

# Implementation of McNemar's Test on the Cellular Operator Company in the Comparative Hypotheses Test for Two Correlated Samples

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## Abstract

McNemar's test is a testing method used in comparing the characteristics of data before and after the treatment in which each object is used its own controller. The test is performed on two interconnected samples, the scale of measurement is nominal (binary response) and for data cross tabulation  $2 \times 2$ . Distribution used to test the changes in the response is used chi-square distribution. As an application, research on a cellular card carrier company to find out whether the new policy run by the company has an effect on consumer behavior in buying their products. The policy is to raise the price of voucher credit, but coupled with the giving of free short messages every day. There were 300 mobile phone owners observed. As many as 80 consumers are unsubscribed, 150 customers remain subscribed, 60 consumers become new customers, while 10 mobile phone owners keep using their old prepaid cards (not switching to new customers). Based on the hypothesis test, it is concluded that the hypothesis is accepted, which means that consumer behavior does not change although new policy is applied.

**Keywords:** McNemar's test, nominal scale, chi-square distribution.

## INTRODUCTION

This paper explains how to select the correct statistical test for a research project, clinical trial, or other investigation. The first step is to decide in what scale of measurement your data are as this will affect your decision-nominal, ordinal, or interval (Demšar, 2006). The next stage is to consider the purpose of the analysis-for example, are you comparing independent or paired groups? Several statistical tests are discussed with an explanation of when it is appropriate to use each one; relevant examples of each are provided. If an incorrect test is used, then invalid results and misleading conclusions may be drawn from the study.

In statistical science terminology, there are parametric and non parametric statistics which are two frequently used things (SiegelS. 1988). Next, what distinguishes the two? Simply speaking, between parametric and non parametric statistics is easily distinguished from the term. Nonparametric statistics are statistics that do not base on statistical parameters. So what are the statistical parameters? If you do the research, of course you make the measurements, well the sizes are termed with parameters. In statistics we know the mean, median, mode and standard deviation, that is the statistical parameters. While in non parametric statistics, the parameter is not used as

a reference. Why? When we use the nominal or ordinal data scale, the parameters become irrelevant, it is more to rank the data. In addition, nonparametric statistics do not affect the distribution of certain data (Sugiyono. 2015).

In this paper I explain how to select the correct statistical test depending on the type of data and purpose of the analysis. When choosing the appropriate statistical test, the first step is to decide what scale of measurement your data is as this will affect your decision (BlandM. 2000). The next stage is to consider the analysis required for example, are you comparing independent or paired groups? I discuss when it is appropriate to use a range of parametric and non-parametric tests including examples of each. If an incorrect test is used, then invalid results and misleading conclusions may be drawn from the study. Definitions of elementary statistical concepts and a useful statistical glossary are provided in.

Non-Parametric Statistics is a test whose model does not specify the conditions concerning the population parameters which are the parent of the research sample. Therefore, the independent observations and the variables studied are basically continuity. A nonparametric or free-spreading method test is a hypothesis testing procedure that does not assume any knowledge of the underlying population distribution unless it is continuous. In short: Non-Parametric Statistics are free-spreading statistics (not requiring the distribution of population parameters, whether normal or not). In addition, non-parametric statistics typically use social measurement scales, i.e. nominal and ordinal which are generally not normally distributed. One of the nonparametric tests for two correlated samples was the McNemar's test (Ciechalski, 2002)

## NONPARAMETRIC STATISTICS

Inferential statistics are of two kinds, namely parametric statistics and nonparametric statistics. Non-Parametric Statistics is a free-spread statistic (not requiring the distribution of population parameters, whether normal or not). In addition, non-parametric statistics typically use social measurement scales, i.e. nominal and ordinal which are generally not normally distributed.

### Characteristics of Non Parametric Statistics

1. Data is not normally distributed.
2. Generally nominal and ordinal data

3. Generally done on social research
4. Generally small number of samples.

As the sample is very small and the data are categorical, I thought the appropriate test was McNemar's test.

Some important notes on the use of nonparametric statistical tests

1. The formulation of the hypothesis must be supported by the appropriate theoretical foundation so that the hypothesis can be justified truth. An example of a correlation between income and expenditure should be determined by theory / substance.
2. It is recommended that researchers try to choose a unilateral hypothesis because it shows the depth of the researcher's knowledge of the problems to be solved.
3. Two way hypothesis is only used if the researcher is less sure about the expected parameter value.
4. True or false hypotheses will never be known with certainty unless we examine the entire population. We therefore take a random sample of the population and use the information it contains to decide whether the hypothesis is likely to be true or false. Evidence of data from samples inconsistent with the hypothesis leads us to the rejection of the hypothesis, and vice versa. It should be emphasized that the acceptance of a statistical hypothesis is the result of insufficient evidence to reject it, and does not imply that the hypothesis is true.
5. In general, hypothesis testing is distinguished 2, testing of comparative hypotheses and associations. Testing the comparative hypothesis relates to testing the mean differences between two or more groups. The association hypothesis testing is concerned with testing between two variables.

**UNDERSTANDING AND PROCEDURE MC NEMAR'S TEST**

McNemar's test was first published in a *Psychometric* article in 1947. It was created by Quinn McNemar, who was a professor in the Psychology and Statistics department at Stanford University. This non-parametric (distribution-free) test assesses if a statistically significant change in proportions have occurred on a dichotomous trait at two time points on the same population. It is applied using a 2x2 contingency table with the dichotomous variable at time 1 and time 2. In medical research, if a researcher wants to determine whether or not a particular drug has an effect on a disease (e.g., yes vs. no), then a count of the individuals is recorded (as + and - sign, or 0 and 1) in a table before and after being given the drug. Then, McNemar's test is applied to make statistical decisions (using the Chi Square test statistic) as to whether or not a drug has an effect on the disease (Xuezheng, 2008).

McNemar's test is used to determine if there are differences on a dichotomous dependent variable between two related groups. It can be considered to be similar to the paired-samples t-test, but for a dichotomous rather than a continuous

dependent variable. The McNemar test is used to analyze pretest-posttest study designs, as well as being commonly employed in analyzing matched pairs and case-control studies. For example, you could use the McNemar test to determine whether the proportion of participants who had low self-esteem (as opposed to high self-esteem) before a series of counseling sessions (i.e., an intervention) decreased after the intervention (i.e., your dependent variable would be "level of self-esteem", which has two categories: "low" and "high"). Alternately, you could use the McNemar's test to determine whether the proportion of participants who felt safe (yes or no) differed when wearing a cycling helmet as opposed to wearing no cycling helmet (i.e., the dependent variable would be "sense of safety", which has two categories: "safe" and "not safe").

McNemar's test is a method used for research by comparing before and after the event / treatment in which each object is used its own controller. The test is performed on two interconnected samples, the scale of measurement is nominal (binary response) and for data cross tabulation 2 x 2 (Agresti, A.1990. Distribution used To test the changes in the response is used chi-square distribution. To test the significance of changes from the observation of the nominal data, arranged in the contingency table as follows (Tiro,2005) :

	-	+
+	A	B
-	C	D

Where:

Cell A : Changes from category +, To category -.

Cell D : Changes from category -, To category +.

If A + D Is the total amount changed, and B and C That does not change. Then 1/2 (A+D) Is the expected frequency below H<sub>0</sub>On both cells ie A and D.

McNemar's test Chi square distributed (χ<sup>2</sup>). Therefore the formula used for hypothesis testing is Chi Square formula. The basic equation is as follows:

$$\chi^2 = \sum_{i=1}^k \frac{(f_0 - f_n)^2}{f_n} \dots \dots \dots (1)$$

The Significance Test is only concerned with A and D. If A = Many cases are observed in Cell A, and D = many cases are observed in Cell D, and 1/2 (A+D) Many cases are expected both A and D cells, The formula can be simplified to be:

$$\chi^2 = \frac{(A-D)^2}{(A+D)} \dots \dots \dots (2)$$

Formula 2 will get better with the "continuity correction" provided by Yates, 1934 Namely: by subtracting by one value. The continuity correction is given because the distribution uses a normal distribution. As already known that the normal distribution is usually used for continuous data. After the correction of continuity, then formula 2 is refined to:

$$\chi^2 = \frac{(|A-D|-1)^2}{(A+D)} \dots\dots\dots(3)$$

The reduction of 1 in the above formula is the correction of reason, because the distribution of the Chi Square is the approximation of the frequency of observation which is the discrete data. McNemar's tests a chi-square approach to the validity of large samples. This is similar to the normal approach to the binomial distribution. If the frequency of expectation is  $\frac{1}{2} (A+D)$  Very small (less than five), McNemar's test Not exactly done.

**Procedure Doing McNemar's test**

1. Create a categorical Table 2 x 2. Sign + dan - Used to indicate a change. For example in cells A and D there is a change from + to - and from - to +. While in cell B and C no change.
2. Determine the expected frequencies (E) from cell A and cell D,  $E = \frac{1}{2} (A+D)$ . Frequency of expectation should be  $\geq 5$ .
3. Hypothesis testing
  - $H_0$  :  $P(A)=P(D)=1/2$ , There was no difference from before treatment with after treatment.
  - $H_1$  :  $P(A) \neq P(D)$ , There is a difference from before treatment with after treatment.
4. If  $E \geq 5$ , Calculate the value  $\chi^2$  menggunakan rumus 3 . Tetapi jika  $E < 5$ , Uji  $\chi^2$  McNemar's test Should not be used, and for the replacement can be used Binomial Test.
5. Deciding Decisions
  - If  $\chi^2_{count} < \chi^2_{table} = H_0$  Accepted and  $H_1$  rejected
  - If  $\chi^2_{count} > \chi^2_{table} = H_0$  rejected and  $H_1$  Accepted

The test is applied to a  $2 \times 2$  contingency table, which tabulates the outcomes of two tests on a sample of  $n$  subjects, as follows.

	Test 2 positive	Test 2 negative	Row total
Test 1 positive	A	B	a + b
Test 1 negative	C	D	c + d
Column total	a + c	b + d	N

The null hypothesis of marginal homogeneity states that the two marginal probabilities for each outcome are the same, i.e.  $p_a + p_b = p_a + p_c$  and  $p_c + p_d = p_b + p_d$ . Thus the null and

alternative hypotheses are. Here  $p_a$ , etc., denote the theoretical probability of occurrences in cells with the corresponding label. The McNemar test, has a chi-squared distribution test statistic is: Under the null hypothesis with a sufficiently large number of discordant cells (cells b and c) with 1 degree of freedom. If the result is significant, this provides sufficient evidence to reject the null hypothesis, in favour of the alternative hypothesis that  $p_b \neq p_c$ , which would mean that the marginal proportions are significantly different from each other.

**VARIATIONS**

If either  $b$  or  $c$  is small ( $b + c < 25$ ) then is not well-approximated by the chi-squared distribution. An exact binomial test can then be used, where  $b$  is compared to a binomial distribution with size parameter  $n = b + c$  and  $p = 0.5$ . Effectively, the exact binomial test evaluates the imbalance in the discordant  $b$  and  $c$ . To achieve a two-sided P-value, the P-value of the extreme tail should be multiplied by 2:

which is simply twice the binomial distribution cumulative distribution function with  $p = 0.5$  and  $n = b + c$ .

The cumulative distribution function of a real-valued random variable  $X$  is the function given by where the right-hand side represents the probability that the random variable  $X$  takes on a value less than or equal to  $x$ . The probability that  $X$  lies in the semi-closed interval  $(a, b]$ , where  $a < b$ , is therefore

In the definition above, the "less than or equal to" sign, " $\leq$ ", is a convention, not a universally used one (e.g. Hungarian literature uses " $<$ "), but is important for discrete distributions. The proper use of tables of the binomial and Poisson distributions depends upon this convention. Moreover, important formulas like Paul Lévy's inversion formula for the characteristic function also rely on the "less than or equal" formulation.

If treating several random variables  $X, Y, \dots$  etc. the corresponding letters are used as subscripts while, if treating only one, the subscript is usually omitted. It is conventional to use a capital  $F$  for a cumulative distribution function, in contrast to the lower-case  $f$  used for probability density functions and probability mass functions. This applies when discussing general distributions: some specific distributions have their own conventional notation, for example the normal distribution. The CDF of a continuous random variable  $X$  can be expressed as the integral of its probability density function  $f_X$  as follows: In the case of a random variable  $X$  which has distribution having a discrete component at a value  $b$ ,

If  $F_X$  is continuous at  $b$ , this equals zero and there is no discrete component at  $b$ .

proposed the following continuity corrected version of the McNemar test to approximate the binomial exact-P-value: The mid-P McNemar's test (mid-p binomial test) is calculated by subtracting half the probability of the observed  $b$  from the exact one-sided P-value, then double it to obtain the two-sided mid-P-value:<sup>[4][5]</sup>

This is equivalent to: where the second term is the binomial distribution probability mass function and  $n = b + c$ . Fortunately, binomial distribution functions are readily available in common software packages and the McNemar's test mid-P test can easily be calculated.<sup>[5]</sup>

The traditional advice has been to use the exact binomial test when  $b + c < 25$ . However, simulations have shown both the exact binomial test and the McNemar test with continuity correction to be overly conservative.<sup>[5]</sup> When  $b + c < 6$ , the exact-P-value always exceeds the common significance level 0.05. The original McNemar's test was most powerful, but often slightly liberal. The mid-P version was almost as powerful as the asymptotic McNemar's test and was not found to exceed the nominal significance level.

Success or failure in placing a phone call in each of the phases (Instruction and Carryover) and for each mode (Standard, Flip and Picture) was noted. Success or failure in answering a phone call in both phases (Instruction and Carryover) was also noted. The McNemar Chi-square test was used to assess a statistical difference between the rates of success for the three dialing modes (Standard, Flip and Picture) for each phase.

### APPLICATIONS OF MC NEMAR'S TEST

In statistics, McNemar's test is a statistical test used on paired nominal data. It is applied to  $2 \times 2$  contingency tables with a dichotomous trait, with matched pairs of subjects, to determine whether the row and column marginal frequencies are equal (that is, whether there is "marginal homogeneity") (Agresti, A.2002). The test is applied to a  $2 \times 2$  contingency table, which tabulates the outcomes of two tests on a sample of n subjects, as follows. In this example, the null hypothesis of "marginal homogeneity" would mean there was no effect of the treatment. From the above data, the McNemar test statistic. The study was conducted by a cellular carrier company to find out whether the new policy being run by the company had an effect on consumer behavior in purchasing the product. The policy is to raise the price of the voucher but accompanied by the giving of free sms every day. There were 300 mobile phone owners observed. As many as 80 consumers unsubscribed, 150 customers remained subscribed, 60 consumers became new customers, while 10 mobile phone owners continued to use their old cardpays (not switching to new customers). The data is seen in this following table

		New policy	
		Consumer behavior	
Policy Long	Not Subscribed	10	60
	Subscribe	80	150

### Hypothesis

$H_0$ : Consumer behavior is unchanged despite new policies enacted

$H_1$ : Consumer behavior has changed since the introduction of new policies.

Hypothesis is that respondent will indicate an increased number of experiences when given the modified version, as compared to the original. Inwith the hypothesis that the modified version will elicit increased rates of admitted perpetration compared to the original version.

McNemar test of symmetry of  $k \times k$  contingency table is inherently 2-sided: the alternative hypothesis is undirected. So, in general case it cannot be used to test a one sided alternative that subdiagonal frequencies are larger/smaller than superdiagonal frequencies. But since in this case the differences are consistently in favor of subdiagonal frequencies, so can use the test for the directional inference (Fagerland, 2013).

The McNemar's test has three assumptions that must be met. If these assumptions are not met, you cannot use a McNemar's test, but may be able to use another statistical test instead. Therefore, in order to run a McNemar's test, you need to check that your study design meets the following three assumptions (Levin, 2000):

The McNemar test has the the following assumptions (Conover, 1999):

1. The pairs  $(X_i, Y_i)$  are mutually independent.
2. Each  $X_i$  and  $Y_i$  can be assigned to one of two possible categories.
3. The difference

$$P(X_i = 0, Y_i = 1) - P(X_i = 1, Y_i = 0)$$

is negative for all  $i$  or zero for all  $i$  or positive for all  $i$ .

If we let  $P_1 = P(X_i = 0, Y_i = 1)$  and  $P_2 = P(X_i = 1, Y_i = 0)$ , then the McNemar test can be formulated as follows.

$H_0$ :  $P_1 = P_2$  for all  $i$   
 (this is equivalent to "new equal to old" or "before equal to after")

$H_a$ :  $P_1 \neq P_2$  for all  $i$   
 (this is equivalent to "new not equal to old" or "before not equal to after")

Test Statistic: If  $b + c > 20$ ,  
 $T_1 = (b - c)^2 / (b + c)$   
 If  $b + c \leq 20$ ,  
 $T_2 = b$   
 There is also a continuity corrected version of the  $T_1$ :

$$T_1' = (|b - c| - 1)^2 / (b + c)$$

Significance A

Level:

Critical Region:  $T_1 > \chi^2_{1-\alpha,1}$

$T_2 \leq \text{BINPPF}(\alpha/2, 0.5, b+c)$

$T_2 \geq \text{BINPPF}(\alpha/2, 0.5, b+c)$

where  $\chi^2_{\alpha, v}$  and BINPPF denote the percent point functions of the chi-square and binomial distributions, respectively

Conclusion: Reject the null hypothesis if the test statistic is in the critical region

**Syntax 1:**

MCNEMAR TEST <y1><y2>

<SUBSET/EXCEPT/FOR qualification>

where <y1> is the first response variable;

<y2> is the second response variable;

and where the <SUBSET/EXCEPT/FOR qualification> is optional.

This syntax is used for the raw data case (i.e., <y1> and <y2> are variable containing 0's and 1's).

**Syntax 2:**

MCNEMAR TEST <m> <SUBSET/EXCEPT/FOR qualification>

where <m> is a matrix containing the two-way table;

and where the <SUBSET/EXCEPT/FOR qualification> is optional.

This syntax is used for the case where we the data have already been cross-tabulated into a two-way table.

**Syntax 3:**

MCNEMAR TEST <n11><n12><n21><n22>

where <n11> is a parameter containing the value for row 1, column 1 of a 2x2 table (i.e., a);

<n12> is a parameter containing the value for row 1, column 2 of a 2x2 table (i.e., b);

<n21> is a parameter containing the value for row 2, column 1 of a 2x2 table (i.e., c);

<n22> is a parameter containing the value for row 2, column 2 of a 2x2 table (i.e., d).

This syntax is used for the special case where you have a 2x2 table. In this case, you can enter the 4 values directly, although you do need to be careful that the parameters are entered in the order expected above.

**Examples:**

MCNEMAR TEST Y1 Y2

MCNEMAR TEST M

MCNEMAR TEST N11 N12 N21 N22

Note:

The McNemar test is essentially a sign test. Conover discusses how to transform a McNemar test to an explicit sign test.

The McNemar test is also a special case of the Cochran test with  $c = 2$  (enter HELP COCHRAN TEST for details).

Note:

Dataplot saves the following internal parameters:

STATVAL = the value of the McNemar test statistic  
 STATCDF = the cdf for the McNemar test statistic

If your study design does not meet these three assumptions, you cannot use a McNemar's test, but you may be able to use another statistical test instead

**McNemar's test steps (Berenson, 2005).**

1. Create a table of frequencies in the form of 2x2 tables
2. Determine the expected frequencies
3. Hypothesis testing
4. If  $E \geq 5$ , calculate the value using the formula  $\chi^2$ . But, if  $E < 5$ , McNemar's test  $\chi^2$ , Should not be used, and for the replacement can be used Binomial Test.
5. Determining the Decision

Counted is the changed cell of 60 people into new subscribers from unsubscribed, and 80 people unsubscribed. With 1 degree and 1 degree  $\alpha = 0,05$ .

Test statistics :

$$\chi^2 = \frac{(1 \ 60 - 80 \ | \ -1)^2}{(60 + 80)}$$

$$= \frac{361}{140} = 2,57$$

**CONCLUSION**

$H_0$  Accepted because  $\chi^2_{hit} < \chi^2_{tab} = 2,57 < 3.84$

An interesting observation when interpreting McNemar's test is that the elements of the main diagonal do not contribute to the decision about whether (in the above example) pre- or post-treatment condition is more favourable. Thus, the sum  $b + c$  can be small and statistical power of the tests described above can be low even though the number of pairs  $a + b + c + d$  is large. An extension of McNemar's test exists in situations where independence does not necessarily hold between the pairs; instead, there are clusters of paired data where the pairs in a cluster may not be independent, but independence holds between different clusters

**Procedure:**

A	B	A+B
C	D	C+D
A+C	B+D	

We assume that the row total is equal to the column total. In other words:

$(A+B) = (A+C)$

$(C+D) = (B+D)$

In this case, we will cancel the A and D equation and this implies that B = C. By using this equation, we will calculate the test as:

$$x^2 = \frac{(B - C)^2}{B + C}$$

### Hypothesis:

**Null hypothesis:** Assumes that the total rows are equal to the sum of columns. The mean of paired samples are equal and no (significant) change has occurred. In medical research, for example, the null hypothesis assumes that the drug has no impact on disease.

**Alternative Hypothesis:** Assumes that the total number of rows is not equal to the total number of columns, or that the paired sample means are not equal. In medical research, for example, alternative hypothesis assumes that the drug has an impact on the disease.

How to carry out a McNemar's test using SPSS Statistics, as well as interpret and report the results from this test. However, before we introduce you to this procedure, you need to understand the different assumptions that your study design must meet in order for a McNemar's test to be an appropriate choice of test.

To perform McNemar's test in SPSS, follow the following procedures (Omolola, 2012):

1. Click on **Analyze** then **Descriptive Statistics** and then **Crosstabs**
2. Click on one of your dichotomous variables into the box marked **Row(s)**
3. Click on one of your dichotomous variables into the box marked **Column(s)**
4. Click on the **Statistics** button, then check **McNemar**, then **Continue**.
5. Optional: Click on the **Cells** button and check **Observed** under the **Counts** box and click on the **Row**, **Column** boxes under **Percentage**.
6. Click **Continue** and then **OK**.
7. To determine if a statistically significant change has occurred, looked under the **Chi-Square Tests** output and check the significance value.

### CONCLUSION

- McNemar's test is a method used for research by comparing before and after the event / treatment in which each object is used its own controller.
- The use of chi-square analysis for examining paired or dependent variables for which McNemar's test is the

most appropriate, the method is simple, quick and easy to perform, has high practical power and "it enables an appropriate confirmatory data. In addition to its use for testing significance of changes in related proportions, McNemar analysis also has potential as an exploratory tool .

- If your study design does not meet these three assumptions, you cannot use a McNemar's test, but you may be able to use another statistical test instead.
- This test is performed on 2 interconnected samples.
- The scale of measurement is nominal (binary response) and for data cross tabulation 2 x 2.
- Based on hypothesis testing, for McNemar's test application. McNemar's test it appears that consumer behaviour has not changed despite new policies applied to a cellular carrier company.

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