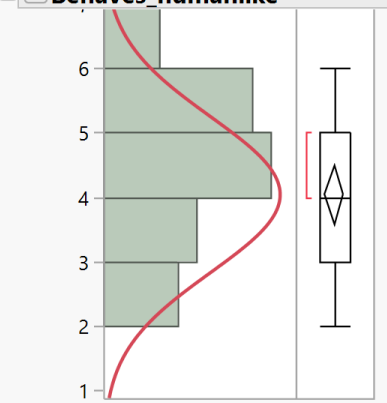
Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	μ	5.9310345	5.5515929	6.3104761
Dispersion	σ	0.9975339	0.7916224	1.3491164

-2log(Likelihood) = 81.1552247582941

Behaves_humanlike



Normal(4.03448,1.20957)

Quantiles

100.0%	maximum	6
99.5%		6
97.5%		6
90.0%		6
75.0%	quartile	5
50.0%	median	4
25.0%	quartile	3
10.0%		2
2.5%		2
0.5%		2
0.0%	minimum	2

Summary Statistics

Mean	4.0344828
Std Dev	1.2095678
Std Err Mean	0.2246111
Upper 95% Mean	4.4945777
Lower 95% Mean	3.5743878
N	29

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	μ	4.0344828	3.5743878	4.4945777
Dispersion	σ	1.2095678	0.9598881	1.635882

-2log(Likelihood) = 92.3336935589375

FactorAnalysis_Data - JMP Pro

File Edit Tables Rows Cols DOE Analyze Graph Tools View Window Help

FactorAnalysis_Data
Source

Columns (21/2)
- Participant ID
- Condition
- Looks_humanlike
- Behaves_humanlike
- Attractive
- Cute
- Cheerful
- Friendly
- Optimistic
- Warm
- Happy
- Knowledgeable
- Responsible
- Intelligent
- Sensible
- Loyal
- Honest
- Cooperative
- Attentive
- You_like_the_robot
- Robot_likes_you

Rows

All rows	29
Selected	0
Excluded	0
Hidden	0
Labelled	0

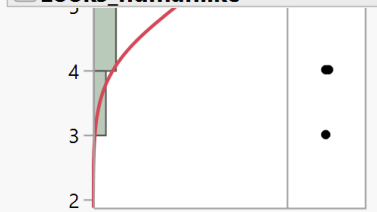
	Participant ID	Condition	Looks_humanlike
1	p01	Control	6
2	p02	Control	6
3	p03	Control	5
4	p04	Control	7
5	p05	Cue	7
6	p06	Cue	6
7	p07	Cue	7
8	p08	Cue	6
9	p09	Cue	6
10	p10	Control	6
11	p11	Control	6
12	p12	Cue	6
13	p13	Cue	5
14	p14	Control	6
15	p15	Control	6
16	p16	Cue	6
17	p17	Cue	6
18	p18	Control	7
19	p19	Control	6
20	p20	Cue	7
21	p21	Control	6
22	p22	Cue	3
23	p23	Control	6
24	p24	Cue	5
25	p25	Control	7
26	p26	Cue	7
27	p27	Control	4
28	p28	Cue	7
29	p29	Cue	4

FactorAnalysis_Data - Distribution of Looks_humanlike, Behaves_humanlike - JMP Pro

File Edit Tables Rows Cols DOE Analyze Graph Tools View Window Help

Distributions

Looks_humanlike



Normal(5.93103,0.99753)

Quantiles

100.0%	maximum	7
99.5%		7
97.5%		7
90.0%		7
75.0%	quartile	7
50.0%	median	6
25.0%	quartile	6
10.0%		4
2.5%		3
0.5%		3
0.0%	minimum	3

Summary Statistics

Mean	5.9310345
Std Dev	0.9975339
Std Err Mean	0.1852374
Upper 95% Mean	6.3104761
Lower 95% Mean	5.5515929
N	29

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	μ	5.9310345	5.5515929	6.3104761
Dispersion	σ	0.9975339	0.7916224	1.3491164

-2log(Likelihood) = 81.1552247582941

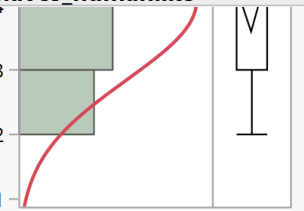
Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.806885	0.0001*

Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.

Behaves_humanlike



Normal(4.03448,1.20957)

Quantiles

100.0%	maximum	6
99.5%		6
97.5%		6
90.0%		6
75.0%	quartile	5
50.0%	median	4
25.0%	quartile	3
10.0%		2
2.5%		2
0.5%		2
0.0%	minimum	2

Summary Statistics

Mean	4.0344828
Std Dev	1.2095678
Std Err Mean	0.2246111
Upper 95% Mean	4.4945777
Lower 95% Mean	3.5743878
N	29

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	μ	4.0344828	3.5743878	4.4945777
Dispersion	σ	1.2095678	0.9598881	1.635882

-2log(Likelihood) = 92.3336935589375

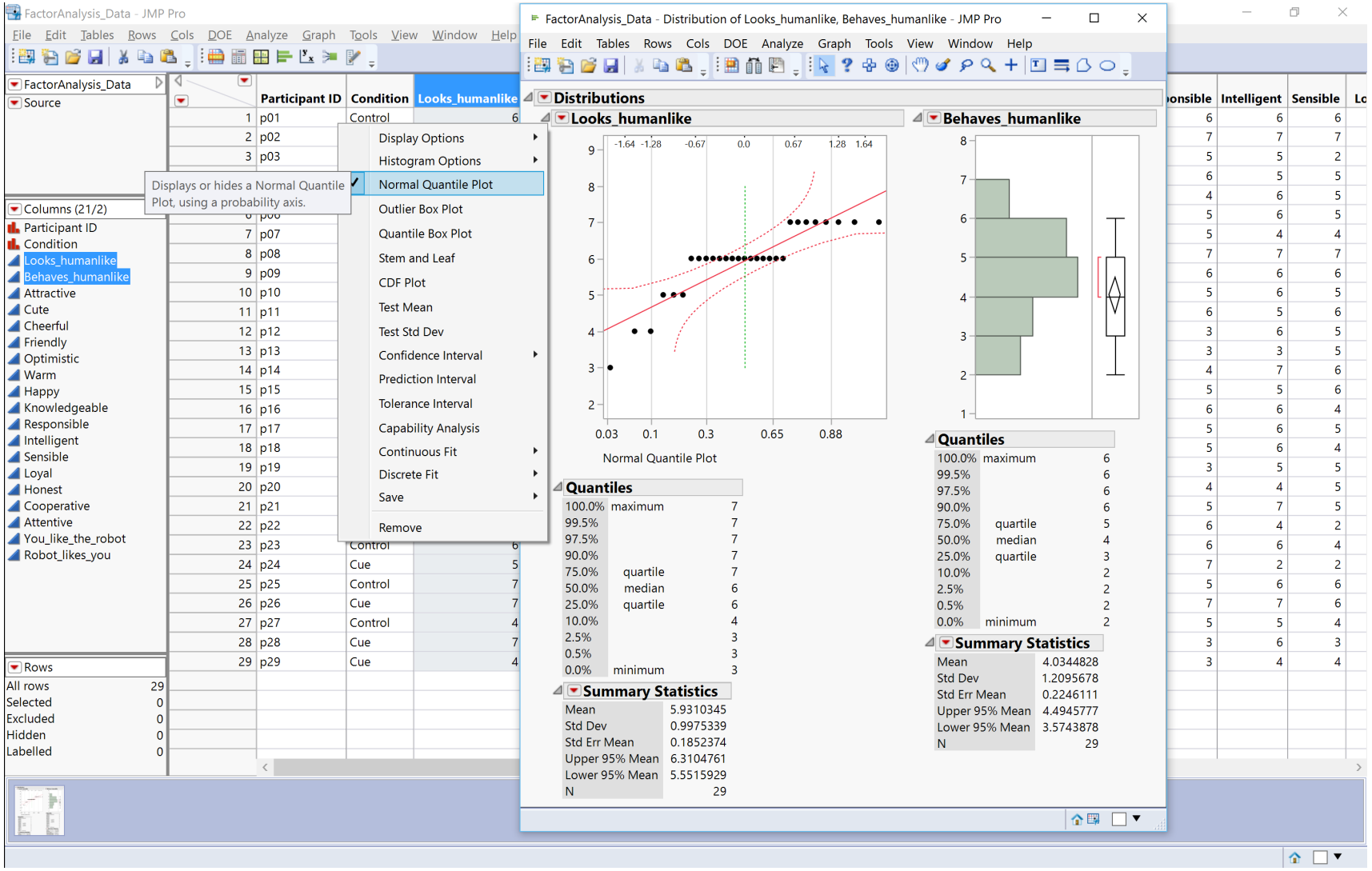
Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.915150	0.0230*

Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.

Normal Probability Plot



Questions?

Reporting Descriptive Statistics

Reporting Decimals

For numbers…	Round to…	Example Raw Value	Example Reported Value
Greater than 100	Whole number	1034.963	1035
10 – 100	1 decimal place	11.4378	11.4
0.10 – 10	2 decimal places	4.3682	4.37
0.001 – 0.10	3 decimal places	0.0352	0.035
Less than 0.001	As many digits as needed for non-zero	0.00038	0.0004

Reporting Tests

Statistic	Example
Mean and standard deviation	$M = 3.45$, $SD = 1.21$
Mann-Whitney	$U = 67.5$, $p = .034$, $r = .38$
Wilcoxon signed-rank	$Z = 4.21$, $p < .001$
Sign test	$Z = 3.47$, $p = .001$
T-test	$t(19) = 2.45$, $p = .031$, $d = 0.54$
ANOVA	$F(2, 1279) = 6.15$, $p = .002$, $\eta_p^2 = 0.010$
Pearson's correlation	$r(1282) = .13$, $p < .001$

The computer use among subjects was very high ($M = 6.27$, $SD = 0.98$) on a scale from 1 to 7. Their familiarity with robots was relatively low ($M = 2.97$, $SD = 1.67$), so was their video gaming experience ($M = 2.92$, $SD = 1.91$).

Mutlu, B., Shiwa, T., Kanda, T., Ishiguro, H., & Hagita, N. (2009). Footing in Human-Robot Conversations: How Robots Might Shape Participant Roles Using Gaze Cues. In Proceedings of the 4th ACM/IEEE Conference on Human-Robot Interaction (HRI'09), March 2009, San Diego, CA.

Table 1 Means and Standard Deviations of Attractiveness Ratings for Avatar Faces

	Female		Male	
Attractiveness	Face 1 *M* (*SD*)	Face 2 *M* (*SD*)	Face 1 *M* (*SD*)	Face 2 *M* (*SD*)
High	5.50 (1.35)	4.32 (1.25)	4.64 (1.19)	4.04 (1.10)
Medium	3.39 (1.47)	3.50 (1.40)	3.11 (1.34)	2.93 (1.65)
Low	2.29 (1.15)	1.18 (0.55)	1.75 (1.11)	1.21 (0.50)

Yee. N. & Bailenson, J. (2007). The Proteus Effect: The Effect of Transformed Self-Representation on Behavior. Human Communication Research, Vol. 33, No. 3. (July 2007), pp. 271-290.

Questions?

Limitations of Descriptive Statistics

Why might descriptive statistics fail to faithfully capture performance?

Limitations of Descriptive Statistics

Why might descriptive statistics fail to faithfully capture performance?

Outliers
Multimodal distributions
Skewed distributions

What we often care about is how the **distribution** of dependent variables changes between independent variables

Inferential Statistics

Inferential Statistics

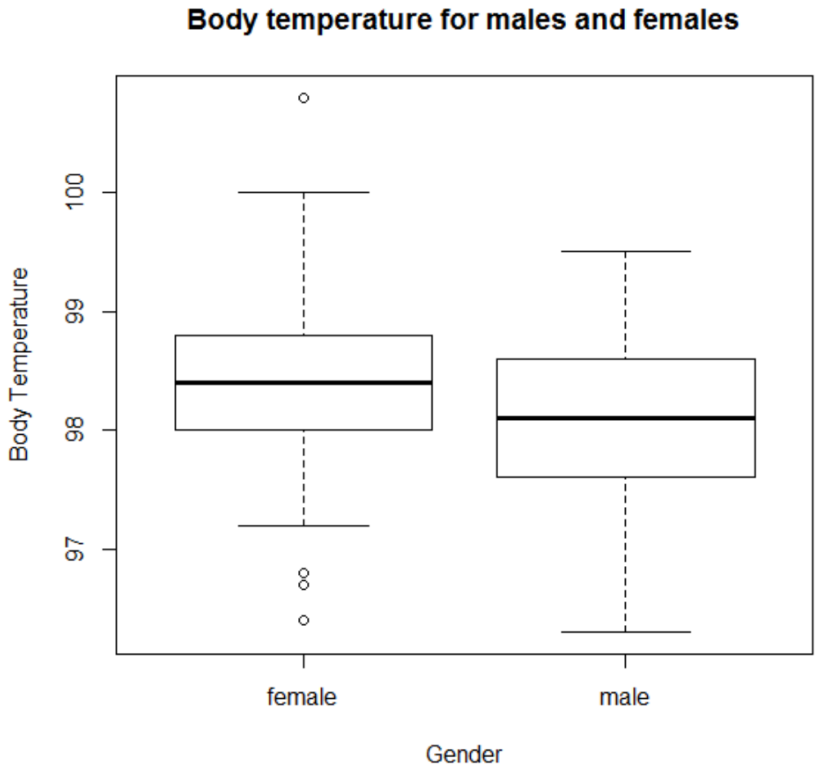
Also called "statistical inference"

Use of drawing **statistical conclusions** on an **unknown aspect** of a population based on data from a **random sample** of the population

"Hypothesis testing"

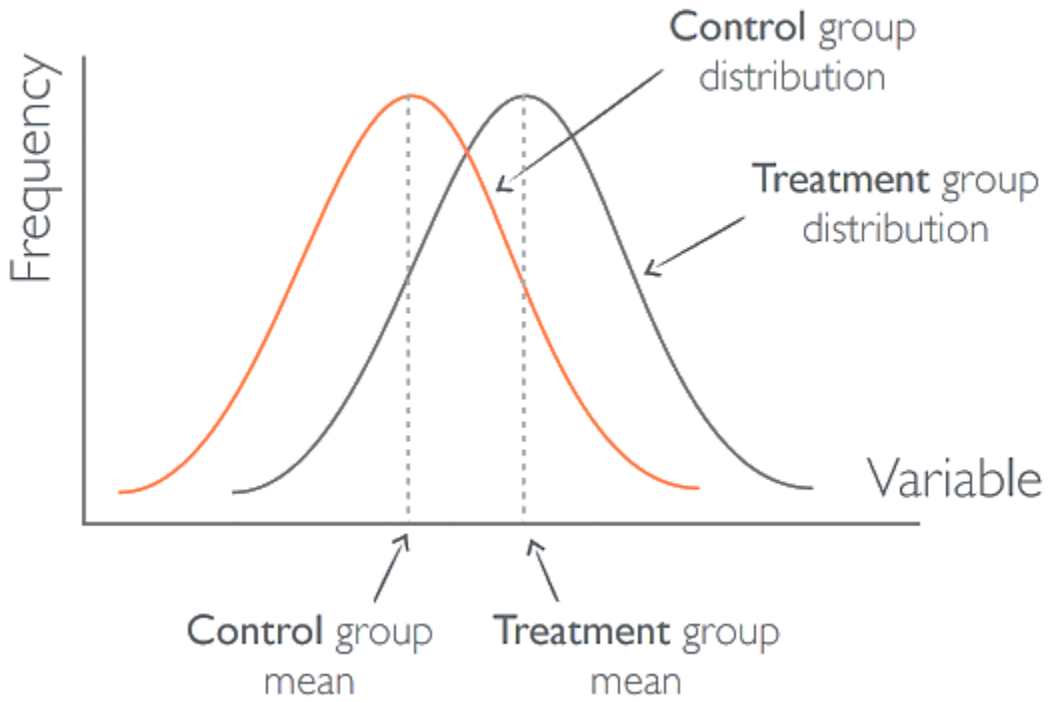
Allows us to make conclusions about whether data was likely drawn from the same or separate distributions

- i.e., did manipulating our independent variables have any effect on the measured values of our dependent variables

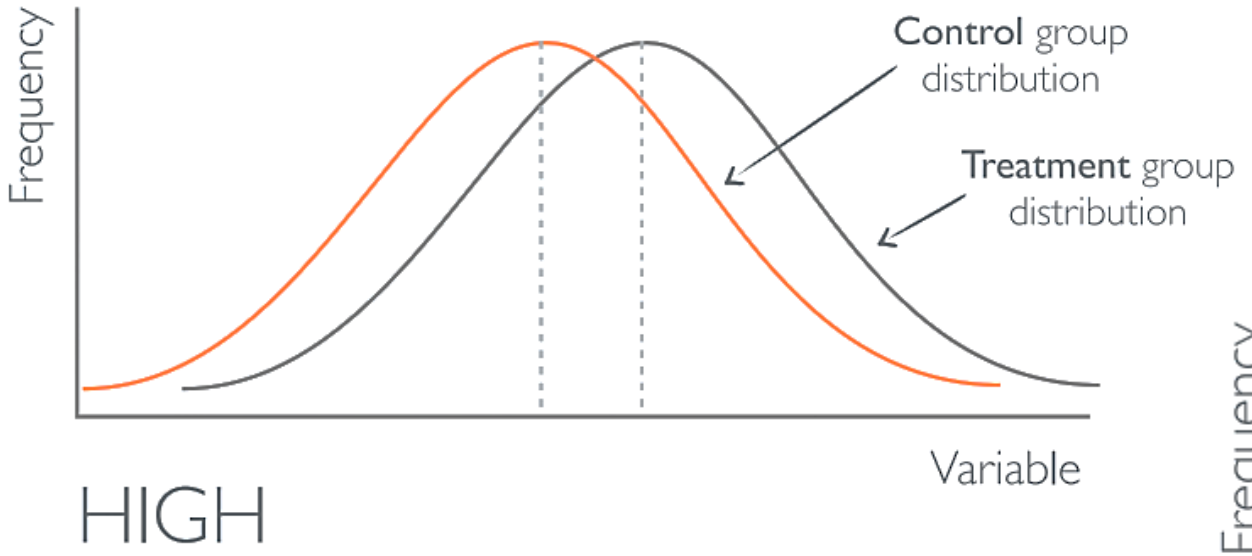


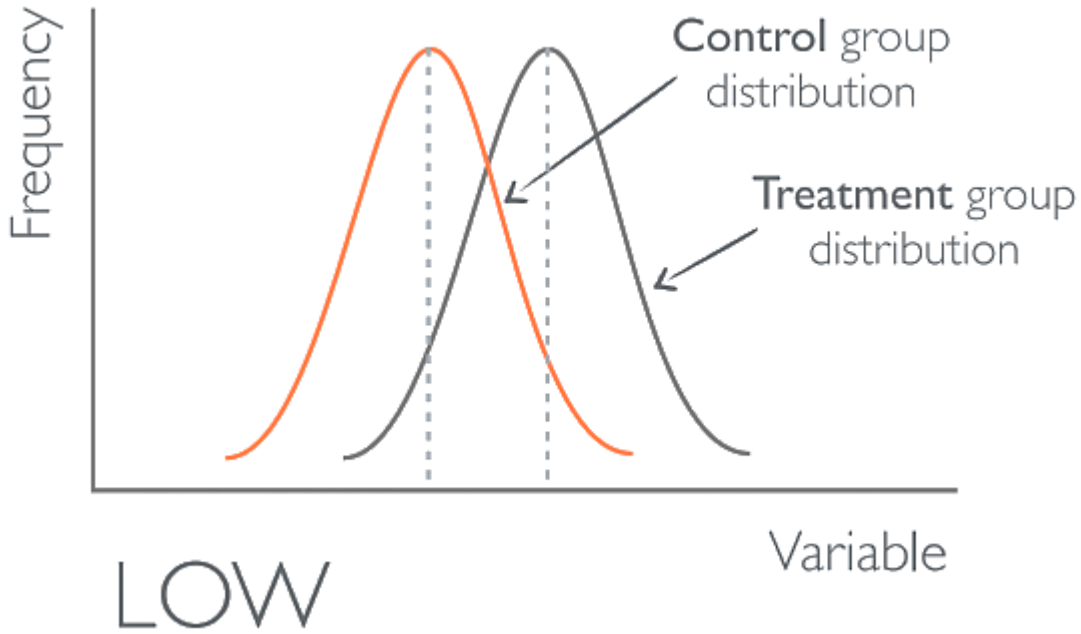
Statistical Difference

Commonly want to determine whether the means of two groups are statistically different



Variability





Significance Testing

- Alpha level (α)
  - Probability of rejecting the null hypothesis if the null hypothesis is true (i.e., P(making a Type 1 error))
  - Sets a "risk" or "significance level"
- Common rule of thumb: $\alpha = 0.05$
  - i.e., we have a 5% chance of incorrectly rejecting H_0
- P-value
  - Probability of obtaining a result as extreme as, or more extreme than, the result actually obtained if the null hypothesis is true
  - If $p < \alpha$ then results are "significant"

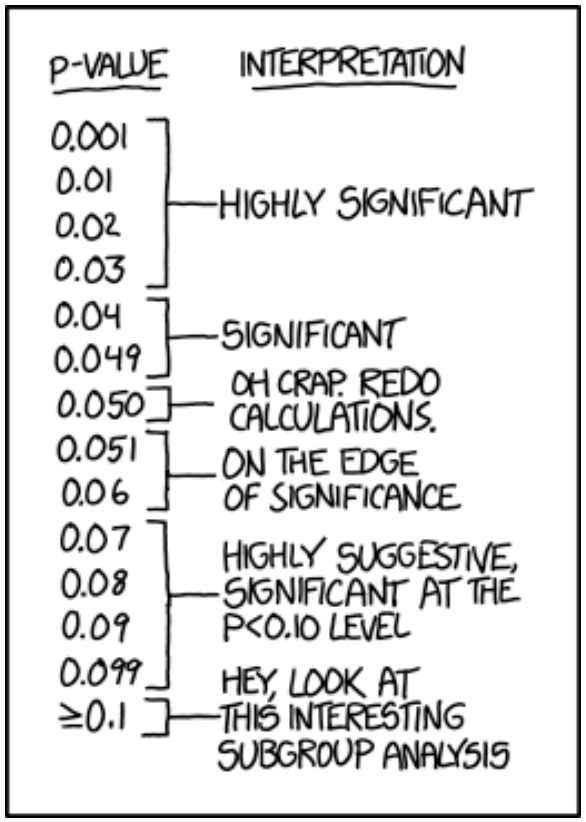
Statistical Errors

Type 1 Error
- Incorrect rejection of the null hypothesis
- E.g., false positive

Type 2 Error
- Incorrectly failing to reject the null hypothesis
- E.g., false negative

Example:
- H_1: Evidence shows that person is guilty
- H_0: Person is innocent
- Type 1 error: convicting person if they really are innocent
- Type 2 error: letting person go free if they are actually guilty

P-value and α level



PHD Comics

Hypothesis

H_0 – Null hypothesis

There is no relationship between two measured phenomena

There is no difference between groups

$\mu_1 = \mu_2$

We always assume this is true

We design and conduct experiments to attempt to disprove this hypothesis!

H_1 – Alternative hypothesis

One-tailed: $\mu_1 < \mu_2$ OR $\mu_1 > \mu$

Two-tailed: $\mu_1 \neq \mu_2$

Can have several alternative hypotheses

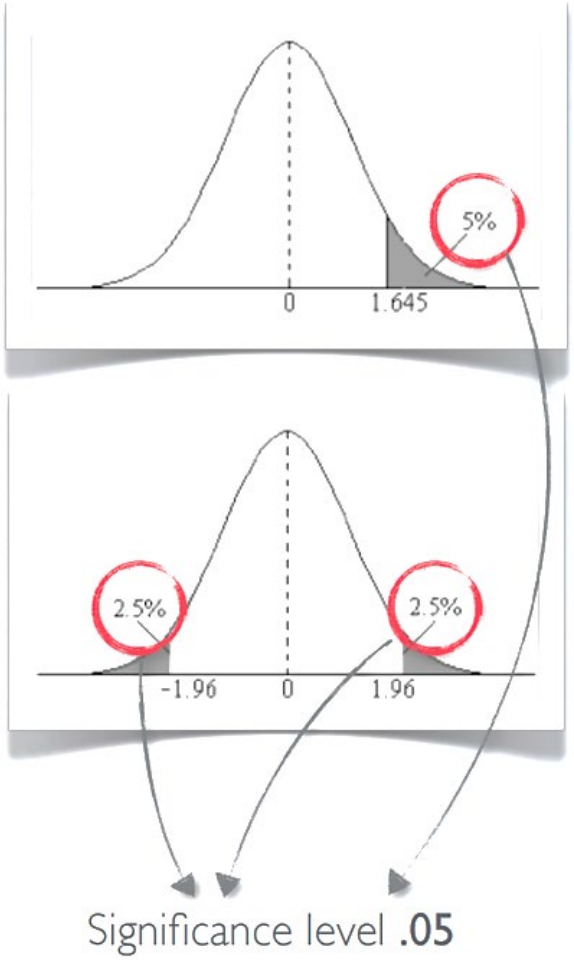
Hypothesis Example

One-tailed

- **H_0:** Robot use of mutual gaze will not affect student learning
- **H_1:** Robot use of mutual gaze will positively affect student learning

Two-tailed

- **H_0:** Robot use of mutual gaze will not affect rapport with the robot
- **H_1:** Robot use of mutual gaze will affect rapport with the robot



Common Inferential Tests

Student's t-test
F-test
Chi-square test
Z-test (normal)
Pearson's chi-square test
Wald test
Mann-Whitney U
Wilcoxon signed-rank test
…

Questions?

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THANKS!

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