

Statistical tests to observe the statistical significance of Categorical variables

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# Learning Objectives:

- (1) Able to understand the factors to apply for the choice of statistical tests in analyzing the data .
- (2) Able to apply appropriately Z-test, Chi-square test, Fisher's exact test & Macnemar's Chi-square test.
- (3) Able to interpret the findings of the analysis using these four tests.

# Choosing the appropriate Statistical test

- Based on the three aspects of the data
  - Types of variables
  - Number of groups being compared &
  - Sample size

# Types of Categorical Data

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graph TD; A[Qualitative/Categorical Data] --> B[Nominal Categories]; A --> C[Ordinal Categories];
```

Qualitative/Categorical Data

Nominal Categories

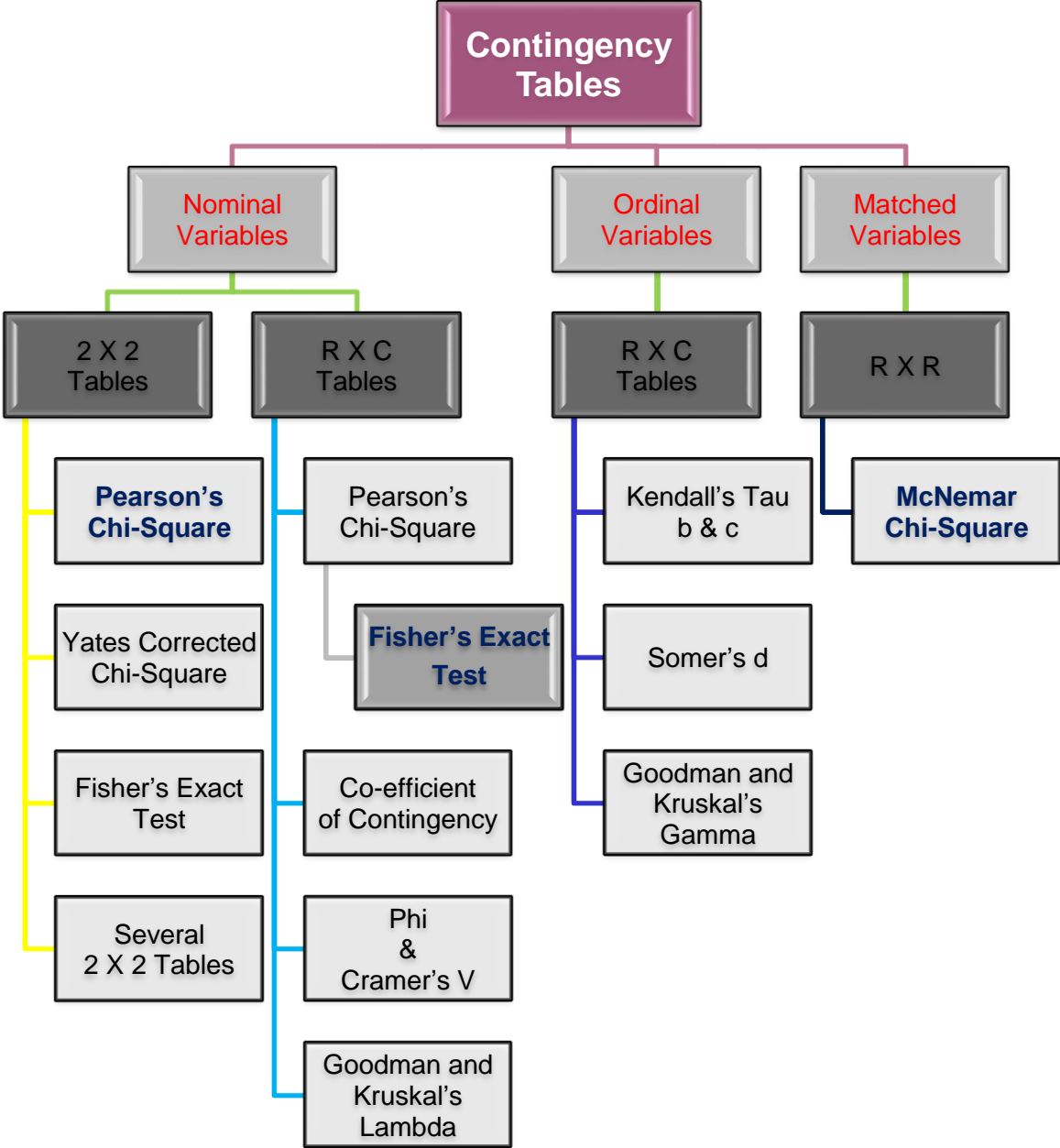
Ordinal Categories

# Types of Analysis for Categorical Data

Type of Analysis

Descriptive  
Rate and Ratio

Analytic  
Confidence Interval  
and  
Test of Significance



# Statistical tests

## Chi-square test:

Study variable: Qualitative

Outcome variable: Qualitative

Comparison: two or more proportions

Sample size:  $> 20$

Expected frequency:  $> 5$

## Fisher's exact test:

Study variable: Qualitative

Outcome variable: Qualitative

Comparison: two proportions

Sample size:  $< 20$

## Macnemar's test: (for paired samples)

Study variable: Qualitative

Outcome variable: Qualitative

Comparison: two proportions

Sample size: Any

# Chi-square test

## Purpose


To find out whether the association between two categorical variables are statistically significant

## Null Hypothesis

There is no association between two variables



# Chi-Square test

$$\chi^2 = \sum \left[ \frac{(o - e)^2}{e} \right]$$


**Figure for Each Cell**

1. ***The summation is over all cells of the contingency table consisting of  $r$  rows and  $c$  columns***
2.  ***$O$  is the observed frequency***
3.  ***$\hat{E}$  is the expected frequency***

$$\hat{E} = \frac{\left( \begin{array}{c} \text{total of row in} \\ \text{which the cell lies} \end{array} \right) \cdot \left( \begin{array}{c} \text{total of column in} \\ \text{which the cell lies} \end{array} \right)}{\text{(total of all cells)}}$$

reject  $H_0$  if  $\chi^2 > \chi^2_{\alpha, df}$

where  $df = (r-1)(c-1)$

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

4. ***The degrees of freedom are  $df = (r-1)(c-1)$***

# Requirements

- **Prior to using the chi square test, there are certain requirements that must be met.**
  - **The data must be in the form of frequencies counted in each of a set of categories. Percentages cannot be used.**
  - **The total number observed must exceed 20.**

# Requirements

- **The expected frequency under the  $H_0$  hypothesis in any one fraction must not normally be less than 5.**
- **All the observations must be independent of each other. In other words, one observation must not have an influence upon another observation.**

# **APPLICATION OF CHI-SQUARE TEST**

- **TESTING INDEPENDENCE (or ASSOCIATION)**
- **TESTING FOR HOMOGENEITY**
- **TESTING OF GOODNESS-OF-FIT**

# Chi-square test

- **Objective : Smoking is a risk factor for MI**
- **Null Hypothesis: Smoking does not cause MI**

|             | D (MI) | No D( No MI) | Total |
|-------------|--------|--------------|-------|
| Smokers     | 29     | 21           | 50    |
| Non-smokers | 16     | 34           | 50    |
| Total       | 45     | 55           | 100   |

# Chi-Square test

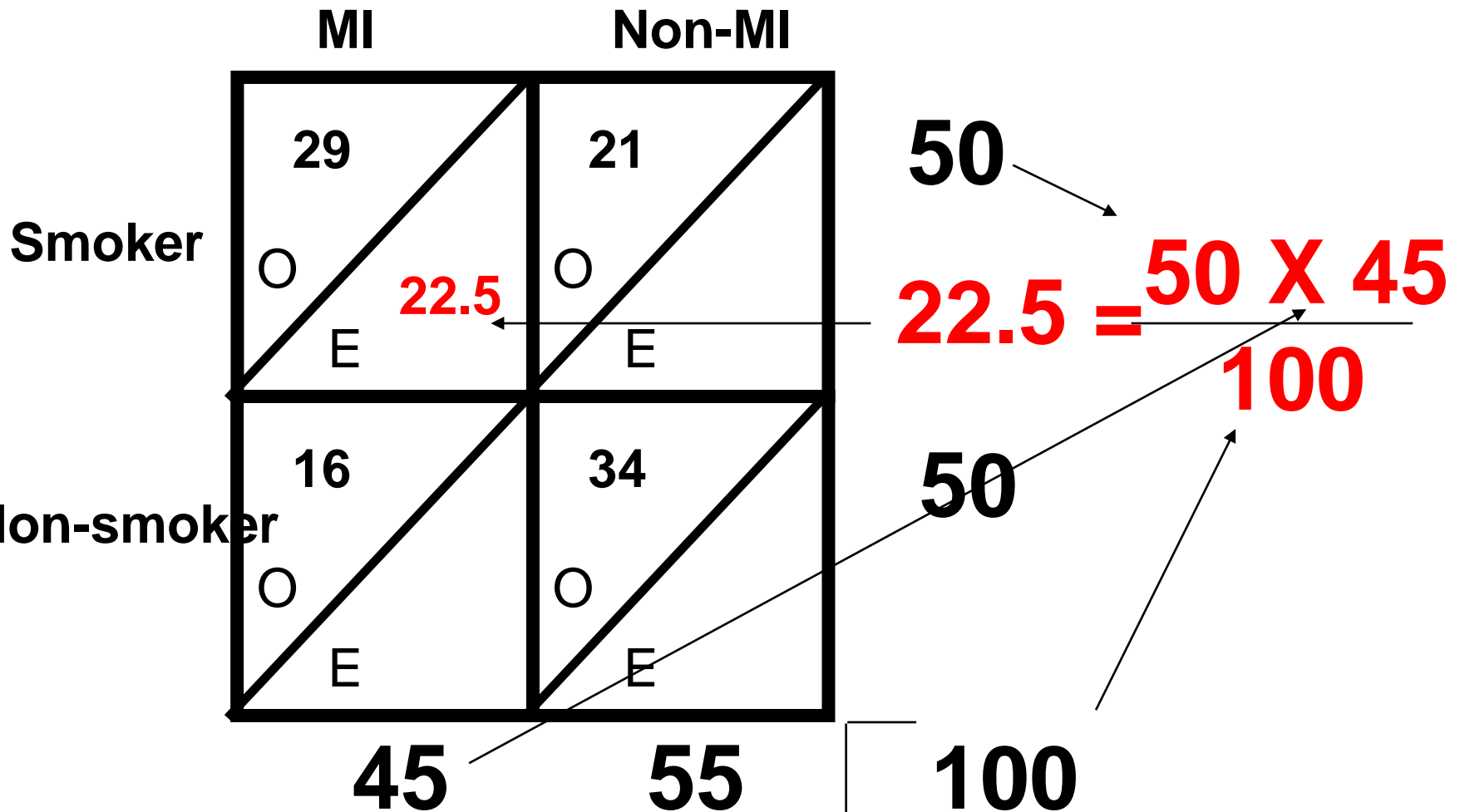
|            | MI           | Non-MI       |
|------------|--------------|--------------|
| Smoker     | 29<br>O<br>E | 21<br>O<br>E |
| Non-Smoker | 16<br>O<br>E | 34<br>O<br>E |

# Chi-square test

|            | MI           | Non-MI       |     |
|------------|--------------|--------------|-----|
| Smoker     | 29<br>O<br>E | 21<br>O<br>E | 50  |
| Non-smoker | 16<br>O<br>E | 34<br>O<br>E | 50  |
|            | 45           | 55           | 100 |



# Chi-square test



# Chi-square test

|            | MI                   | No MI                |     |
|------------|----------------------|----------------------|-----|
| smoker     | 29<br>O<br>22.5<br>E | 21<br>O<br>27.5<br>E | 50  |
| Non smoker | 16<br>O<br>22.5<br>E | 34<br>O<br>27.5<br>E | 50  |
|            | 45                   | 55                   | 100 |

# Chi-Square

Degrees of Freedom

$$\begin{aligned}df &= (r-1)(c-1) \\ &= (2-1)(2-1) = 1\end{aligned}$$

Critical Value (Table A.6) = 3.84

$$\chi^2 = 6.84$$

Calculated value(6.84) is greater than critical (table) value (3.84) at 0.05 level with 1 d.f.f

Hence we reject our  $H_0$  and conclude that there is highly statistically significant association between smoking and MI.

# Chi- square test

Find out whether the gender is equally distributed among each age group

| Gender | Age     |         |         | Total |
|--------|---------|---------|---------|-------|
|        | <30     | 30-45   | >45     |       |
| Male   | 60 (60) | 20 (30) | 40 (30) | 120   |
| Female | 40 (40) | 30 (20) | 10 (20) | 80    |
| Total  | 100     | 50      | 50      | 200   |

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# Test for Homogeneity (Similarity)

To test similarity between frequency distribution or group.  
It is used in assessing the similarity between non-responders and responders in any survey

| Age (yrs) | Responders | Non-responders | Total |
|-----------|------------|----------------|-------|
| <20       | 76 (82)    | 20 (14)        | 96    |
| 20 – 29   | 288 (289)  | 50 (49)        | 338   |
| 30-39     | 312 (310)  | 51 (53)        | 363   |
| 40-49     | 187 (185)  | 30 (32)        | 217   |
| >50       | 77 (73)    | 9 (13)         | 86    |
| Total     | 940        | 160            | 1100  |

# Association between Diabetes and Heart Disease?

- **Background:**

Contradictory opinions:

- 1. A diabetic's risk of dying after a first heart attack is the same as that of someone without diabetes. There is no link between diabetes and heart disease.

vs.

- 2. Diabetes takes a heavy toll on the body and diabetes patients often suffer heart attacks and strokes or die from cardiovascular complications at a much younger age.
- So we use hypothesis test based on the latest data to see what's the right conclusion.
- There are a total of 5167 managed-care patients, among which 1131 patients are non-diabetics and 4036 are diabetics. Among the non-diabetic patients, 42% of them had their blood pressure properly controlled (therefore it's 475 of 1131). While among the diabetic patients only 20% of them had the blood pressure controlled (therefore it's 807 of 4036).

# Association between Diabetes and Heart Disease?

- Data

|              | Controlled | Uncontrolled | Total |
|--------------|------------|--------------|-------|
| Non-diabetes | 475        | 656          | 1131  |
| Diabetes     | 807        | 3229         | 4036  |
| Total        | 1282       | 3885         | 5167  |

# Association between Diabetes and Heart Disease?

Data:

Diabetes: 1=Not have diabetes, 2=Have Diabetes

Control: 1=Controlled, 2=Uncontrolled

**DIABETES \* CONTROL Crosstabulation**

Count

|          |      | CONTROL |      | Total |
|----------|------|---------|------|-------|
|          |      | 1.00    | 2.00 |       |
| DIABETES | 1.00 | 475     | 656  | 1131  |
|          | 2.00 | 807     | 3229 | 4036  |
| Total    |      | 1282    | 3885 | 5167  |



# Association between Diabetes and Heart Disease?

**DIABETES \* CONTROL Crosstabulation**

|          |                   |                   | CONTROL |        | Total  |
|----------|-------------------|-------------------|---------|--------|--------|
|          |                   |                   | 1.00    | 2.00   |        |
| DIABETES | 1.00              | Count             | 475     | 656    | 1131   |
|          |                   | % within DIABETES | 42.0%   | 58.0%  | 100.0% |
|          |                   | % within CONTROL  | 37.1%   | 16.9%  | 21.9%  |
|          |                   | % of Total        | 9.2%    | 12.7%  | 21.9%  |
|          | 2.00              | Count             | 807     | 3229   | 4036   |
|          |                   | % within DIABETES | 20.0%   | 80.0%  | 100.0% |
|          |                   | % within CONTROL  | 62.9%   | 83.1%  | 78.1%  |
|          |                   | % of Total        | 15.6%   | 62.5%  | 78.1%  |
| Total    | Count             | 1282              | 3885    | 5167   |        |
|          | % within DIABETES | 24.8%             | 75.2%   | 100.0% |        |
|          | % within CONTROL  | 100.0%            | 100.0%  | 100.0% |        |
|          | % of Total        | 24.8%             | 75.2%   | 100.0% |        |

# Association between Diabetes and Heart Disease?

Hypothesis test:

- 1)  $H_0$ : There is no association between diabetes and heart disease. (There is no association between diabetes and heart disease. (or) Diabetes and heart disease are independent.)
- 2)  $H_A$ : There is a association between diabetes and heart disease. (There is an association between diabetes and heart disease. (or) Diabetes and heart disease are dependent.)
- 3) Assume a significance level of .05

# Association between Diabetes and Heart Disease?

## SPSS Output

### Chi-Square Tests

|                                    | Value                | df | Asymp. Sig.<br>(2-sided) | Exact Sig.<br>(2-sided) | Exact Sig.<br>(1-sided) |
|------------------------------------|----------------------|----|--------------------------|-------------------------|-------------------------|
| Pearson Chi-Square                 | 229.268 <sup>b</sup> | 1  | .000                     |                         |                         |
| Continuity Correction <sup>a</sup> | 228.091              | 1  | .000                     |                         |                         |
| Likelihood Ratio                   | 212.149              | 1  | .000                     |                         |                         |
| Fisher's Exact Test                |                      |    |                          | .000                    | .000                    |
| Linear-by-Linear<br>Association    | 229.224              | 1  | .000                     |                         |                         |
| N of Valid Cases                   | 5167                 |    |                          |                         |                         |

a. Computed only for a 2x2 table

b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 280.62.

# Association between Diabetes and Heart Disease?

- 4) The computer gives us a Chi-Square Statistic of 229.268
- 5) The computer gives us a p-value of .000 i.e., ( $<0.0001$ ).
- 6) Because our p-value is less than alpha (0.05), we would reject the null hypothesis.
- 7) There is sufficient evidence to conclude that there is an association between diabetes and heart disease.

# Example

- The following data relate to suicidal feelings in samples of psychotic and neurotic patients:

|                      | Psychotics | Neurotics | Total |
|----------------------|------------|-----------|-------|
| Suicidal feelings    | 2          | 6         | 8     |
| No suicidal feelings | 18         | 14        | 32    |
| Total                | 20         | 20        | 40    |

# Example

- The following data compare malocclusion of teeth with method of feeding infants.

|            | Normal teeth | Malocclusion |
|------------|--------------|--------------|
| Breast fed | 4            | 16           |
| Bottle fed | 1            | 21           |

# Fisher's Exact Test:

- The method of Yates's correction was useful when manual calculations were done. Now different types of statistical packages are available. Therefore, it is better to use Fisher's exact test rather than Yates's correction as it gives exact result.

$$\textit{Fisher's Exact Test} = \frac{R_1!R_2!C_1!C_2!}{n!a!b!c!d!}$$

**What to do when we have a paired samples and both the exposure and outcome variables are qualitative variables (Binary).**



# Problem

- A researcher has done a matched case-control study of endometrial cancer (cases) and exposure to conjugated estrogens (exposed).
- In the study cases were individually matched 1:1 to a non-cancer hospital-based control, based on age, race, date of admission, and hospital.

# McNemar's test

## Situation:

- ✦ **Two paired binary variables that form a particular type of 2 x 2 table**
- ✦ **e.g. matched case-control study or cross-over trial**

# Data

|             | Cases | Controls | Total |
|-------------|-------|----------|-------|
| Exposed     | 55    | 19       | 74    |
| Not exposed | 128   | 164      | 292   |
| Total       | 183   | 183      | 366   |

- ⦿ can't use a **chi-squared test** - observations are not independent - they're paired.
- ⦿ we must present the 2 x 2 table differently
- ⦿ each cell should contain a count of the number of pairs with certain criteria, with the columns and rows respectively referring to each of the subjects in the matched pair
- ⦿ the information in the standard 2 x 2 table used for unmatched studies is insufficient because it doesn't say who is in which pair - ignoring the matching

# Data

| Cases       | Controls |             | Total |
|-------------|----------|-------------|-------|
|             | Exposed  | Not exposed |       |
| Exposed     | 12       | 43          | 55    |
| Not exposed | 7        | 121         | 128   |
| Total       | 19       | 164         | 183   |

We construct a matched 2 x 2 table:

| Cases       | Controls |             | Total |
|-------------|----------|-------------|-------|
|             | Exposed  | Not exposed |       |
| Exposed     | e        | f           | e+f   |
| Not exposed | g        | h           | g+h   |
| Total       | e+g      | f+h         | n     |

# Formula

The odds ratio is:  $f/g$

The test is:

$$X^2 = \frac{(|f - g| - 1)^2}{f + g}$$

Compare this to the  $\chi^2$  distribution on 1 df

$$X^2 = \frac{(|43 - 7| - 1)^2}{43 + 7} = \frac{1225}{50} = 24.5$$

$P < 0.001$ , Odds Ratio =  $43/7 = 6.1$

$p_1 - p_2 = (55/183) - (19/183) = 0.197$  (20%)

s.e.( $p_1 - p_2$ ) = 0.036

95% CI: 0.12 to 0.27 (or 12% to 27%)



- Degrees of Freedom
$$df = (r-1) (c-1)$$
$$= (2-1) (2-1) = 1$$
- Critical Value (Table A.6) = 3.84
- $\chi^2 = 25.92$
- Calculated value(25.92) is greater than critical (table) value (3.84) at 0.05 level with 1 d.f.f
- Hence we reject our  $H_0$  and conclude that there is highly statistically significant association between Endometrial cancer and Estrogens.

## Two-tailed critical ratios of $\chi^2$

| Degrees<br>of<br>freedom<br>df | .10    | .05    | .02    | .01    |
|--------------------------------|--------|--------|--------|--------|
| 1                              | 2.706  | 3.841  | 5.412  | 6.635  |
| 2                              | 4.605  | 5.991  | 7.824  | 9.210  |
| 3                              | 6.251  | 7.815  | 9.837  | 11.341 |
| 4                              | 7.779  | 9.488  | 11.668 | 13.277 |
| 5                              | 9.236  | 11.070 | 13.388 | 15.086 |
| 6                              | 10.645 | 12.592 | 15.033 | 16.812 |
| 7                              | 12.017 | 14.067 | 16.622 | 18.475 |
| 8                              | 13.362 | 15.507 | 18.168 | 20.090 |
| 9                              | 14.684 | 16.919 | 19.679 | 21.666 |
| 10                             | 15.987 | 18.307 | 21.161 | 23.209 |
| 11                             | 17.275 | 19.675 | 22.618 | 24.725 |
| 12                             | 18.549 | 21.026 | 24.054 | 26.217 |
| 13                             | 19.812 | 22.362 | 25.472 | 27.688 |
| 14                             | 21.064 | 23.685 | 26.873 | 29.141 |
| 15                             | 22.307 | 24.996 | 28.259 | 30.578 |

# Stata Output

| Cases     | Controls |           |       |
|-----------|----------|-----------|-------|
|           | Exposed  | Unexposed | Total |
| Exposed   | 12       | 43        | 55    |
| Unexposed | 7        | 121       | 128   |
| Total     | 19       | 164       | 183   |

McNemar's chi2(1) = 25.92 Prob > chi2 = 0.0000  
Exact McNemar significance probability = 0.0000

## Proportion with factor

|            |          |          |                      |
|------------|----------|----------|----------------------|
| Cases      | .3005464 |          |                      |
| Controls   | .1038251 |          | [95% Conf. Interval] |
| difference | .1967213 | .1210924 | .2723502             |
| ratio      | 2.894737 | 1.885462 | 4.444269             |
| rel. diff. | .2195122 | .1448549 | .2941695             |
| odds ratio | 6.142857 | 2.739772 | 16.18458 (exact)     |

# Statistical Tests

## Z-test:

Study variable: Qualitative

Outcome variable: Qualitative

Comparison: Sample proportion with population proportion; two sample proportions

Sample size: larger in each group(>30)

# Test for sample proportion with population proportion

## Problem

In an otological examination of school children, out of 146 children examined 21 were found to have some type of otological abnormalities. Does it confirm with the statement that 20% of the school children have otological abnormalities?

**a . Question to be answered:**

Is the sample taken from a population of children with 20% otological abnormality

**b. Null hypothesis :** The sample has come from a population with 20% otological abnormal children

# Test for sample prop. with population prop.

## c. Test statistics

$$z = \frac{p - P}{\sqrt{\frac{pq}{n}}} = \frac{14.4 - 20.0}{\sqrt{\frac{14.4 * 85.6}{146}}} = 1.69$$

**P** – Population. Prop.  
**p**- sample prop.  
**n**- number of samples

## d. Comparison with theoretical value

$$Z \sim N(0,1); \quad Z_{0.05} = 1.96$$

The prob. of observing a value equal to or greater than 1.69 by chance is more than 5%.  
We therefore do not reject the Null Hypothesis

## e. Inference

There is a evidence to show that the sample is taken from a population of children with 20% abnormalities

# Example

Researchers wished to know if urban and rural adult residents of a developing country differ with respect to prevalence of a certain eye disease. A survey revealed the following information

| Residence | Eye disease |     | Total |
|-----------|-------------|-----|-------|
|           | Yes         | No  |       |
| Rural     | 24          | 276 | 300   |
| Urban     | 15          | 485 | 500   |

Test at 5% level of significance, the difference in the prevalence of eye disease in the 2 groups

# Z-test for (two independent sample proportions)

$$Z = \frac{P_1 - P_2}{\sqrt{\frac{P_1(1-P_1)}{n_1} + \frac{P_2(1-P_2)}{n_2}}}$$

P1= proportion in the first group

P2= proportion in the second group

n1= first sample size

n2= second sample size



# Critical z =

- **1.96** at **5%** level of significance
- **2.58** at **1%** level of significance

# Answer

$$P_1 = 24/300 = 0.08 \quad p_2 = 15/500 = 0.03$$

$$Z = \frac{0.08 - 0.03}{\sqrt{\frac{0.08(1-0.08)}{300} + \frac{0.03(1-0.03)}{500}}} = 2.87$$

**2.87 > 1.96 ( from Z-table at  $\alpha=0.05$ )**

**Hence we can conclude that,  
the difference of prevalence of eye disease  
between the two groups is statistically significant**

# In Conclusion !

When both the study variables and outcome variables are categorical (Qualitative):

Apply

- (i) Chi square test (for two and more than two groups)
- (ii) Fisher's exact test (Small samples)
- (iii) Mac Nemar's test ( for paired samples)
- (iv) Z-test for single sample (comparing sample proportion with population proportion) and two samples (two sample proportions)