Emperical Methods for Marketing Research and Analytics Using R

Prof. Dr. Martin Wetzels
Maastricht University

Maastricht University

About Me

- **Name:** Prof. Dr. Martin Wetzels
  Professor in Marketing and Supply Chain Research

- **Address:** Maastricht University
  School of Business and Economics
  Department of Marketing and SCM
  P.O. Box 616, 6200 MD Maastricht
  Tongersestraat 53, F1.05
  T: +31 43 388 3250/3839
  F: +31 43 388 4918
  E: m.wetzels@maastrichtuniversity.nl
  W: https://www.maastrichtuniversity.nl/m.wetzels

Using R for Basic Analysis

Prof. Dr. Martin Wetzels
Maastricht University

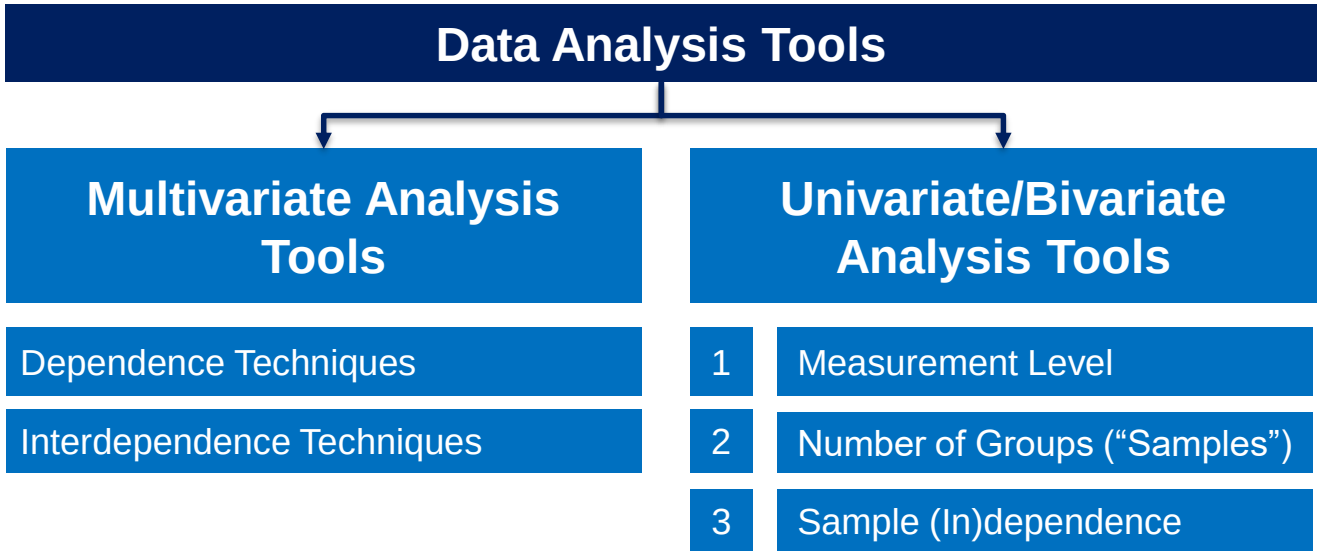
Maastricht University

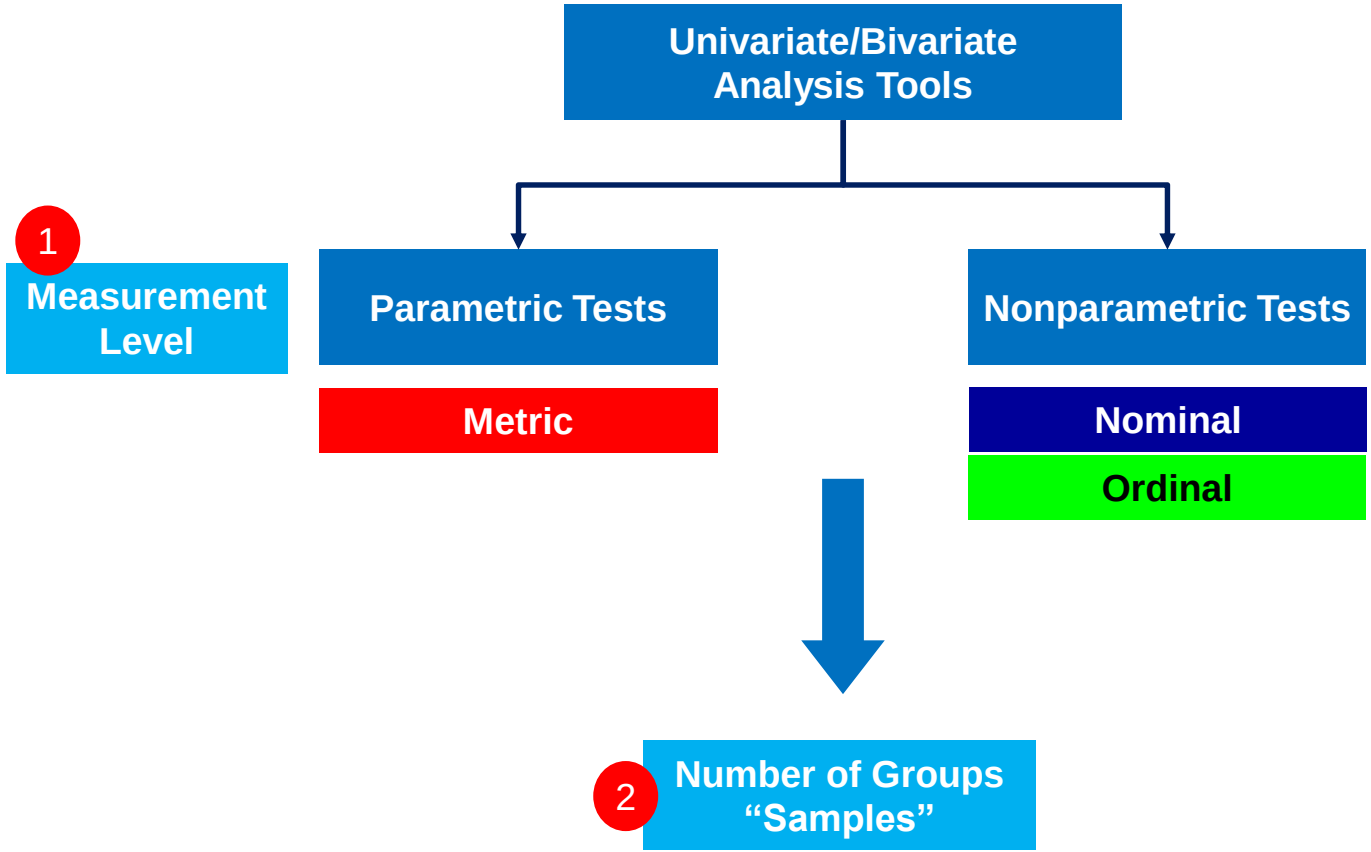
Course Outline

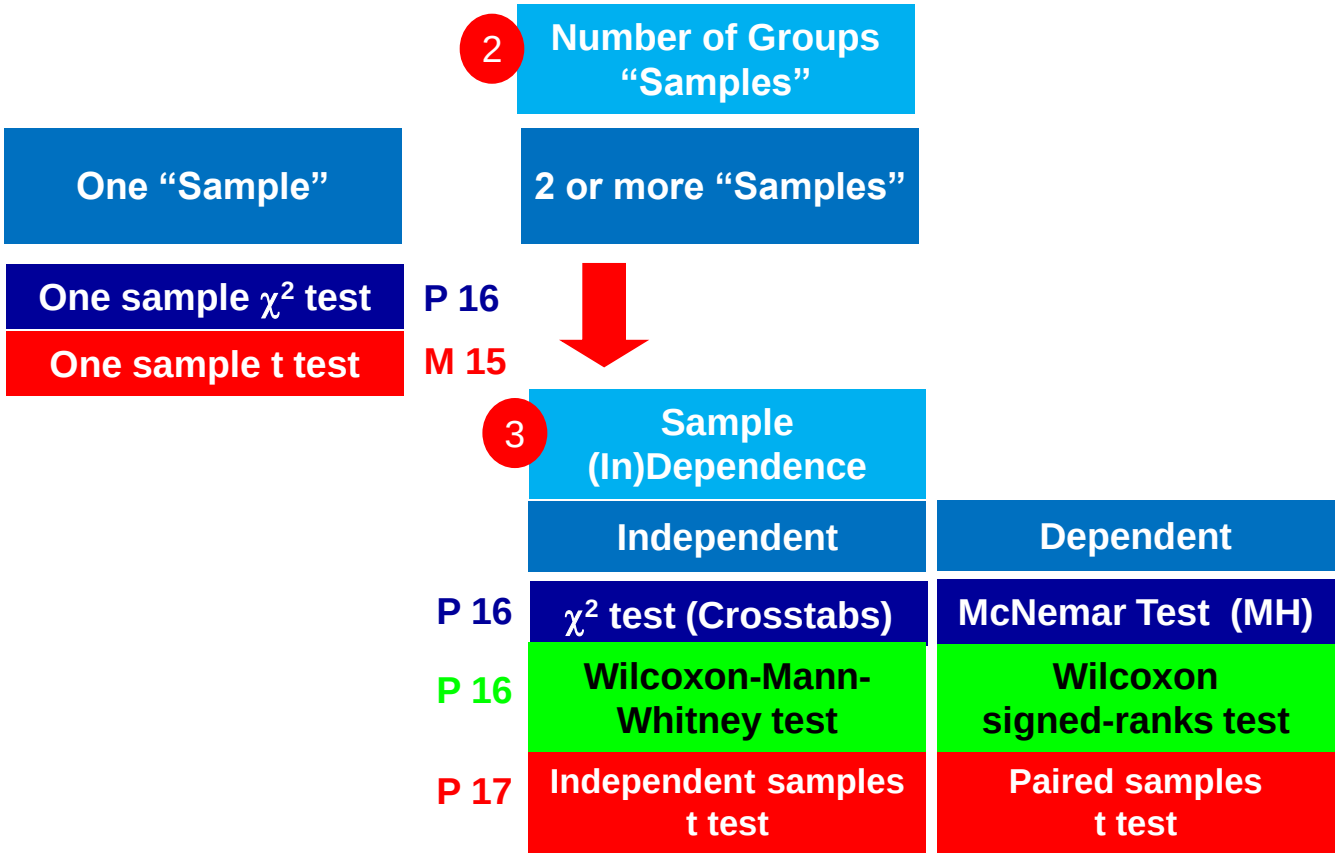
Session:	TOPIC:
DAY 1	
Session 1	INTRODUCING MULTIVARIATE ANALYSIS AND R
Session 2	USING R FOR BASIC ANALYSIS
DAY 2	
Session 3	USING R FOR AN(C)OVA
Session 4	USING R FOR REGRESSION ANALYSIS
DAY 3	
Session 5	USING R FOR SCALING AND FACTOR ANALYSIS
Session 6	USING R FOR SEM and PLS PATH MODELING

Overview over Data Analysis Tools for Marketing Research

Malhotra (2010); Pallant (2016)




Univariate/Bivariate Analysis Tools
1
Measurement Level
Parametric Tests
Metric
Nonparametric Tests
Nominal
Ordinal
2
Number of Groups "Samples"


2
Number of Groups "Samples"
One "Sample"
2 or more "Samples"
One sample χ^2 test
P 16
One sample t test
M 15
3
Sample (In)Dependence
Independent
Dependent
P 16
χ^2 test (Crosstabs)
McNemar Test (MH)
P 16
Wilcoxon-Mann-Whitney test
Wilcoxon signed-ranks test
P 17
Independent samples t test
Paired samples t test

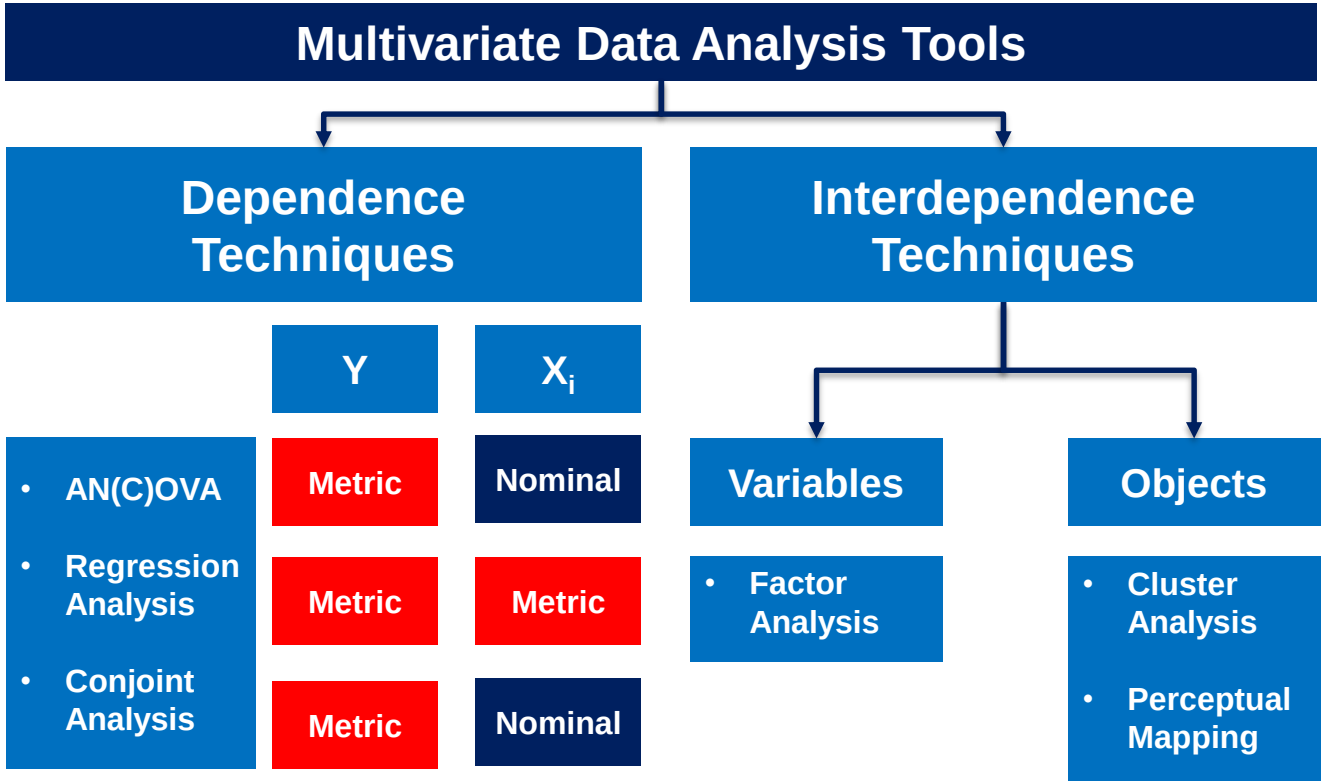
Hypothesis Testing Procedure

Malhotra (2010); Pallant (2016)

1	Research Problem	→	H_0: "No Effect" H_1: "Effect"
2	▪ Choose Appropriate Test Statistic ▪ Specify significance level (α → 0.05)		
3	Collect Data		
4	Calculate Test Statistic and Probability Value (p value)		
5	If $p \leq \alpha$, reject H_0 If $p > \alpha$, do not reject H_0		

Data Analysis Tools

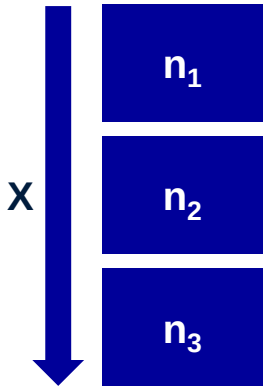
Hair et al. (2018); Malhotra (2010)



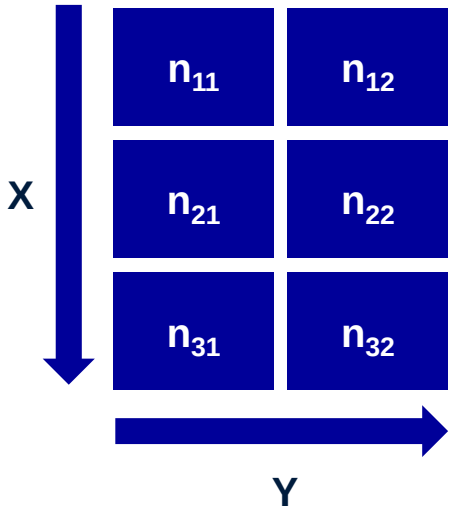
Refresher: Comparing Frequencies: χ^2 Tests

Malhotra (2010); Pallant (2016)

One-Sample χ^2 Test



"Two-Sample" χ^2 Test for Cross-Tabulations



χ^2 Tests

Malhotra (2010); Pallant (2016)

- One-Sample χ^2 Test
  - Assumptions
    - Independent (Random) Sample
    - Nominal Data with two or more categories
    - Theory for Expected Distribution
  - Hypotheses

    H_0: Expected Frequencies (E) = Observed Frequencies (O)

    H_1: Expected Frequencies (E) ≠ Observed Frequencies (O)

χ^2 Tests

Malhotra (2010); Pallant (2016)

- One-Sample χ^2 Test
  - Limiting conditions one-sample chi-square test
    - df =1 (or k = 2)
      Each Expected Frequency (E) should be ≥ 5
    - df >1 (or k > 2)
      No more than 20 percent of Expected Frequencies (E) < 5
      No Expected Frequencies (E) < 1

SPSS evaluates these limiting conditions

χ^2 Tests

Malhotra (2010); Pallant (2016)

- "Two-sample" χ^2 Test for Cross-Tabulations
  - Assumptions
    - Independent (Random) Samples
    - Nominal Data with two or more categories (for X and Y)
    - Theory for Expected Distribution (*Independence!*)
  - Hypotheses

    H_0: X and Y are independent

    H_1: X and Y are not independent

χ^2 Tests

Malhotra (2010); Pallant (2016)

- "Two-sample" χ^2 Test for Cross-Tabulations
  - Limiting Conditions
    - df = 1 (2*2 cross-table)

      $N \geq 20$ → Fischer Exact Test

      $20 < N \leq 40$ → $E_{ij} \geq 5$ → χ^2 Test

      → $E_{ij} < 5$ → Fischer Exact Test

      $N > 40$ → χ^2 Test with continuity correction

    - df > 1 (r*k cross-table)

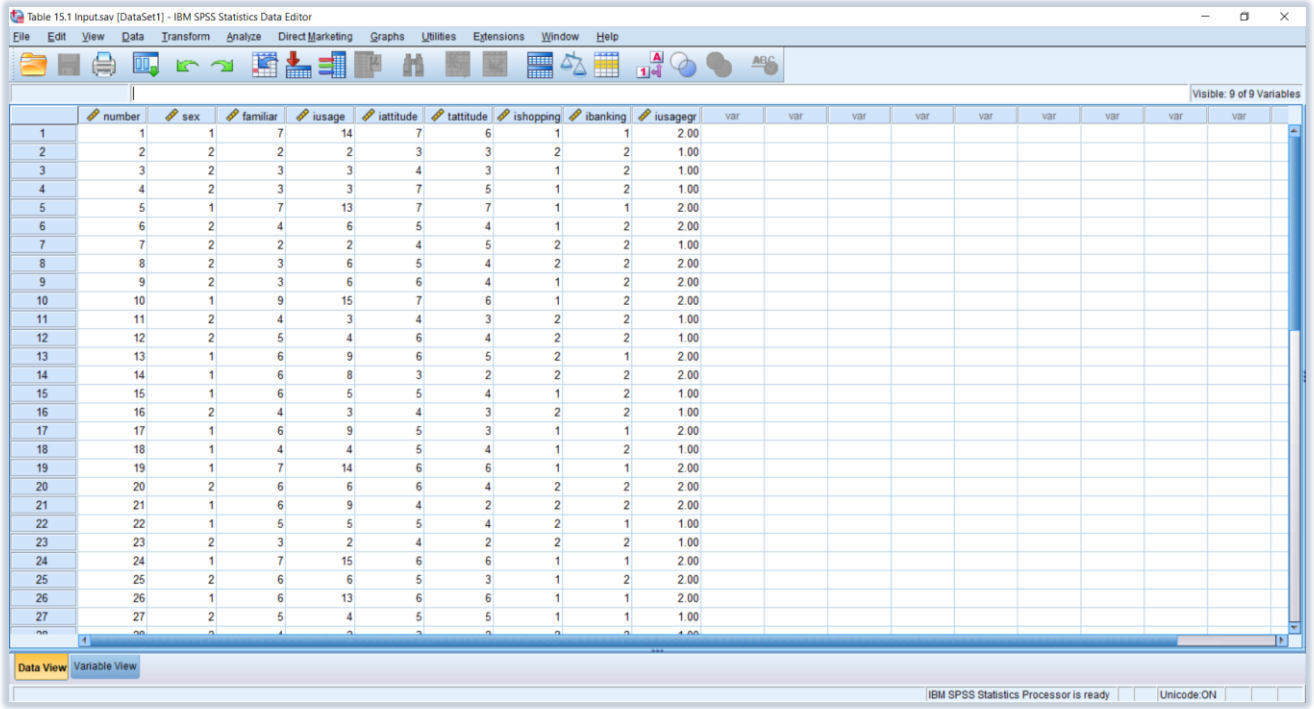
      $E_{ij} < 5$ → Fewer than 20% of the Cells

      $E_{ij} < 1$ → No Cell

SPSS evaluates these limiting conditions and presents the appropriate test

SPSS Data File: Internet Usage Data

Malhotra (2010, Table 15.1)

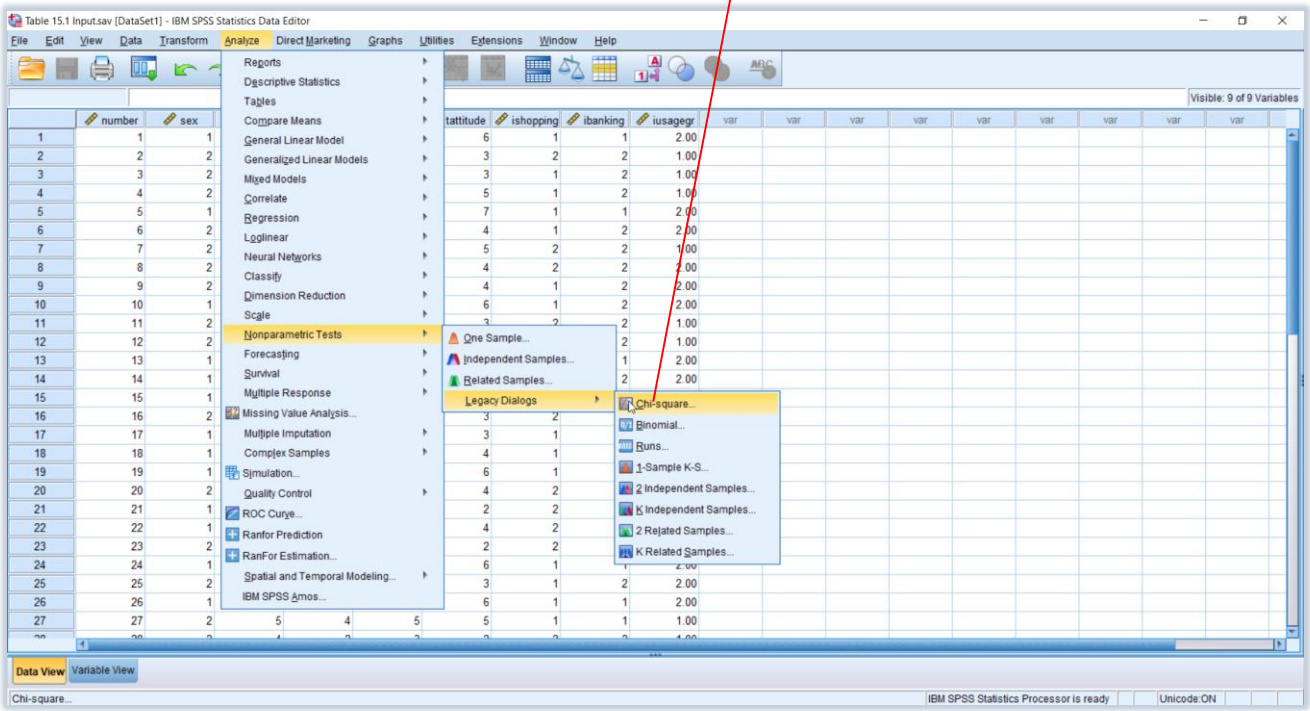


	number	sex	familiar	iusage	iattitude	tattitude	ishopping	ibanking	iusagegr
1	1	1	7	14	7	6	1	1	2.00
2	2	2	2	2	3	3	2	2	1.00
3	3	2	3	3	4	3	1	2	1.00
4	4	2	3	3	7	5	1	2	1.00
5	5	1	7	13	7	7	1	1	2.00
6	6	2	4	6	5	4	1	2	2.00
7	7	2	2	2	4	5	2	2	1.00
8	8	2	3	6	5	4	2	2	2.00
9	9	2	3	6	6	4	1	2	2.00
10	10	1	9	15	7	6	1	2	2.00
11	11	2	4	3	4	3	2	2	1.00
12	12	2	5	4	6	4	2	2	1.00
13	13	1	6	9	6	5	2	1	2.00
14	14	1	6	8	3	2	2	2	2.00
15	15	1	6	5	5	4	1	2	1.00
16	16	2	4	3	4	3	2	2	1.00
17	17	1	6	9	5	3	1	1	2.00
18	18	1	4	4	5	4	1	2	1.00
19	19	1	7	14	6	6	1	1	2.00
20	20	2	6	6	6	4	2	2	2.00
21	21	1	6	9	4	2	2	2	2.00
22	22	1	5	5	5	4	2	1	1.00
23	23	2	3	2	4	2	2	2	1.00
24	24	1	7	15	6	6	1	1	2.00
25	25	2	6	6	5	3	1	2	2.00
26	26	1	6	13	6	6	1	1	2.00
27	27	2	5	4	5	5	1	1	1.00

χ^2 Tests

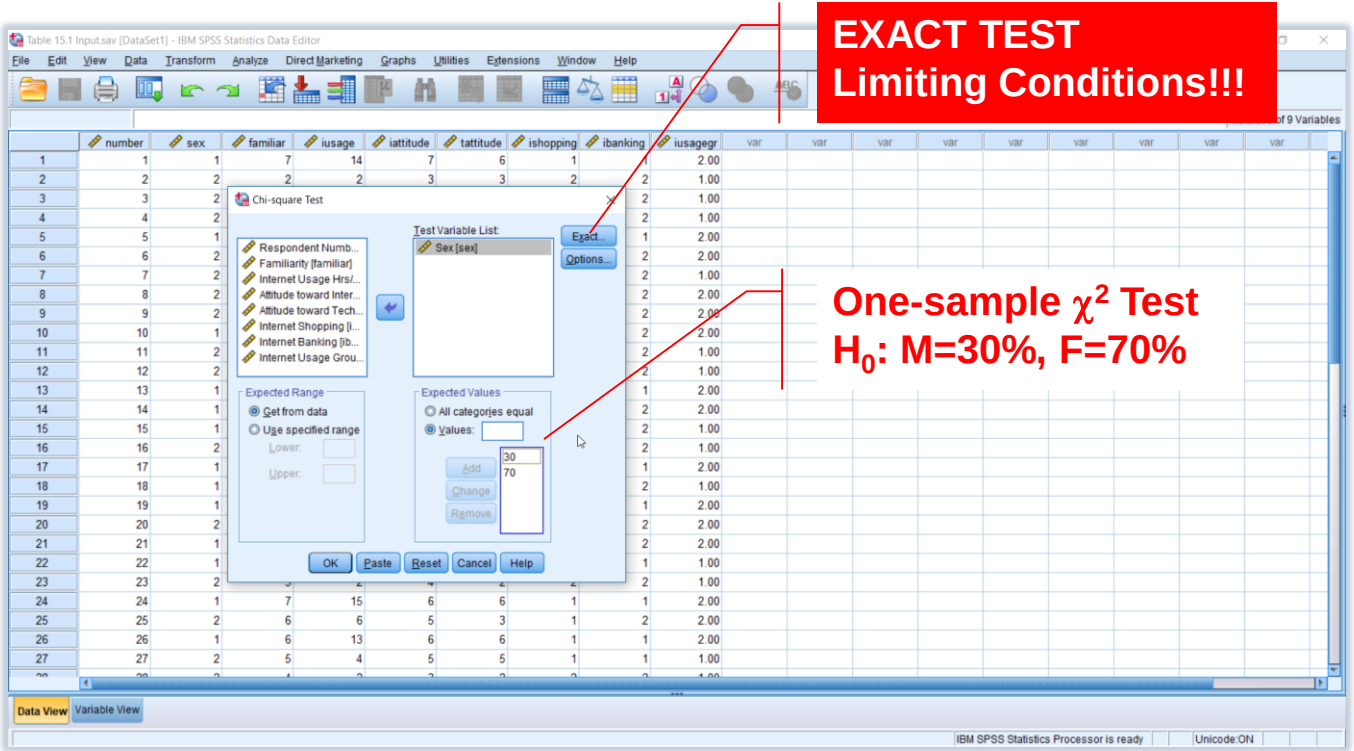
Internet Usage Data (Malhotra, 2010, Table 15.1)

One-Sample χ^2 Test



χ^2 Tests

Internet Usage Data (Malhotra, 2010, Table 15.1)



χ^2 Tests

Internet Usage Data (Malhotra, 2010, Table 15.1)

One-sample χ^2 Test

H_0: M=30% (=9), F=70%(=21)

Sex

	Observed N	Expected N	Residual
Male	15	9.0	6.0
Female	15	21.0	-6.0
Total	30		

Test Statistics

	Sex
Chi-Square	5.714[a]
df	1
Asymp. Sig.	.017
Exact Sig.	.026
Point Probability	.018

a. 0 cells (.0%) have expected frequencies less than 5. The minimum expected cell frequency is 9.0.

χ^2 (1)=5.714 (p=0.017)

$$\chi^2 = \sum \frac{(O_{ij}-E_{ij})^2}{E_{ij}}$$

$$\chi^2 = \frac{6^2}{9} + \frac{6^2}{21} = 5.714$$

Sex

	Observed N	Expected N	Residual
Male	15	15.0	.0
Female	15	15.0	.0
Total	30		

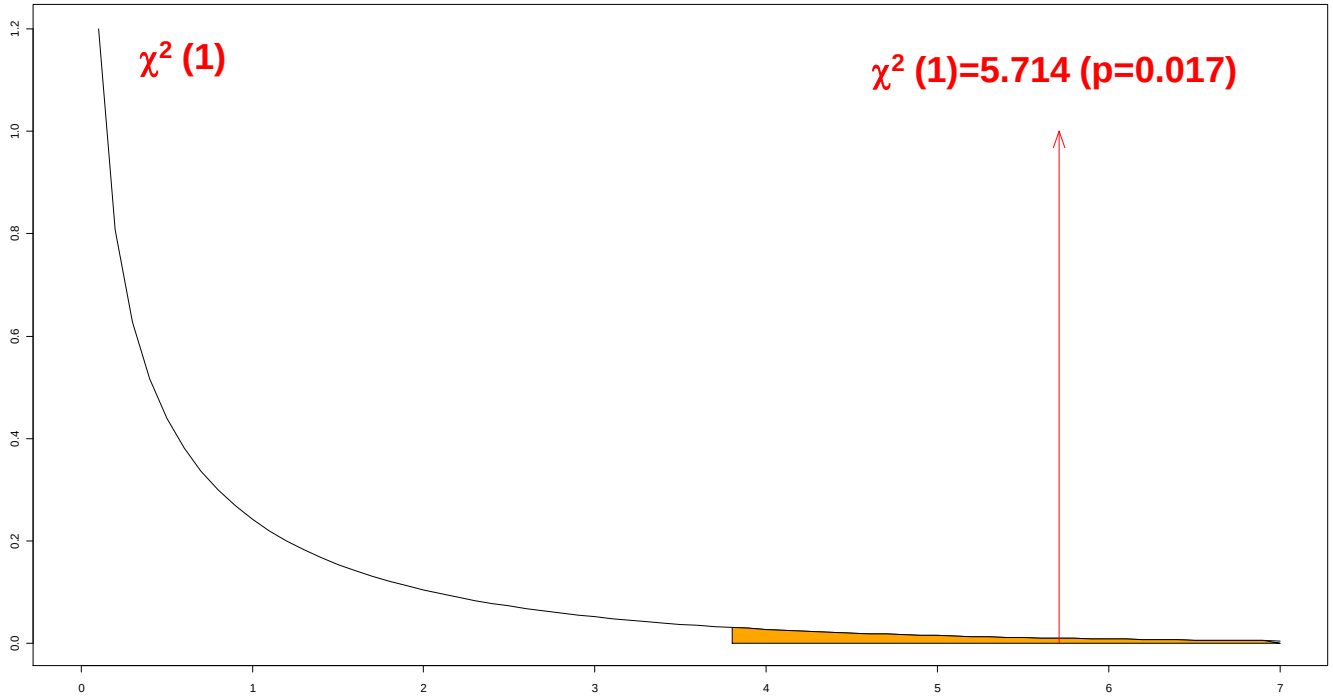
Test Statistics

	Sex
Chi-Square	.000[a]
df	1
Asymp. Sig.	1.000
Exact Sig.	1.000
Point Probability	.144

a. 0 cells (.0%) have expected frequencies less than 5. The minimum expected cell frequency is 15.0.

χ^2 Tests

Internet Usage Data (Malhotra, 2010, Table 15.1)



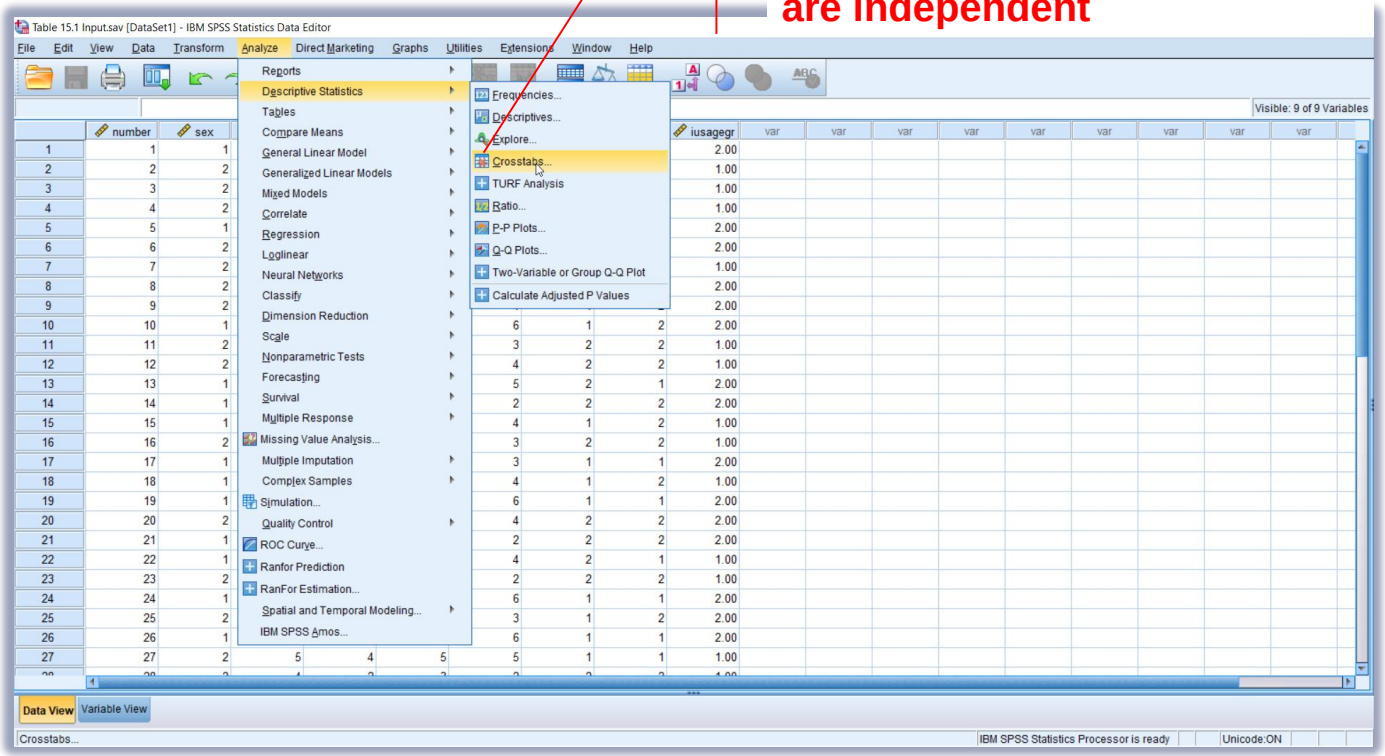
Rejection Region [3.84,→]

χ^2 Tests

Internet Usage Data (Malhotra, 2010, Table 15.1)

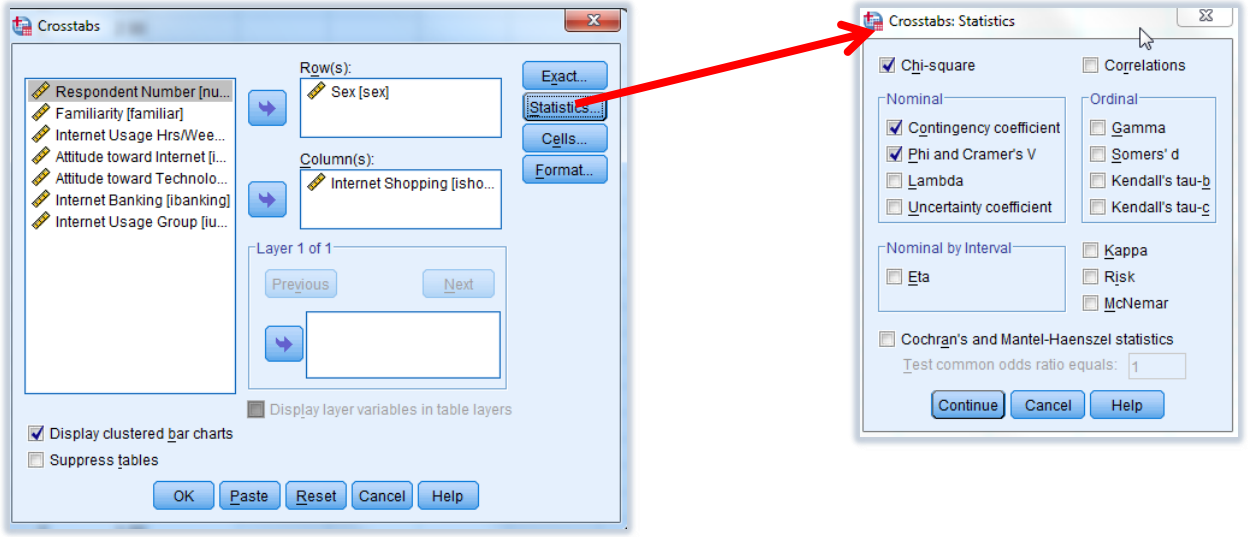
χ^2 Test for Crosstabulations

H_0: Sex and Internet shopping are independent



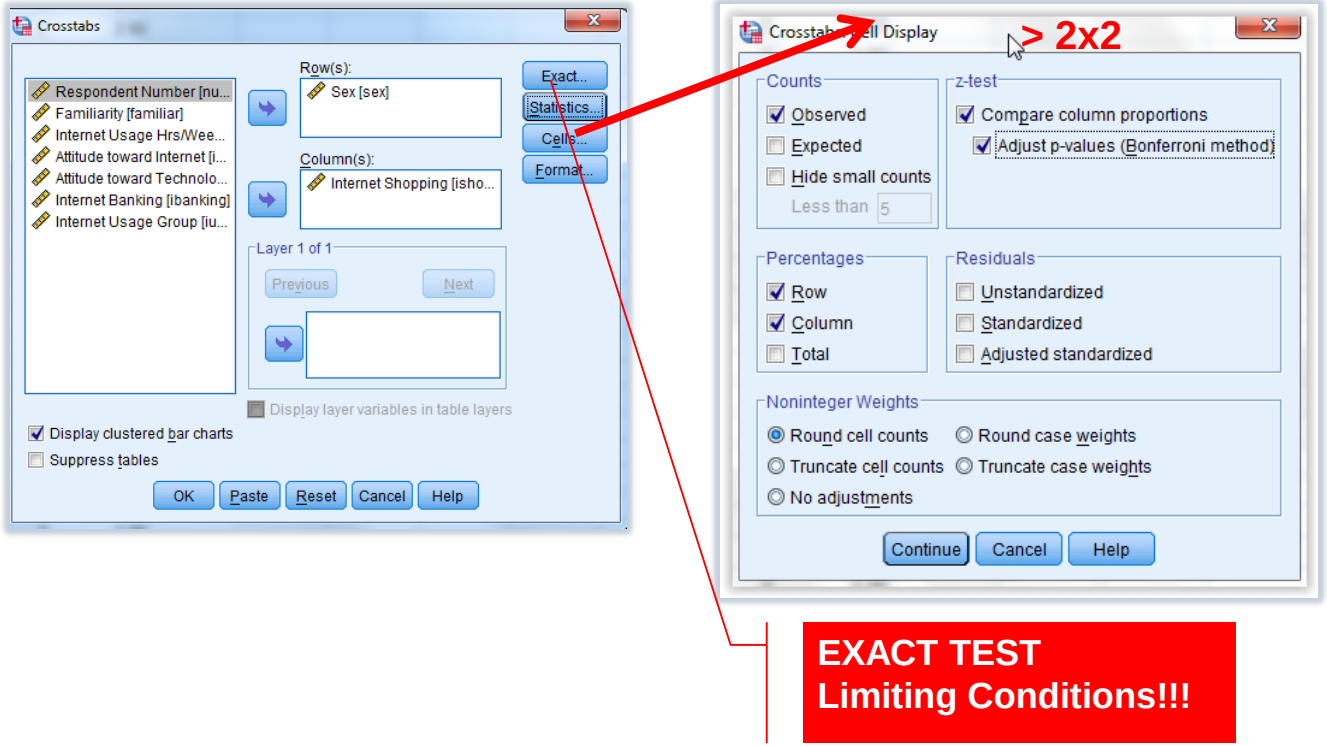
χ^2 Tests

Internet Usage Data (Malhotra, 2010, Table 15.1)



χ^2 Tests

Internet Usage Data (Malhotra, 2010, Table 15.1)



χ^2 Tests

Internet Usage Data (Malhotra, 2010, Table 15.1)

Sex * Internet Shopping Crosstabulation

			Internet Shopping		
			Yes	No	Total
Sex	Male	Count	11	4	15
		% within Sex	73.3%	26.7%	100.0%
		% within Internet Shopping	64.7%	30.8%	50.0%
	Female	Count	6	9	15
		% within Sex	40.0%	60.0%	100.0%
		% within Internet Shopping	35.3%	69.2%	50.0%
Total		Count	17	13	30
		% within Sex	56.7%	43.3%	100.0%
		% within Internet Shopping	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	3.394[a]	1	.065		
Continuity Correction[b]	2.172	1	.141		
Likelihood Ratio	3.466	1	.063		
Fisher's Exact Test				.139	.070
Linear-by-Linear Association	3.281	1	.070		
N of Valid Cases	30				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 6.50.
b. Computed only for a 2x2 table

!

Crosstabulation

H_0: Sex and Internet shopping are independent

$\chi^2(1)=3.394$ ($p=0.065$)

$\chi^2_{CC}(1)=2.172$ ($p=0.141$) → (2*2)

EXACT TEST
Limiting Conditions!!!

χ^2 Tests

Internet Usage Data (Malhotra, 2010, Table 15.1)

sex * ishopping Crosstabulation

			ishopping		
			1 Yes	2 No	Total
sex	1 Male	Count	22	8	30
		% within sex	73.3%	26.7%	100.0%
		% within ishopping	64.7%	30.8%	50.0%
	2 Female	Count	12	18	30
		% within sex	40.0%	60.0%	100.0%
		% within ishopping	35.3%	69.2%	50.0%
Total		Count	34	26	60
		% within sex	56.7%	43.3%	100.0%
		% within ishopping	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	6.787[a]	1	.009		
Continuity Correction[b]	5.498	1	.019		
Likelihood Ratio	6.932	1	.008		
Fisher's Exact Test				.018	.009
Linear-by-Linear Association	6.674	1	.010		
N of Valid Cases	60				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 13.00.

b. Computed only for a 2x2 table

!

Crosstabulation
Double Sample Size

H_0: Sex and Internet shopping are independent

$\chi^2(1)=6.787$ (p=0.009)

$\chi^2_{CC}(1)=5.498$ (p=0.019) → (2*2)

χ^2 Tests

Internet Usage Data (Malhotra, 2010, Table 15.1)

$$\chi^2 = \sum \frac{(O_{ij} - E_{ij})^2}{E_{ij}}$$

Sex * Internet Shopping Crosstabulation

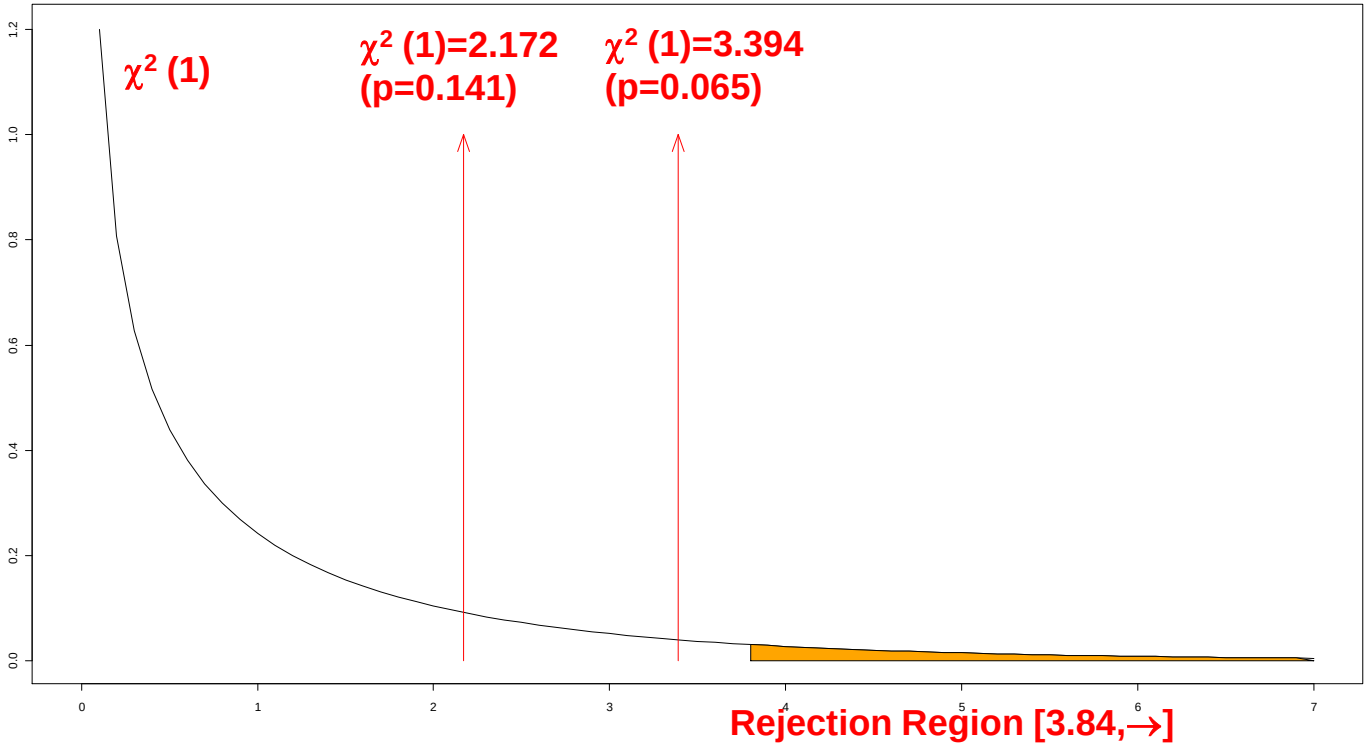
			Internet Shopping		
			Yes	No	Total
Sex	Male	Count	11	4	15
		Expected Count	8.5	6.5	15.0
		Residual	2.5	-2.5	
	Female	Count	6	9	15
		Expected Count	8.5	6.5	15.0
		Residual	-2.5	2.5	
Total		Count	17	13	30
		Expected Count	17.0	13.0	30.0

$$E_{11} = \frac{(15*17)}{30} = 8.5$$

$$\chi^2 = \frac{2.5^2}{8.5} + \frac{-2.5^2}{6.5} + \frac{-2.5^2}{8.5} + \frac{2.5^2}{6.5} = 3.3937$$

χ^2 Tests

Internet Usage Data (Malhotra, 2010, Table 15.1)



χ^2 Tests

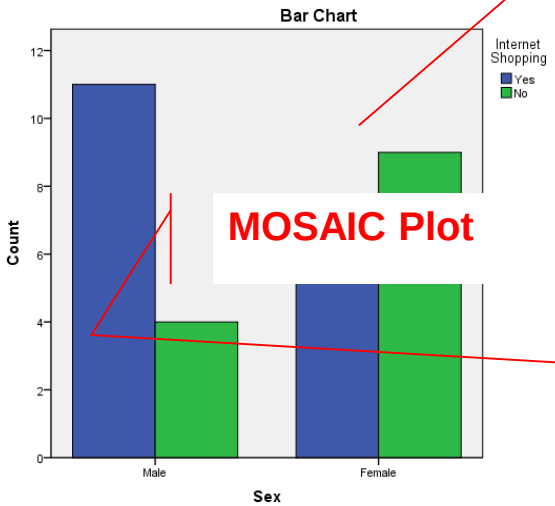
Internet Usage Data (Malhotra, 2010, Table 15.1)

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	.336	.065
	Cramer's V	.336	.065
	Contingency Coefficient	.319	.065
N of Valid Cases		30	

EFFECT SIZE!

Clustered Bar Chart



MOSAIC Plot

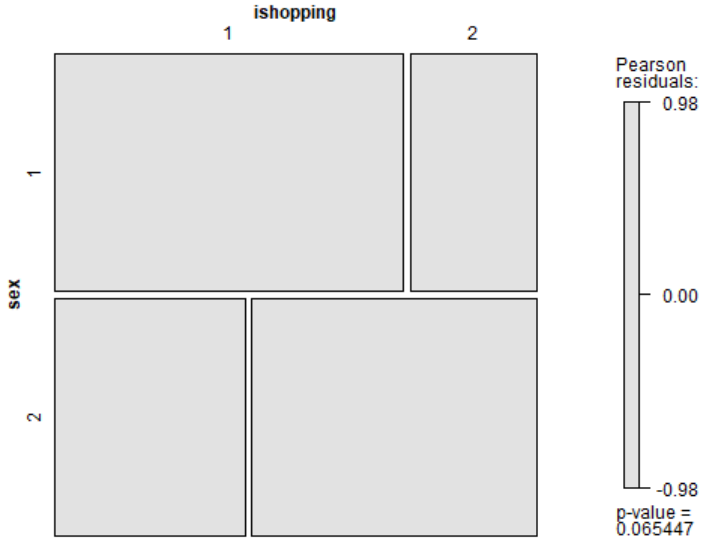
χ^2 Tests

Internet Usage Data (Malhotra, 2010, Table 15.1)

```
1   * Encoding: UTF-8.
2   * Mosaic plot.
3
4   * Open SPSS Data File.
5
6   BEGIN PROGRAM R.
7
8   # Mosaic plot
9
10  install.packages("vcd", repos="http://cran.rstudio.com")
11  library(vcd)
12
13  DATA<-spssdata.GetDataFromSPSS()
14
15  mosaic(~sex + ishopping, data=DATA, shade=TRUE, legend=TRUE)
16
17  END PROGRAM.
18
```

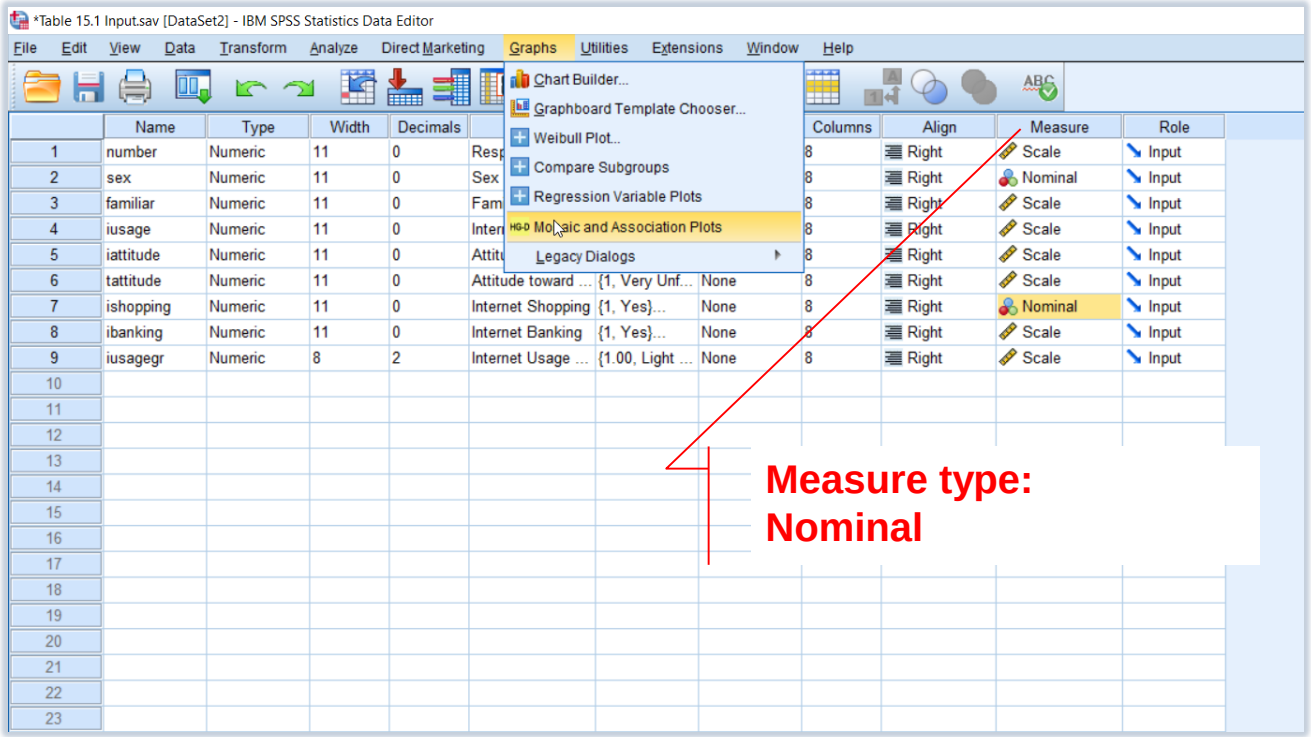
χ^2 Tests

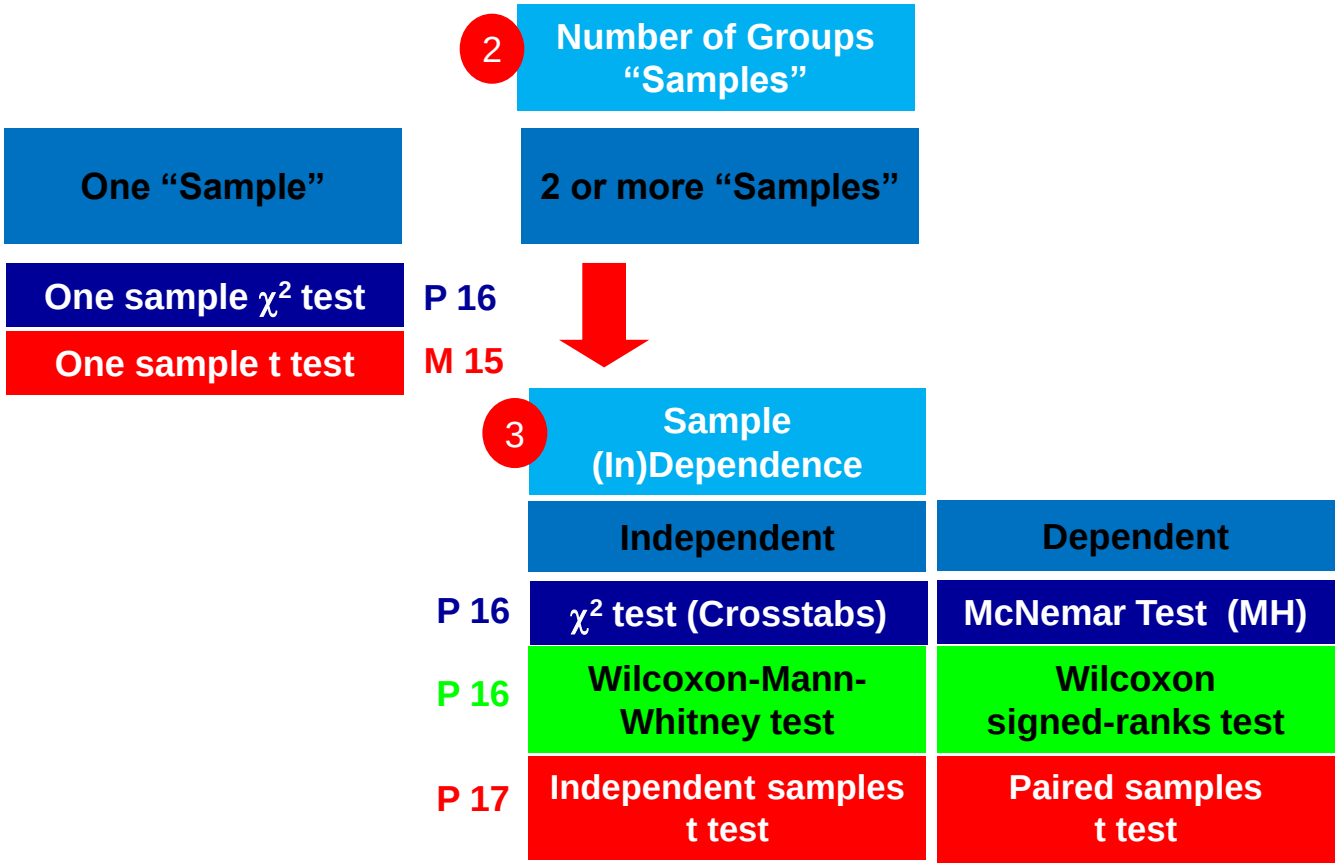
Internet Usage Data (Malhotra, 2010, Table 15.1)



χ^2 Tests

Internet Usage Data (Malhotra, 2010, Table 15.1)




2
Number of Groups "Samples"
One "Sample"
2 or more "Samples"
One sample χ^2 test
P 16
One sample t test
M 15
3
Sample (In)Dependence
Independent
Dependent
P 16
χ^2 test (Crosstabs)
McNemar Test (MH)
P 16
Wilcoxon-Mann-Whitney test
Wilcoxon signed-ranks test
P 17
Independent samples t test
Paired samples t test

Chi-Square Goodness of Fit

Editor

```
1
2
3   # Chi Square Goodness of Fit Test
4
5   attach(Table15.1)
6
7   table(sex)
8
9   ftable(sex)
10
11  prop.table(table(sex))
12
13
14  chisq.test(table(sex), p = c(0.30,0.70))
15
16  chisq.test(table(sex), p = c(0.30,0.70), simulate.p.value=TRUE)
17
18
19
```

Chi-Square Goodness of Fit

Console

```
> table(sex)
sex
 1  2
15 15
>
> ftable(sex)
sex  1  2

    15 15
>
> prop.table(table(sex))
sex
  1   2
0.5 0.5
>
>
> chisq.test(table(sex), p = c(0.30,0.70))

 Chi-squared test for given probabilities

data:  table(sex)
X-squared = 5.7143, df = 1, p-value = 0.01683

>
> chisq.test(table(sex), p = c(0.30,0.70), simulate.p.value=TRUE)

 Chi-squared test for given probabilities with simulated p-value (based on
 2000 replicates)

data:  table(sex)
X-squared = 5.7143, df = NA, p-value = 0.02099
```

Chi-Square Test for Independence (Crosstabs)

Editor

```
20
21  # Chi Square for Crosstabulation
22
23  chisq.test(table(sex,ishopping))
24
25  chisq.test(table(sex,ishopping), correct=FALSE)
26
27  chisq.test(table(sex,ishopping), simulate.p.value=TRUE)
28
29  # Package vcd
30
31  library(vcd)
32
33  fisher.test(table(sex,ishopping))
34
35  assocstats(table(sex,ishopping))
36
37
38
```

Chi-Square Test for Independence (Crosstabs)

Console

```
> chisq.test(table(sex,ishopping))

 Pearson's Chi-squared test with Yates' continuity correction

data:  table(sex, ishopping)
X-squared = 2.1719, df = 1, p-value = 0.1405

>
> chisq.test(table(sex,ishopping), correct=FALSE)

 Pearson's Chi-squared test

data:  table(sex, ishopping)
X-squared = 3.3937, df = 1, p-value = 0.06545
```

Chi-Square Test for Independence (Crosstabs)

Console

```
> fisher.test(table(sex,ishopping))

 Fisher's Exact Test for Count Data

data:  table(sex, ishopping)
p-value = 0.1394
alternative hypothesis: true odds ratio is not equal to 1
95 percent confidence interval:
  0.7101042 25.9039064
sample estimates:
odds ratio
  3.919659

>
> assocstats(table(sex,ishopping))
                    X^2 df P(> X^2)
Likelihood Ratio 3.4661  1 0.062639
Pearson          3.3937  1 0.065447

Phi-Coefficient   : 0.336
Contingency Coeff.: 0.319
Cramer's V        : 0.336
```

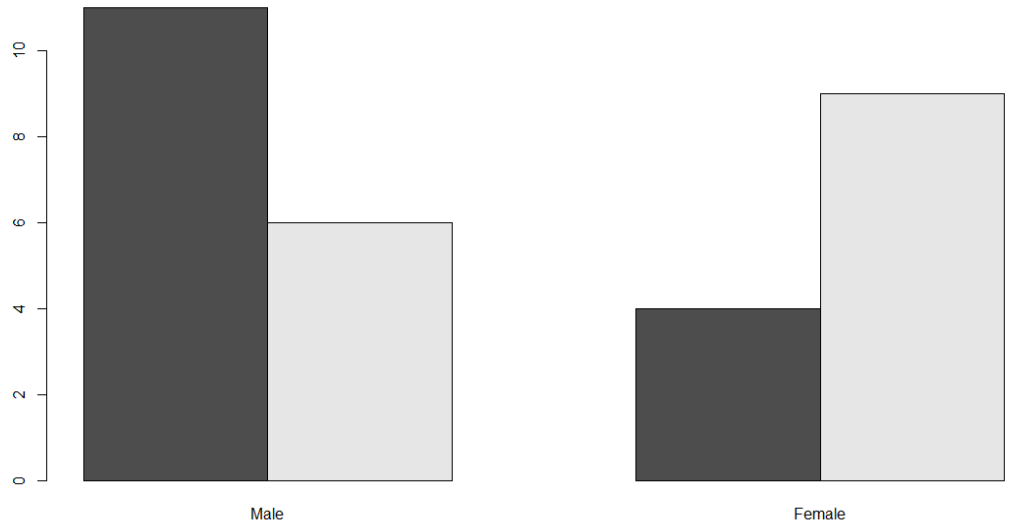
Graphs

Editor

```
39
40  # Plots
41
42  barplot(table(sex,ishopping), names.arg=c("Male", "Female"), beside=TRUE)
43
44  mosaicplot(table(sex,ishopping),color=c("red", "blue"))
45
46
```

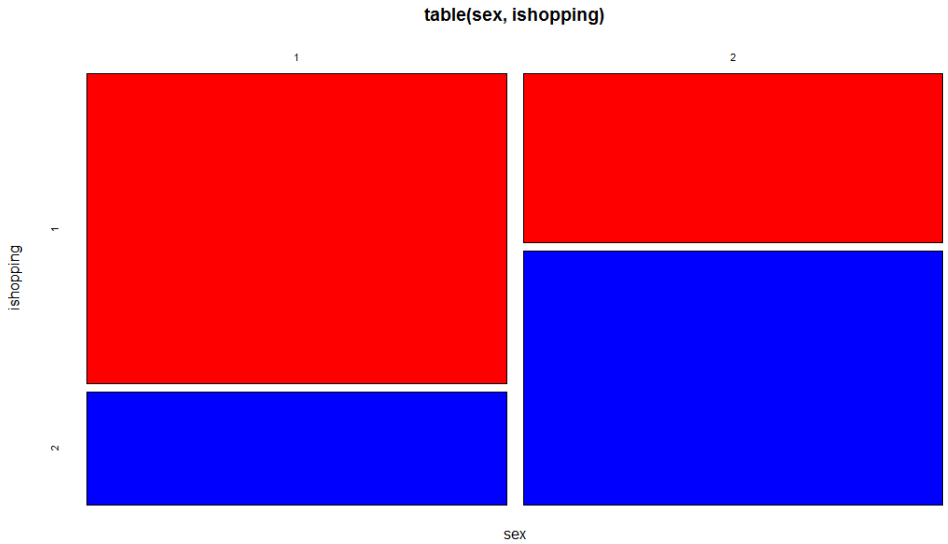
Graphs

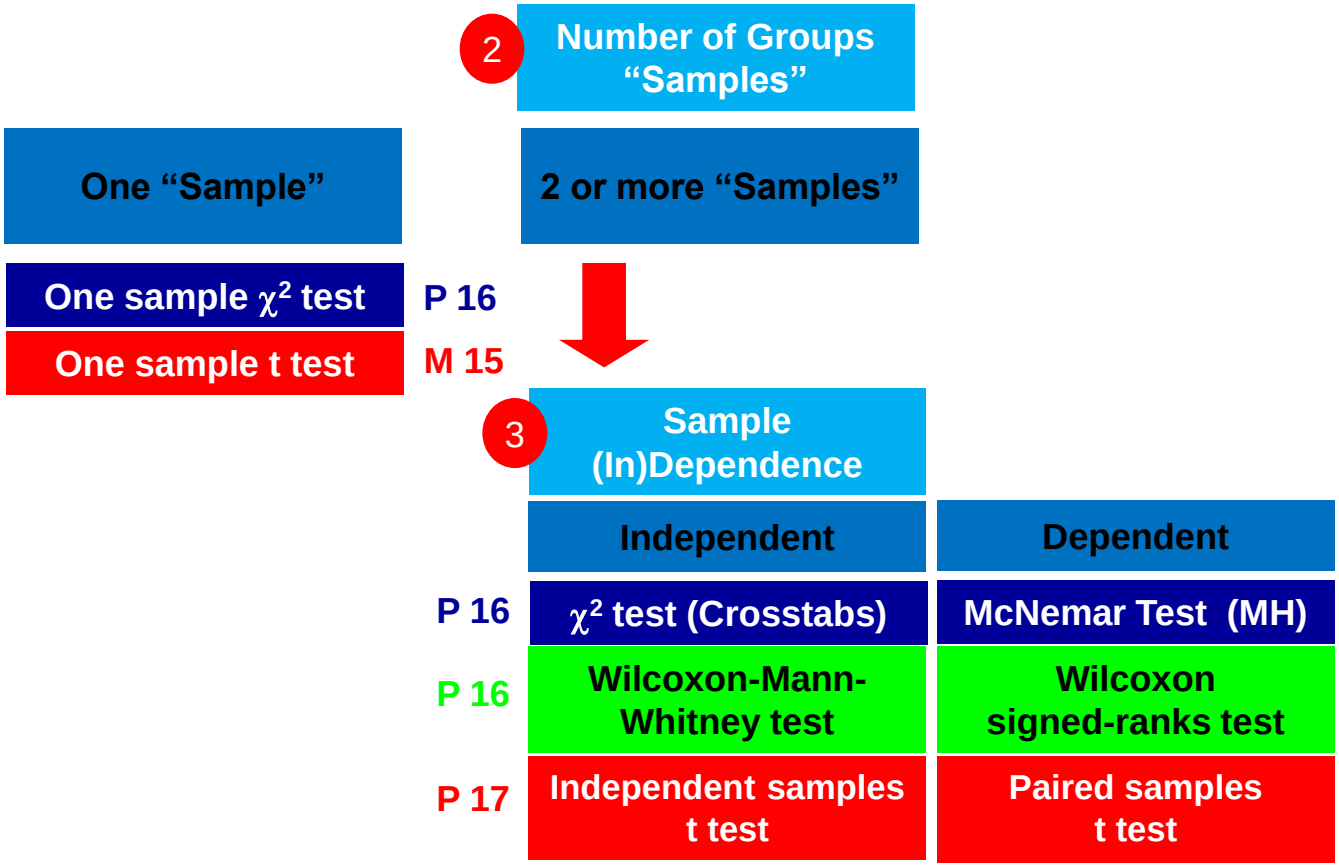
Graphics



Graphs

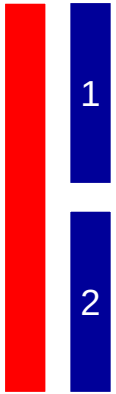
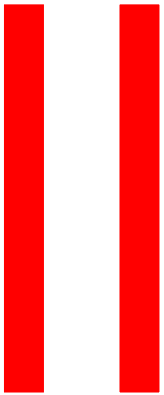
Graphics




2
Number of Groups "Samples"
One "Sample"
2 or more "Samples"
One sample χ^2 test
P 16
One sample t test
M 15
3
Sample (In)Dependence
Independent
Dependent
P 16
χ^2 test (Crosstabs)
McNemar Test (MH)
P 16
Wilcoxon-Mann-Whitney test
Wilcoxon signed-ranks test
P 17
Independent samples t test
Paired samples t test

T-Tests

Malhotra (2010); Pallant (2016)

TEST	One-Sample	"Two"-Sample Independent-Samples	"Two"-Sample Paired-Samples
		 X_{1i} X_{2i}	
	Y_i	Y_i X_i	Y_{1i} Y_{2i}
H_0 (one-sided)	$M \geq 3$	$M_{X1} \geq M_{X2}$	$M_{Y1} \geq M_{Y2}$
H_0 (two-sided)	$M = 3$	$M_{X1} = M_{X2}$	$M_{Y1} = M_{Y2}$

SPSS conducts two-sided tests by default!!!

T Tests

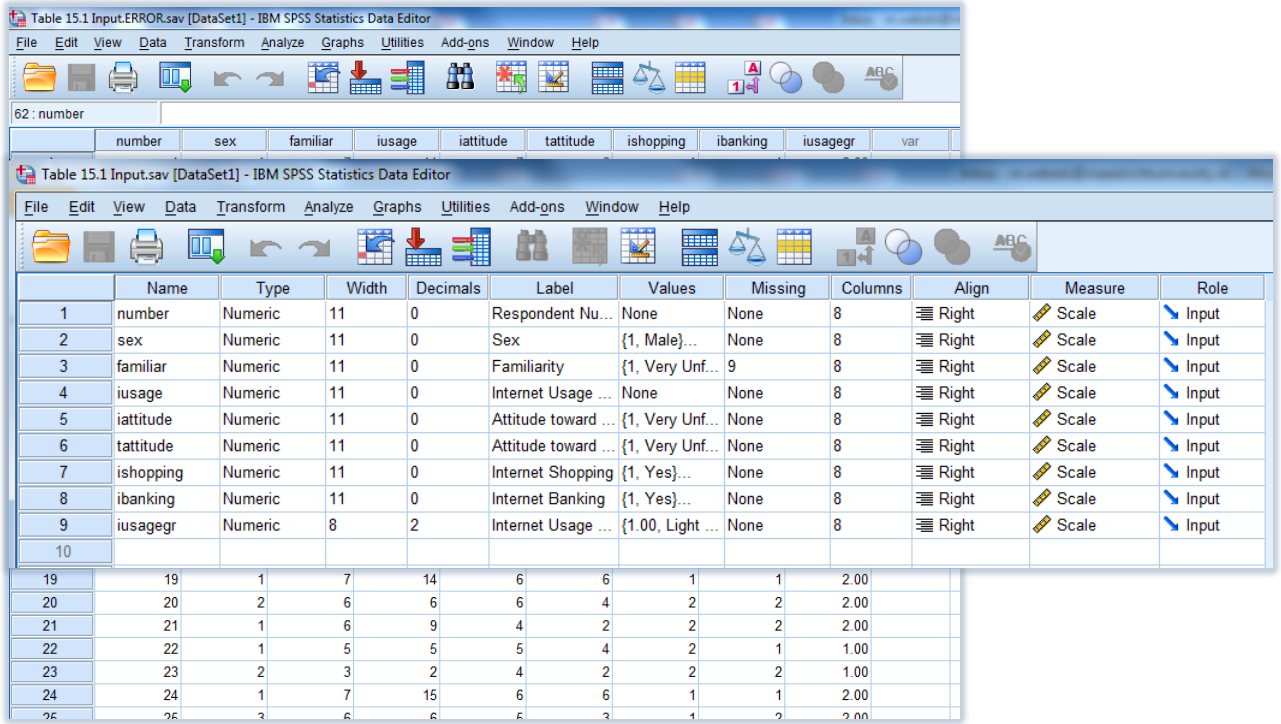
Pallant (2016), Ch. 17

- Assumptions
  - Random Sample(s)
  - Normal distribution (Central Limit Theorem, n>30)
  - Unknown Population Variance (Equal for independent-samples t test; *homogeneity assumption*)

- **At least 3 scale points**
- **Symmetric distribution**

T Tests

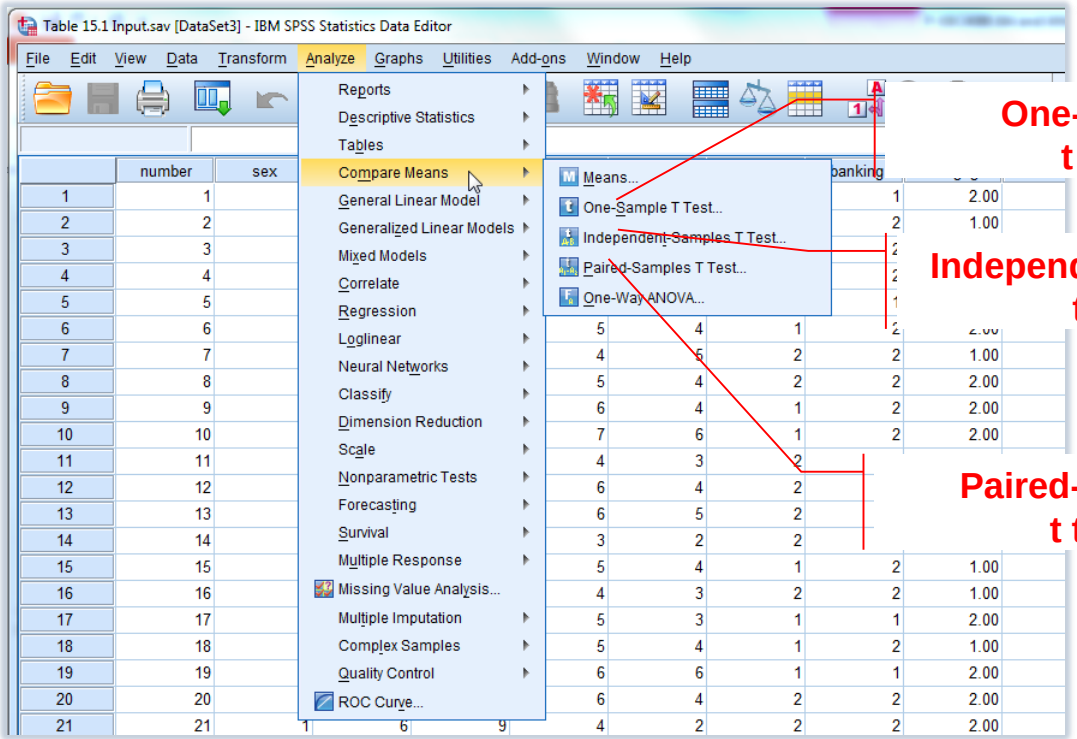
Internet Usage Data (Malhotra, 2010, Table 15.1)



	Name	Type	Width	Decimals	Label	Values	Missing	Columns	Align	Measure	Role
1	number	Numeric	11	0	Respondent Nu...	None	None	8	Right	Scale	Input
2	sex	Numeric	11	0	Sex	{1, Male}...	None	8	Right	Scale	Input
3	familiar	Numeric	11	0	Familiarity	{1, Very Unf...	9	8	Right	Scale	Input
4	iusage	Numeric	11	0	Internet Usage ...	None	None	8	Right	Scale	Input
5	iattitude	Numeric	11	0	Attitude toward ...	{1, Very Unf...	None	8	Right	Scale	Input
6	tattitude	Numeric	11	0	Attitude toward ...	{1, Very Unf...	None	8	Right	Scale	Input
7	ishopping	Numeric	11	0	Internet Shopping	{1, Yes}...	None	8	Right	Scale	Input
8	ibanking	Numeric	11	0	Internet Banking	{1, Yes}...	None	8	Right	Scale	Input
9	iusagegr	Numeric	8	2	Internet Usage ...	{1.00, Light ...	None	8	Right	Scale	Input
10											

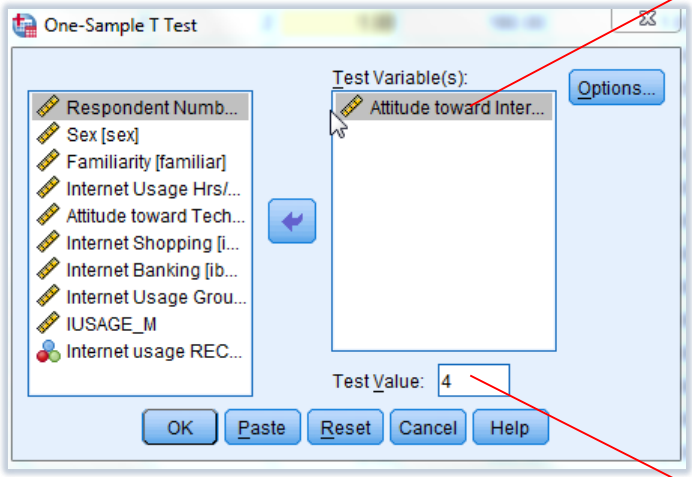
19	19	1	7	14	6	6	1	1	2.00
20	20	2	6	6	6	4	2	2	2.00
21	21	1	6	9	4	2	2	2	2.00
22	22	1	5	5	5	4	2	1	1.00
23	23	2	3	2	4	2	2	2	1.00
24	24	1	7	15	6	6	1	1	2.00

T-Tests in SPSS



One-Sample T-Test

Internet Usage Data (Malhotra, 2010, Table 15.1)



Test Variable: iattitude

Test Value = 4 (two-sided test!!!)

One-Sample T-Test

Internet Usage Data (Malhotra, 2010, Table 15.1)

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Attitude toward Internet	30	5.17	1.234	.225

H_0: M=4
H_1: M≠4

$t(29)=5.178$ ($p_2<0.001$)
ES = $\eta^2 = t^2/(t^2+df) = 0.480$

One-Sample Test

	Test Value = 4					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Attitude toward Internet	5.178	29	.000	1.167	.71	1.63

Sig. = p value!

Effect Size (ES)
REMINDER

- Effect Size (ES)

	(Partial) η^2 (Cohen, 1988)	r (Cohen, 1988)
Small	0.01	0.10
Medium	0.06	0.30
Large	0.138	0.50

One-Sample T-Test

Internet Usage Data (Malhotra, 2010, Table 15.1)

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Attitude toward Internet	30	5.17	1.234	.225

H_0: M=5
H_1: M≠5

t(29)=0.740 (p_2=0.465)
ES = $\eta^2 = t^2/(t^2+df)$ = 0.019!

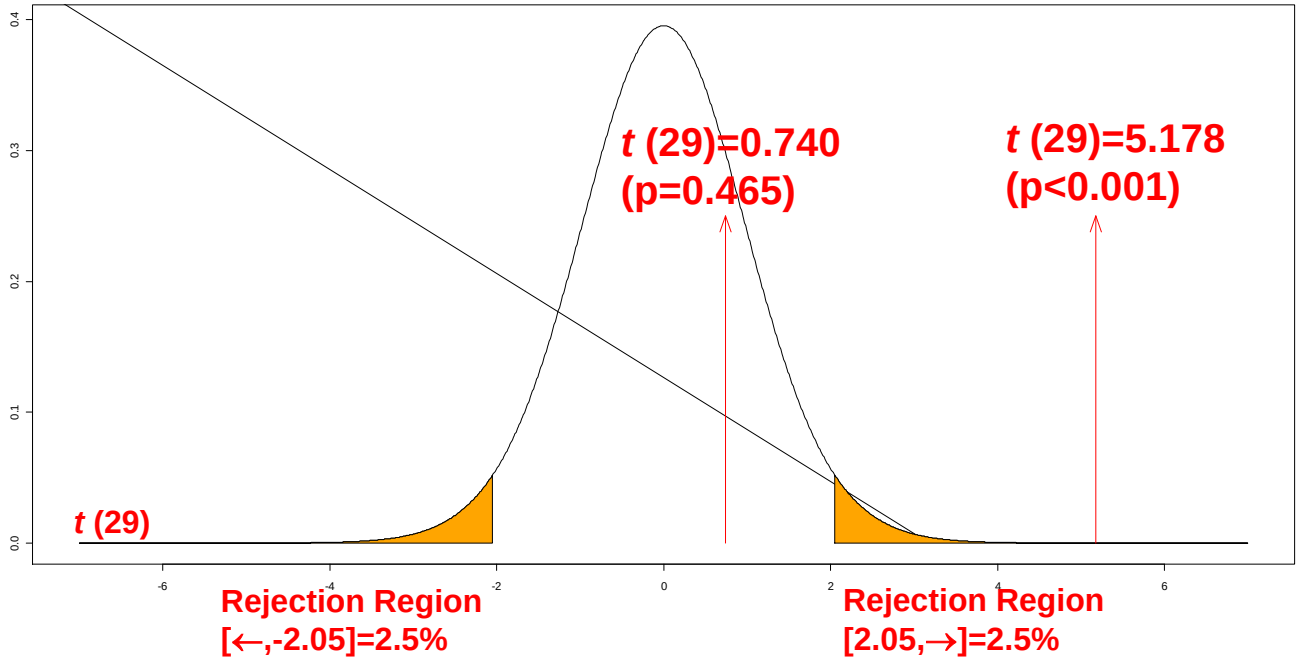
One-Sample Test

	Test Value = 5					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Attitude toward Internet	.740	29	.465	.167	-.29	.63

Sig. = p value!

One-Sample T-Test

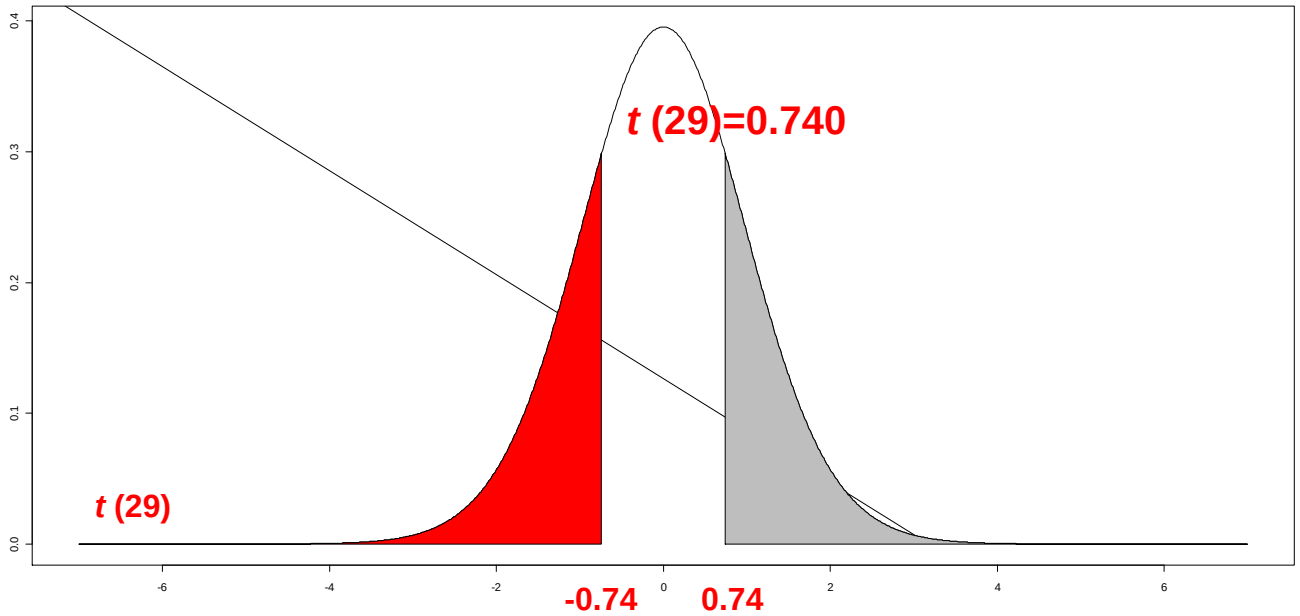
Internet Usage Data (Malhotra, 2010, Table 15.1)



One-Sample T-Test

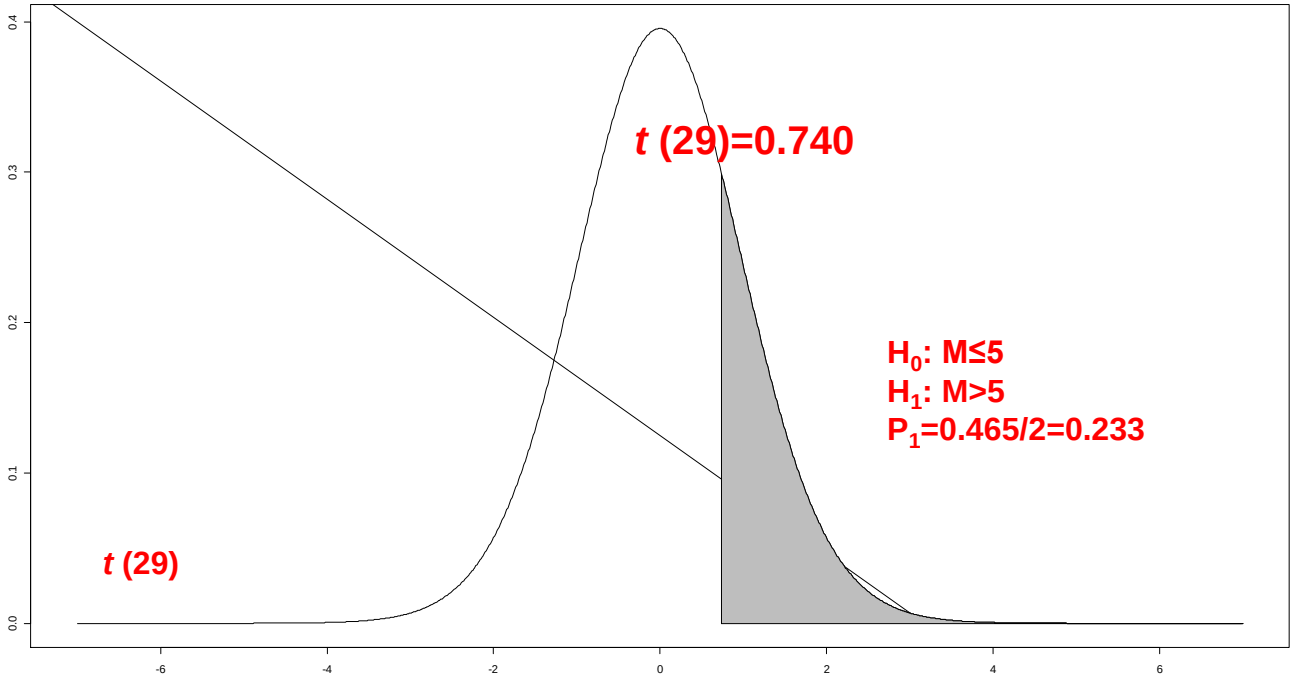
Internet Usage Data (Malhotra, 2010, Table 15.1)

H_0: M=5
H_1: M≠5
P_2=0.465



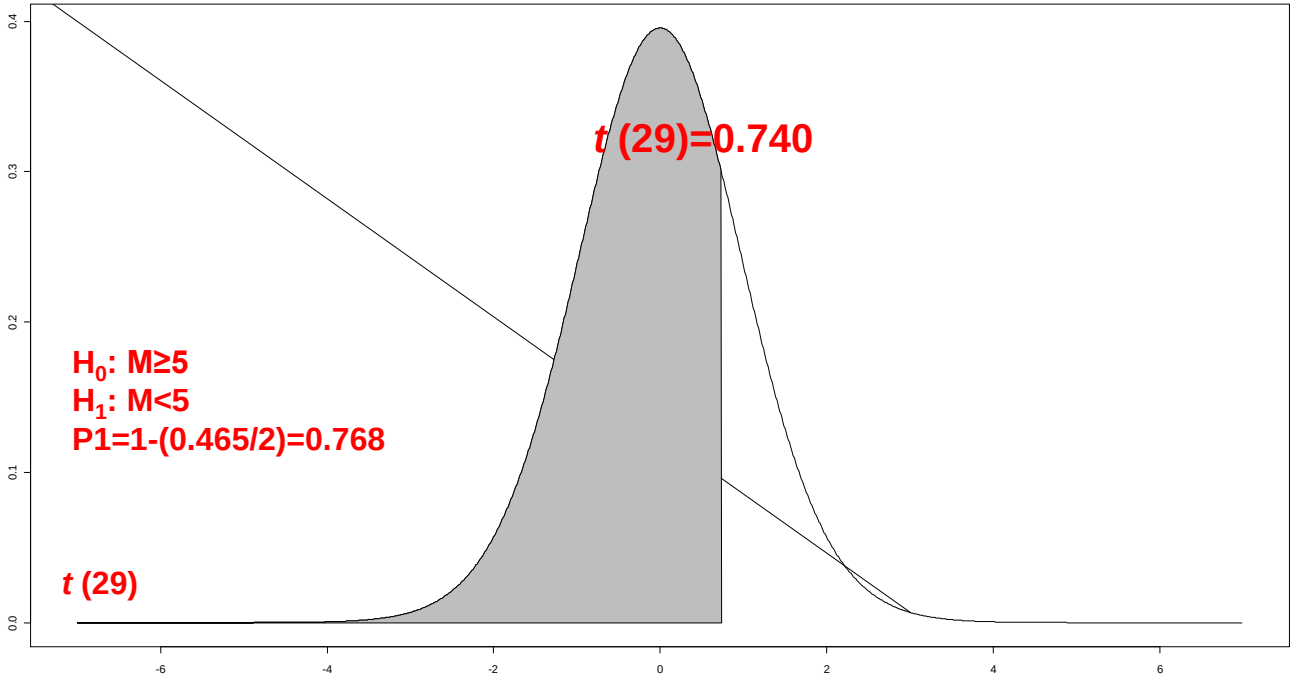
One-Sample T-Test

Internet Usage Data (Malhotra, 2010, Table 15.1)



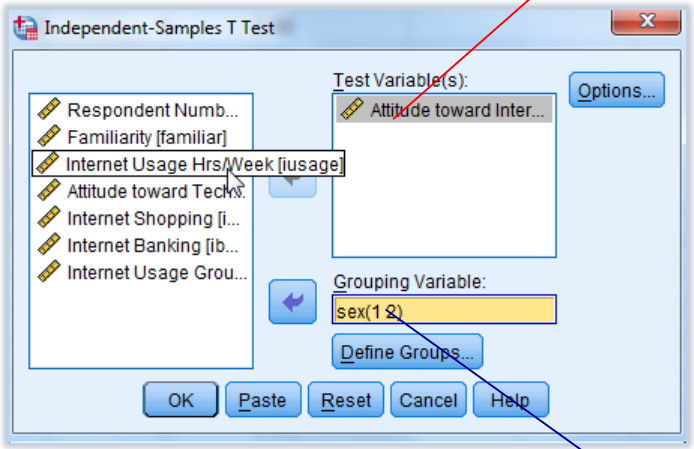
One-Sample T-Test

Internet Usage Data (Malhotra, 2010, Table 15.1)



Independent-Samples T-Test

Internet Usage Data (Malhotra, 2010, Table 15.1)



Attitude toward Internet (iattitude) (=“Dependent” Variable)

Sex (1=‘Male’, 2=‘Female’ Grouping Variable (=“Independent Variable)

Independent-Samples T-Test

Internet Usage Data (Malhotra, 2010, Table 15.1)

Group Statistics

	Sex	N	Mean	Std. Deviation	Std. Error Mean
Attitude toward Internet	Male	15	5.60	1.183	.306
	Female	15	4.73	1.163	.300

$H_0: M_{MALE}=M_{FEMALE}$
$H_1: M_{MALE}\neq M_{FEMALE}$

F test: H_0 cannot be rejected
Equal variances assumed

$t(28)=2.023$ ($p_2=0.053$)
$ES=\eta^2= t^2/(t^2+df)=0.128$

Independent Samples Test

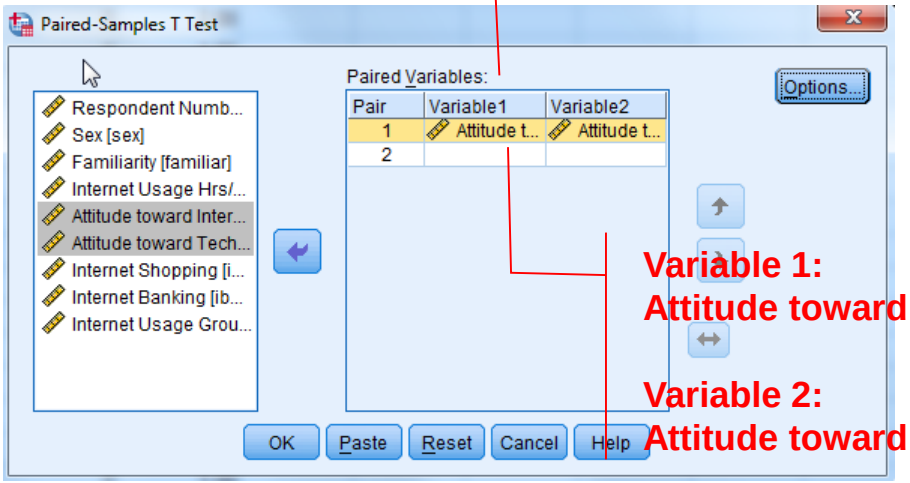
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Attitude toward Internet	Equal variances assumed	.001	.969	2.023	28	.053	.867	.428	-.011	1.744
	Equal variances not assumed			2.023	27.992	.053	.867	.428	-.011	1.744

Paired-Samples T-Test

Internet Usage Data (Malhotra, 2010, Table 15.1)

$H_0: M_{Y1} = M_{Y2}$

$H_0: M_D = M_{Y1} - M_{Y2} = 0$



Variable 1:
Attitude toward Internet (iattitude)

Variable 2:
Attitude toward Technology (tattitude)

Paired-Samples T-Test

Internet Usage Data (Malhotra, 2010, Table 15.1)

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Attitude toward Internet	5.17	30	1.234	.225
	Attitude toward Technology	4.10	30	1.398	.255

$H_0: M_D=0$
$H_1: M_D\neq0$

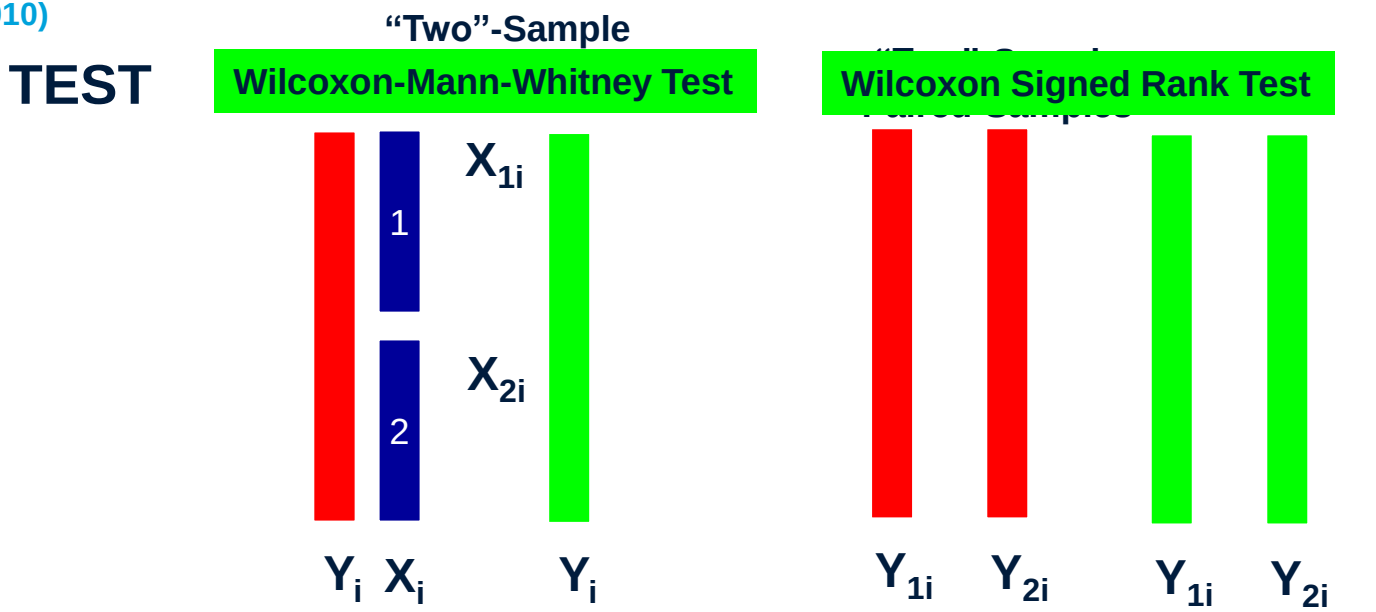
Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Attitude toward Internet - Attitude toward Technology	1.067	.828	.151	.758	1.376	7.059	29	.000

$t(29)=7.059(p_2<0.001)$
$ES = \eta^2= t^2/(t^2+df) = 0.632$

Nonparametric Alternatives

Malhotra (2010)



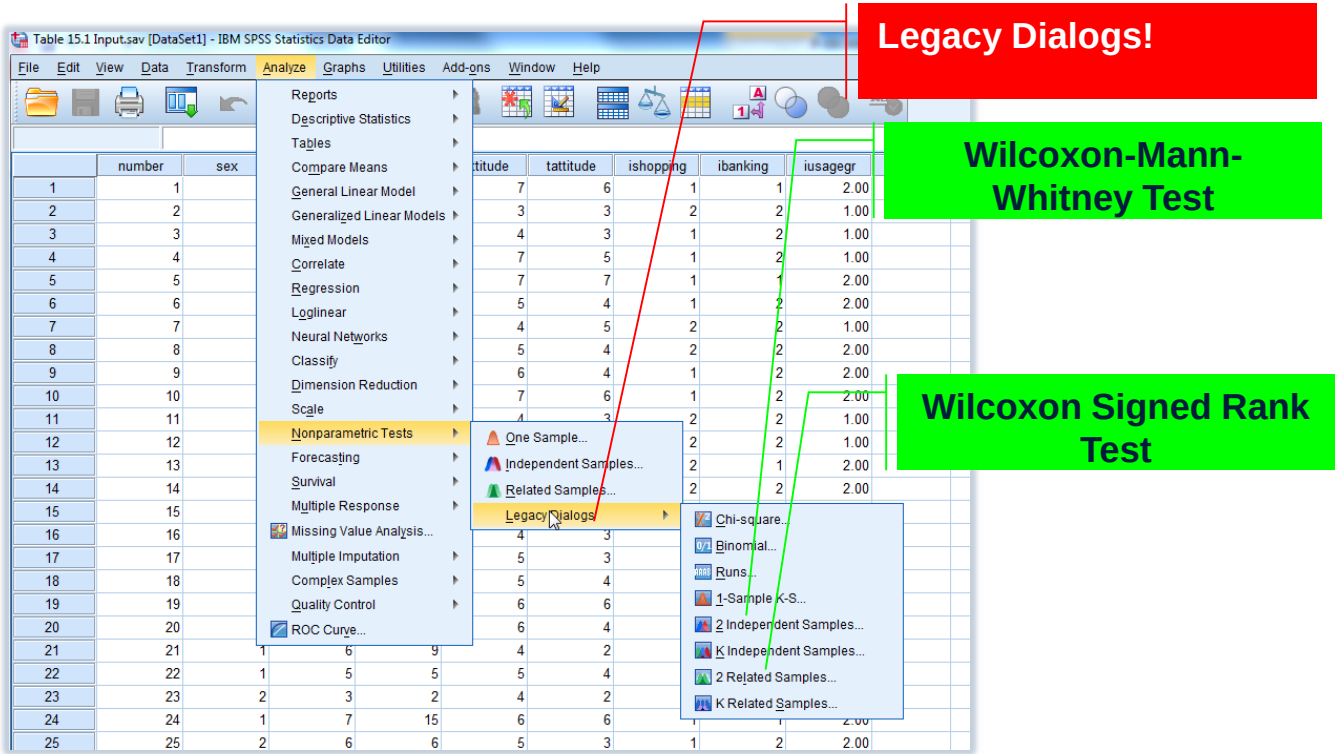
H_0 (one-sided) $MEDIAN_{X1} \geq MEDIAN_{X2}$ $MEDIAN_{Y1} \geq MEDIAN_{Y2}$

H_0 (two-sided) $MEDIAN_{X1} = MEDIAN_{X2}$ $MEDIAN_{Y1} = MEDIAN_{Y2}$

SPSS conducts two-sided test by default!!!

Nonparametric Alternatives

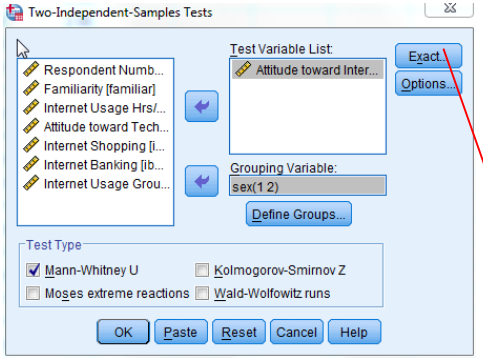
Malhotra (2010)



Nonparametric Alternatives

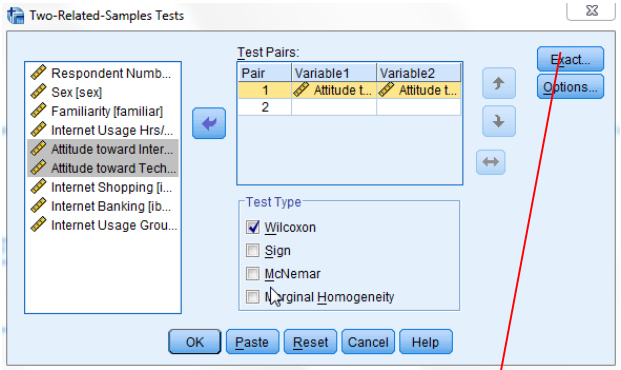
Internet Usage Data (Malhotra, 2010, Table 15.1)

Wilcoxon-Mann-Whitney Test



EXACT!

Wilcoxon Signed Rank Test



EXACT!

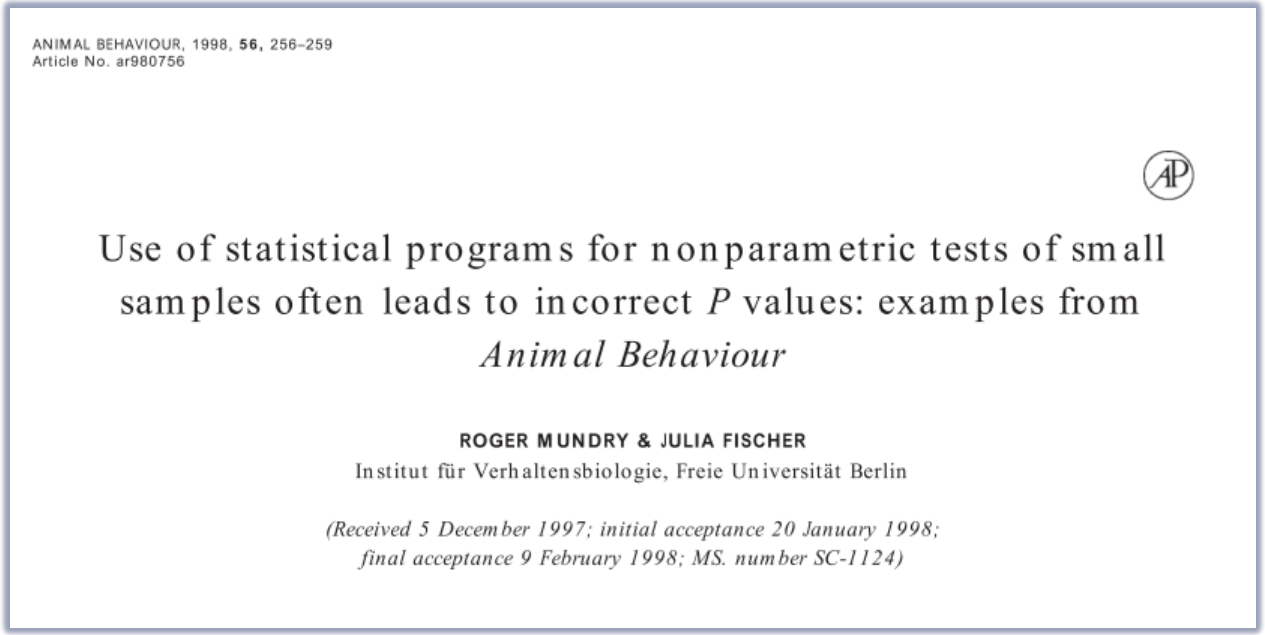
Exact Tests …

- Nonparametric Tests
  - Sample Size Matters … (Mundry and Fischer, 1998; Siegel and Castellan, 1988)
    - Large samples (“asymptotic testing”)
    - Small samples (“exact testing”)

  - What “exactly” is large? (Mundry and Fischer, 1998)
    - Wilcoxon signed-ranks test — n>15
    - Wilcoxon-Mann-Whitney test — n1=3 or 4 and n2>12 or n1>4 and n2>10
    - Kruskal-Wallis test — k>3 and all n>5

Exact Tests

Mundry and Fischer (1998)



ANIMAL BEHAVIOUR, 1998, **56**, 256–259
Article No. ar980756

Use of statistical programs for nonparametric tests of small samples often leads to incorrect *P* values: examples from *Animal Behaviour*

ROGER MUNDRY & JULIA FISCHER
Institut für Verhaltensbiologie, Freie Universität Berlin

(Received 5 December 1997; initial acceptance 20 January 1998; final acceptance 9 February 1998; MS. number SC-1124)

Nonparametric Alternatives…

Internet Usage Data (Malhotra, 2010, Table 15.1)

Wilcoxon-Mann-Whitney Test

Ranks

	Sex	N	Mean Rank	Sum of Ranks
Attitude toward Internet	Male	15	18.57	278.50
	Female	15	12.43	186.50
	Total	30		

RANKS

Independent Samples t Test

Group Statistics

	Sex	N	Mean	Std. Deviation	Std. Error Mean
Attitude toward Internet	Male	15	5.60	1.183	.306
	Female	15	4.73	1.163	.300

M, SD

Data	Rank
1	1
2	2.5
2	2.5
3	4
4	5
5	6.5
5	6.5

$$\text{Sum of Ranks} = \frac{n(n+1)}{2} = 28$$

Nonparametric Alternatives…

Internet Usage Data (Malhotra, 2010, Table 15.1)

	number	sex	familiar	iusage	iattitude	tattitude	ishopping	ibanking	iusagegr	Riattitu
1	1	1	7	14	7	6	1	1	2.00	28.000
2	5	1	7	13	7	7	1	1	2.00	28.000
3	10	1	9	15	7	6	1	2	2.00	28.000
4	13	1	6	9	6	5	2	1	2.00	22.000
5	14	1	6	8	3	2	2	2	2.00	2.000
6	15	1	6	5	5	4	1	2	1.00	14.000
7	17	1	5	9	5	3	1	1	2.00	14.000
8	18	1	4	4	5	4	1	2	1.00	14.000
9	19	1	7	14	6	6	1	1	2.00	22.000
10	21	1	6	9	4	2	2	2	2.00	6.500
11	22	1	5	5	5	4	2	1	1.00	14.000
12	24	1	7	15	6	6	1	1	2.00	22.000
13	26	1	6	13	6	6	1	1	2.00	22.000
14	29	1	4	4	5	3	1	2	1.00	14.000
15	30	1	3	3	7	5	1	2	1.00	28.000
16	2	2	2	2	3	3	2	2	1.00	2.000
17	3	2	3	3	4	3	1	2	1.00	6.500
18	4	2	3	3	7	5	1	2	1.00	28.000
19	6	2	4	6	5	4	1	2	2.00	14.000
20	7	2	2	2	4	5	2	2	1.00	6.500
21	8	2	3	6	5	4	2	2	2.00	14.000
22	9	2	4	6	6	4	1	2	2.00	22.000
23	11	2	4	3	4	3	2	2	1.00	6.500
24	12	2	5	4	6	4	2	2	1.00	22.000
25	16	2	4	3	4	3	2	2	1.00	6.500
26	20	2	6	6	6	4	2	2	2.00	22.000
27	23	2	3	2	4	2	2	2	1.00	6.500
28	25	2	6	6	5	3	1	2	2.00	14.000
29	27	2	5	4	5	5	1	1	1.00	14.000
30	28	2	4	2	3	2	2	2	1.00	2.000

Male

M_R 18.57

Female

M 4.73

M_R 12.43

Nonparametric Alternatives

Internet Usage Data (Malhotra, 2010, Table 15.1)

Wilcoxon-Mann-Whitney Test

Ranks

	Sex	N	Mean Rank	Sum of Ranks
Attitude toward Internet	Male	15	18.57	278.50
	Female	15	12.43	186.50
	Total	30		

RANKS

Test Statistics[b]

	Attitude toward Internet
Mann-Whitney U	66.500
Wilcoxon W	186.500
Z	-1.960
Asymp. Sig. (2-tailed)	.050
Exact Sig. [2*(1-tailed Sig.)]	.056[a]
Exact Sig. (2-tailed)	.052
Exact Sig. (1-tailed)	.026
Point Probability	.003

a. Not corrected for ties.
b. Grouping Variable: Sex

U=66.5
z=-1.96 (p_2=0.05)

ES
r=z/ √n
r=-1.96/√30=-0.358

Wilcoxon Signed Rank Test

Ranks

		N	Mean Rank	Sum of Ranks
Attitude toward Internet - Attitude toward Technology	Negative Ranks	1[a]	7.50	7.50
	Positive Ranks	23[b]	12.72	292.50
	Ties	6[c]		
	Total	30		

a. Attitude toward Internet < Attitude toward Technology
b. Attitude toward Internet > Attitude toward Technology
c. Attitude toward Internet = Attitude toward Technology

Test Statistics[b]

	Attitude toward Internet - Attitude toward Technology
Z	-4.207[a]
Asymp. Sig. (2-tailed)	.000
Exact Sig. (2-tailed)	.000
Exact Sig. (1-tailed)	.000
Point Probability	.000

a. Based on negative ranks.
b. Wilcoxon Signed Ranks Test

z= -4.207 (p_2<0.001)

ES
r=z/ √n
r=-4.207/√30=-0.768

One Sample T Test

Editor

```
1  # T Test
2
3  attach(Table15.1)
4
5  # One-sample T Test
6
7  t.test(iattitude, mu=4)
8
9  t.test(iattitude, mu=5)
10
11
```

One Sample T Test

Console

```
> t.test(iattitude, mu=4)

 One Sample t-test

data:  iattitude
t = 5.178, df = 29, p-value = 1.547e-05
alternative hypothesis: true mean is not equal to 4
95 percent confidence interval:
 4.705848 5.627485
sample estimates:
mean of x
 5.166667

>
> t.test(iattitude, mu=5)

 One Sample t-test

data:  iattitude
t = 0.7397, df = 29, p-value = 0.4654
alternative hypothesis: true mean is not equal to 5
95 percent confidence interval:
 4.705848 5.627485
sample estimates:
mean of x
 5.166667
```

Independent Samples T Test


```
13
14  # Independent Samples T Test
15
16  t.test(iattitude ~ sex, alternative="two.sided", var.equal=FALSE)
17
18  t.test(iattitude ~ sex, alternative="less")
19
20  t.test(iattitude ~ sex, alternative="greater")
21
22
23
```

Independent Samples T Test

Console

```
> t.test(iattitude ~ sex, alternative="two.sided", var.equal=FALSE)

 Welch Two Sample t-test

data:  iattitude by sex
t = 2.0232, df = 27.992, p-value = 0.05269
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -0.01080031  1.74413364
sample estimates:
mean in group 1 mean in group 2
       5.600000        4.733333
```

Independent Samples T Test

Console

```
> t.test(iattitude ~ sex, alternative="less")

 Welch Two Sample t-test

data:  iattitude by sex
t = 2.0232, df = 27.992, p-value = 0.9737
alternative hypothesis: true difference in means is less than 0
95 percent confidence interval:
    -Inf 1.59537
sample estimates:
mean in group 1 mean in group 2
       5.600000        4.733333

>
> t.test(iattitude ~ sex, alternative="greater")

 Welch Two Sample t-test

data:  iattitude by sex
t = 2.0232, df = 27.992, p-value = 0.02635
alternative hypothesis: true difference in means is greater than 0
95 percent confidence interval:
 0.1379632       Inf
sample estimates:
mean in group 1 mean in group 2
       5.600000        4.733333
```

Levene's Test

Editor

```
22
23  # Levene's Test
24
25  library(lawstat)
26
27  levene.test(iattitude,sex, location="mean")
28
29
```

Levene's Test

Console

```
>
> levene.test(iattitude,sex, location="mean")

 classical Levene's test based on the absolute deviations from the mean (
 none not applied because the location is not set to median )

data:  iattitude
Test Statistic = 0.0015, p-value = 0.9695
```

Paired Samples T Test


```
27
28  # Paired Samples T Test
29
30  t.test(iattitude, tattitude, paired=TRUE)
31
```

Paired Samples T Test

Console

```
> t.test(iattitude, tattitude, paired=TRUE)

 Paired t-test

data:  iattitude and tattitude
t = 7.0587, df = 29, p-value = 9.16e-08
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 0.7576051 1.3757282
sample estimates:
mean of the differences
                1.066667
```

Wilcoxon-Mann-Whitney Test

Editor

```
35
36  # Wilcoxon-Mann-Whitney Test
37
38  wilcox.test(iattitude ~ sex, exact=FALSE, correct=FALSE)
39
40
```

Wilcoxon-Mann-Whitney Test

Console

```
> wilcox.test(iattitude ~ sex, exact=FALSE, correct=FALSE)

 Wilcoxon rank sum test

data:  iattitude by sex
W = 158.5, p-value = 0.05001
alternative hypothesis: true location shift is not equal to 0
```

Wilcoxon Signed Rank Test


```
44
45  # Wilcoxon Signed Rank Test
46
47  wilcox.test(iattitude,tattitude, paired=TRUE, exact=FALSE, correct=FALSE)
48
```

Wilcoxon Signed Rank Test

Console

```
> wilcox.test(iattitude,tattitude, paired=TRUE, exact=FALSE, correct=FALSE)

 Wilcoxon signed rank test

data:  iattitude and tattitude
V = 292.5, p-value = 2.592e-05
alternative hypothesis: true location shift is not equal to 0

>
```

References

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences.* Hillsdale, NJ: Lawrence Erlbaum Associates, Publishers.

Cohen, J. (1992). “A Power Primer,” *Psychological Bulletin*, 112 (1), 155-159. [condensed version].

Everitt, B. S. (1992). *The Analysis of Contingency Tables*. CRC Press.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). “G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences,” *Behavior Research Methods, 39* (2), 175-191.

Hair, J.F., Jr., Black, W.C., Babin, B.J, and Anderson, R.E. (2018). *Multivariate Data Analysis.*Cengage.

Howell, D. C. (2012). *Statistical Methods for Psychology*. Cengage Learning.

Malhotra, N. (2010). *Marketing Research: An Applied Orientation*. Upper Saddle River: Pearson/Prentice-Hall.

References

Mundry, R. and Fischer, J. (1998). Use of Statistical Programs for Nonparametric Tests of Small Samples often Leads to Incorrect P Values: Examples from Animal Behaviour. *Animal Behaviour*, 56, 256-259.

Pallant, J. (2016). *SPSS Survival Manual: A Step by Step Guide to Data Analysis Using SPSS for Windows*. Maidenhead: Open University Press/McGraw-Hill.

Siegel, S. and Castellan, N.J. (1988). *Nonparametric Statistics for the Behavioral Sciences*. New York: McGraw-Hill.

References

Chapman, C., & Feit, E. M. (2015). *R for Marketing Research and Analytics.* New York, NY: Springer.

Crawley, MJ (2013). *The R Book.* Chichester, UK: John Wiley and Sons.

Everitt, BS and Hothorn, T (2006). *A Handbook of Statistical Analysis Using R.* Boca Raton, FL: Chapman and Hall/CRC.

Field, A, Miles, J and Field, Z (2012). *Discovering Statistics Using R.* Los Angeles, CA: Sage Publications.

Kabacoff, RI (2011). *R in Action*. Shelter Island, NY: Manning.

Muenchen, RA (2009). *R for SAS and SPSS Users.* New York, NY; Springer Science and Business Media.


Thank you for
Your Attention!