Introduction to Statistical Analysis (using Shiny Apps)

CRUK:- Monday 28th November 2016

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www.tiny.cc/crukStats

Acknowledgements:- Sarah Vowler, Sarah Dawson, Liz Merrell, Deepak Parashar, Rob Nicholls

Tests for continuous variables non-parametric methods

When to use which test

		RESPONSE		
NO OF SAMPLES		**NOMINAL**	**ORDINAL OR NON-NORMAL**	**NORMALLY DISTRIBUTED**
ONE SAMPLE		χ^2-test, Z-test	Kolmogorov-Smirnov Sign test	t-test
TWO SAMPLE	**INDEPENDENT**	χ^2-test (r x c), Fisher's exact test	Mann-Whitney U Median test	Unpaired t-test
	PAIRED	McNemar's test Stuart-Maxwell test	Wilcoxon signed rank Sign test	Paired t-test
MULTIPLE SAMPLES (K>2)	**INDEPENDENT**	χ^2-test (r x k) Fisher-Freeman-Halton	Kruskal-Wallis test Median Test Jonckheere-Terpstra test	Analysis of variance (ANOVA)
	PAIRED	Cochran Q test	Friedman test Page test Quade test	Repeated measures ANOVA
ASSOCIATION BETWEEN TWO VARIABLES		Contingency coefficient Phi, r_ϕ Cramér, C	Spearman's rank Kendall's tau	Pearson product moment correlation
AGREEMENT BETWEEN TWO VARIABLES		Simple kappa	Weighted kappa	Limits of agreement

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Sign Test

- A very simple non-parametric test
  - based on the Binomial distribution
- Uses directions of differences
- One-sample case: compares to proposed value
- Paired two-sample case: compares medians

One-Sample Sign Test

- Assumptions:
  - Order in coding system (minimally requires ordinal data)
  - Randomly selected observations (independent)

- Hypotheses:
  - H_0: median is equal to a specific value
  - H_A: median is not equal to that specific value

One-Sample Sign Test

Method:

- Compare values to a specific value:
  - \+ : if bigger
  - – : if smaller
  - = : if equal
- Count the number of +'s and -'s, and calculate:

  x = smallest of the positives and negatives

  n = number of non-ties
- Compare to binomial tables

  With p = 0.5 (binomial success probability, not p-value)

One-Sample Sign Test

- General health section of SF-36 collected in a breast cancer study
- Expected value in general population: 72

H_0 : median value in sample is equal to 72

One-Sample Sign Test

GH Value
60
55
75
100
55
60
50
60
72
40
90
75
70
75
55

One-Sample Sign Test

GH Value	Sign
60	-
55	-
75	+
100	+
55	-
60	-
50	-
60	-
72	=
40	-
90	+
75	+
70	-
75	+
55	-

9 : observations <72

5 : observations >72

1 : observation =72

One-Sample Sign Test

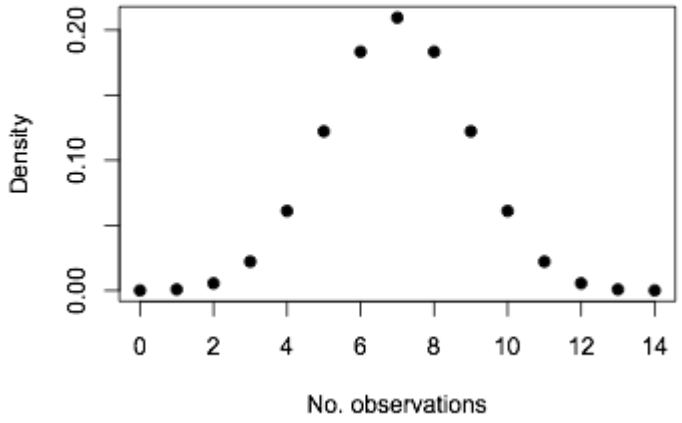
GH Value	Sign
60	-
55	-
75	+
100	+
55	-
60	-
50	-
60	-
72	=
40	-
90	+
75	+
70	-
75	+
55	-

9 : observations <72

5 : observations >72

1 : observation =72

Binomial tables: n=14, p=0.5, x=5



One-Sample Sign Test

GH Value	Sign
60	-
55	-
75	+
100	+
55	-
60	-
50	-
60	-
72	=
40	-
90	+
75	+
70	-
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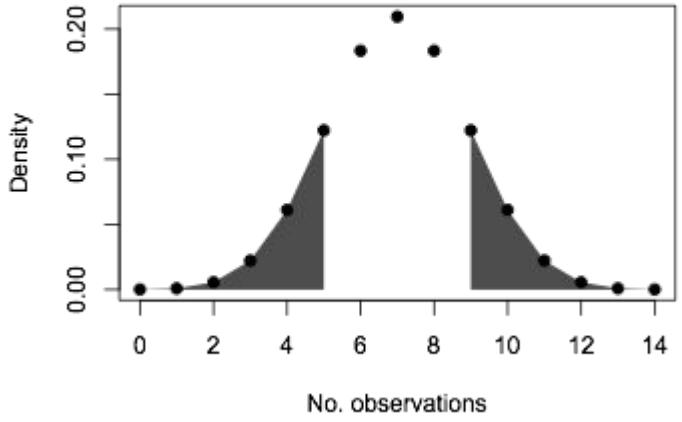

P-value = 0.42

One-Sample Sign Test

H_0 : median value in sample is equal to 72

- Sign test p-value = 0.42
- Insufficient evidence to reject H_0

Conclusion: insufficient evidence to suggest that the median value is different from 72

When to use which test

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Two-Sample Sign Test

Method:

- Compare paired values between the two samples:
  - \+ : if the value in sample 1 is bigger
  - – : if the value in sample 1 is smaller
  - = : if the value in the two samples is equal
- Count the number of +'s and -'s, and calculate:

  x = smallest of the positives and negatives

  n = number of non-ties
- Compare to binomial tables

  With p = 0.5 (binomial success probability, not p-value)

Two-Sample Sign Test

- General health section of SF-36 collected in a breast cancer study
- Data collected at two time points
- Is there a difference between the time points?

H_0 : medians of the two samples are the same

Two-Sample Sign Test

GH Value 1	GH Value 2
60	70
55	65
75	100
100	50
55	70
60	95
50	95
60	65
72	85
40	55
90	95
75	45
70	75
75	65
55	60

Data are paired

Two-Sample Sign Test

GH Value 1	GH Value 2	Difference
60	70	-10
55	65	-10
75	100	-25
100	50	50
55	70	-15
60	95	-35
50	95	-45
60	65	-5
72	85	-13
40	55	-15
90	95	-5
75	45	30
70	75	-5
75	65	10
55	60	-5

Data are paired

Two-Sample Sign Test

GH Value 1	GH Value 2	Difference	Sign
60	70	-10	-
55	65	-10	-
75	100	-25	-
100	50	50	+
55	70	-15	-
60	95	-35	-
50	95	-45	-
60	65	-5	-
72	85	-13	-
40	55	-15	-
90	95	-5	-
75	45	30	+
70	75	-5	-
75	65	10	+
55	60	-5	-

Data are paired

Negative signs : 12

Positive signs : 3

Two-Sample Sign Test

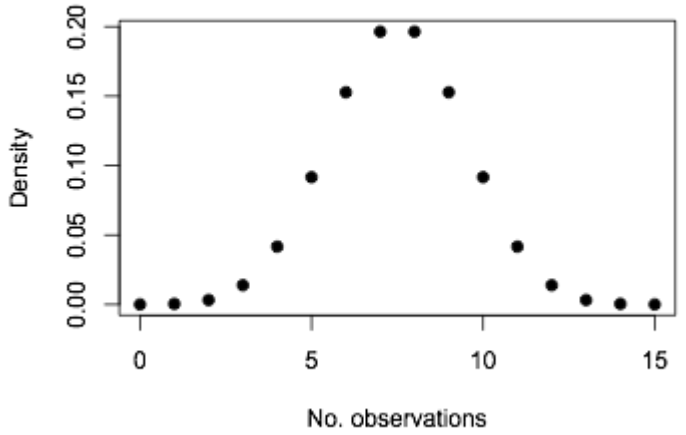
GH Value 1	GH Value 2	Difference	Sign
60	70	-10	-
55	65	-10	-
75	100	-25	-
100	50	50	+
55	70	-15	-
60	95	-35	-
50	95	-45	-
60	65	-5	-
72	85	-13	-
40	55	-15	-
90	95	-5	-
75	45	30	+
70	75	-5	-
75	65	10	+
55	60	-5	-

Data are paired

Negative signs : 12

Positive signs : 3

Binomial tables: n=15, p=0.5, x=3



Two-Sample Sign Test

GH Value 1	GH Value 2	Difference	Sign
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55	65	-10	-
75	100	-25	-
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50	95	-45	-
60	65	-5	-
72	85	-13	-
40	55	-15	-
90	95	-5	-
75	45	30	+
70	75	-5	-
75	65	10	+
55	60	-5	-

Data are paired

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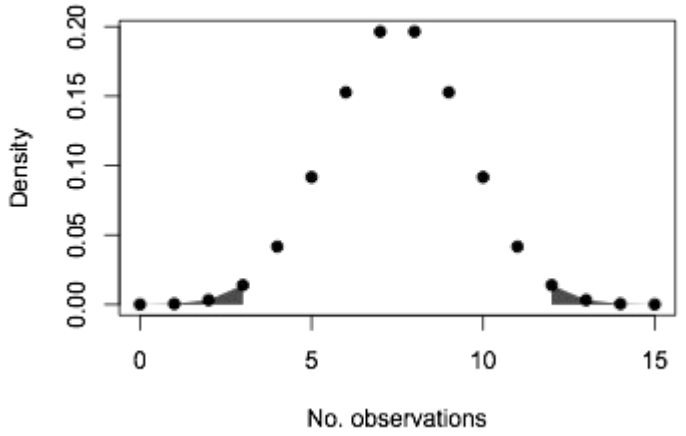

P-value = 0.035

Two-Sample Sign Test

H_0 : medians of the two samples are the same

- Sign test p-value = 0.035
- Reject the null hypothesis

Conclusion: there is a difference in general health between the two time points

Presentation of the Results

- One-sample case:

  "There is insufficient evidence to suggest a significant difference between the median general health value (60) observed in this sample and the value (72) observed in the general population (p=0.42, sign test)."

- Two-sample case:

  "The median general health value observed at the second time point (70) was found to be significantly higher than the median (60) observed at the first time point (p=0.035, sign test)."

Sign Test - Advantages & Limitations

- Simple - few assumptions thus widely applicable
- Significance threshold can be adjusted
- Less powerful than other tests
  - Does not consider magnitude of differences
  - May fail to reject null hypothesis when other tests would achieve significance.
- Can be used for quick assessment of direction

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Wilcoxon Signed Rank Test

- Alternative to sign test
- Assumptions:
  - Paired data (e.g. matched samples, repeated measurements)
  - Each pair is independent
  - Continuous or ordinal data (Normality not assumed)
  - Symmetry of difference scores about true median difference (test by looking at histogram/boxplot)
- Hypothesis:

  H_0: sum of positive ranks equals sum of negative ranks

  H_A: sum of positive ranks not equal to sum of negative ranks

Wilcoxon Signed Rank Test

Method:

- Calculate differences for each pair
- Rank the paired differences by magnitude
- Split the ranks into two groups:
  - positive and negative signed differences
- Calculate sum of positive ranks: W^+
- Calculate sum of negative ranks: W^-
- Compare smaller of and W^+ and W^- to the critical value from the tables

Wilcoxon Signed Rank Test

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H_0 : medians of the two samples are the same

Wilcoxon Signed Rank Test

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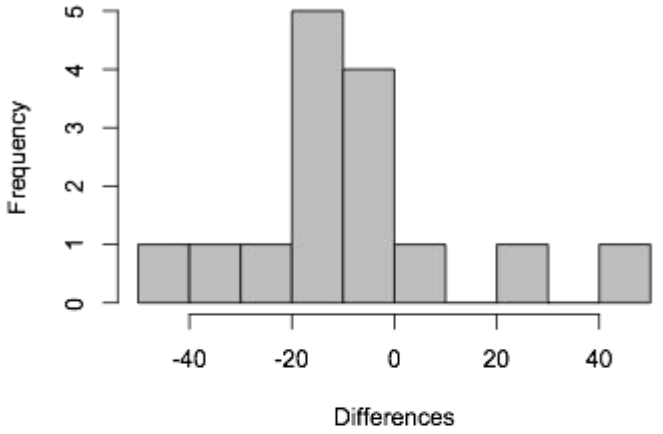
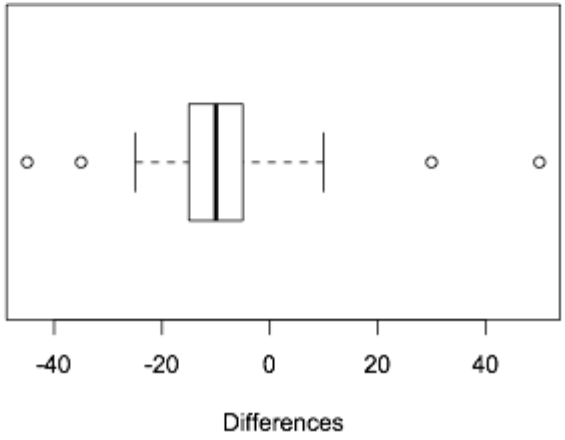
~~H_0 : medians of the two samples are the same~~

H_0 : distribution of paired differences is symmetric about zero

Wilcoxon Signed Rank Test

GH Value 1	GH Value 2	Difference	Sign
60	70	-10	-
55	65	-10	-
75	100	-25	-
100	50	50	+
55	70	-15	-
60	95	-35	-
50	95	-45	-
60	65	-5	-
72	85	-13	-
40	55	-15	-
90	95	-5	-
75	45	30	+
70	75	-5	-
75	65	10	+
55	60	-5	-





Wilcoxon Signed Rank Test

GH Value 1	GH Value 2	Difference	Sign	Abs.Diff.
60	70	-10	-	10
55	65	-10	-	10
75	100	-25	-	25
100	50	50	+	50
55	70	-15	-	15
60	95	-35	-	35
50	95	-45	-	45
60	65	-5	-	5
72	85	-13	-	13
40	55	-15	-	15
90	95	-5	-	5
75	45	30	+	30
70	75	-5	-	5
75	65	10	+	10
55	60	-5	-	5

Wilcoxon Signed Rank Test

GH Value 1	GH Value 2	Difference	Sign	Abs.Diff.
60	65	-5	-	5
90	95	-5	-	5
70	75	-5	-	5
55	60	-5	-	5
60	70	-10	-	10
55	65	-10	-	10
75	65	10	+	10
72	85	-13	-	13
55	70	-15	-	15
40	55	-15	-	15
75	100	-25	-	25
75	45	30	+	30
60	95	-35	-	35
50	95	-45	-	45
100	50	50	+	50

Wilcoxon Signed Rank Test

GH Value 1	GH Value 2	Difference	Sign	Abs.Diff.	Rank
60	65	-5	-	5	2.5
90	95	-5	-	5	2.5
70	75	-5	-	5	2.5
55	60	-5	-	5	2.5
60	70	-10	-	10	6
55	65	-10	-	10	6
75	65	10	+	10	6
72	85	-13	-	13	8
55	70	-15	-	15	9.5
40	55	-15	-	15	9.5
75	100	-25	-	25	11
75	45	30	+	30	12
60	95	-35	-	35	13
50	95	-45	-	45	14
100	50	50	+	50	15

Wilcoxon Signed Rank Test

GH Value 1	GH Value 2	Difference	Sign	Abs.Diff.	Rank	Signed-Rank
60	65	-5	-	5	2.5	-2.5
90	95	-5	-	5	2.5	-2.5
70	75	-5	-	5	2.5	-2.5
55	60	-5	-	5	2.5	-2.5
60	70	-10	-	10	6	-6
55	65	-10	-	10	6	-6
75	65	10	+	10	6	6
72	85	-13	-	13	8	-8
55	70	-15	-	15	9.5	-9.5
40	55	-15	-	15	9.5	-9.5
75	100	-25	-	25	11	-11
75	45	30	+	30	12	12
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55	60	-5	-	5	2.5	-2.5
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55	65	-10	-	10	6	-6
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40	55	-15	-	15	9.5	-9.5
75	100	-25	-	25	11	-11
75	45	30	+	30	12	12
60	95	-35	-	35	13	-13
50	95	-45	-	45	14	-14
100	50	50	+	50	15	15

Rank-Sums:

$W^+ = 33$

$W^- = 87$

Wilcoxon Signed Rank Test

GH Value 1	GH Value 2	Difference	Sign	Abs.Diff.	Rank	Signed-Rank
60	65	-5	-	5	2.5	-2.5
90	95	-5	-	5	2.5	-2.5
70	75	-5	-	5	2.5	-2.5
55	60	-5	-	5	2.5	-2.5
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75	100	-25	-	25	11	-11
75	45	30	+	30	12	12
60	95	-35	-	35	13	-13
50	95	-45	-	45	14	-14
100	50	50	+	50	15	15

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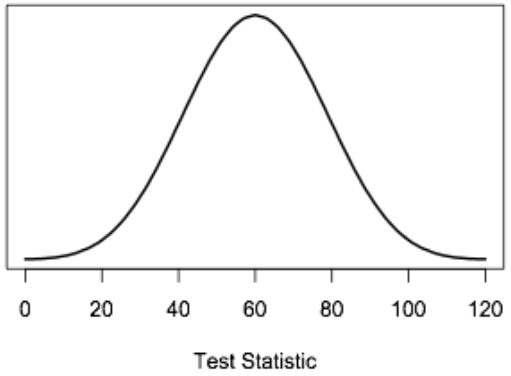

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60	70	-10	-	10	6	-6
55	65	-10	-	10	6	-6
75	65	10	+	10	6	6
72	85	-13	-	13	8	-8
55	70	-15	-	15	9.5	-9.5
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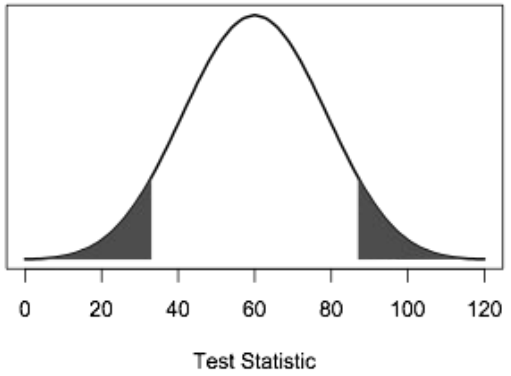


P-value = 0.12

Wilcoxon Signed Rank Test

H_0 : distribution of paired differences is symmetric about zero

- Wilcoxon test p-value = 0.12
- Insufficient evidence to reject the null hypothesis

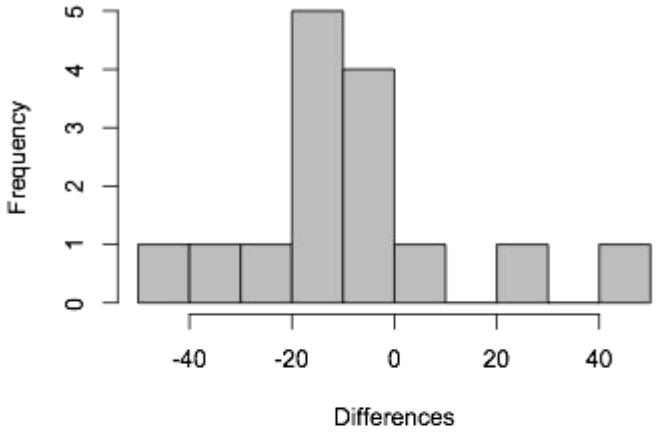
Conclusion: Insufficient evidence to conclude that there is a difference in general health between the two time points

Wilcoxon Signed Rank Test

Note:

Validity of assumptions

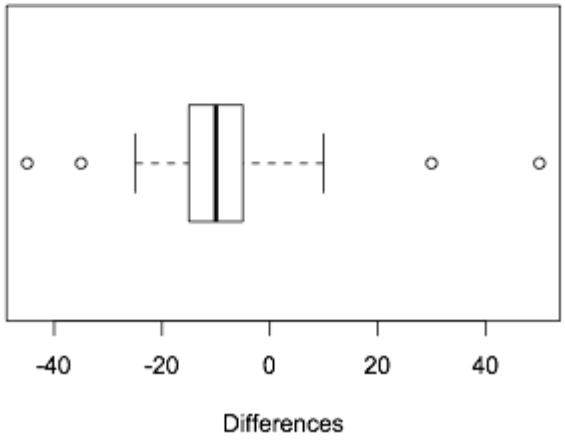
may affect results.



~~H_θ : medians of the two samples are the same~~

H_0 : distribution of paired differences is

symmetric about zero



Advantages and Limitations

- Easy to apply
- Powerful
  - Utilises more information than the Sign test (but less than the paired t-test)
- Sometimes misinterpreted
  - Assumes symmetry of difference scores about the true median difference

When to use which test

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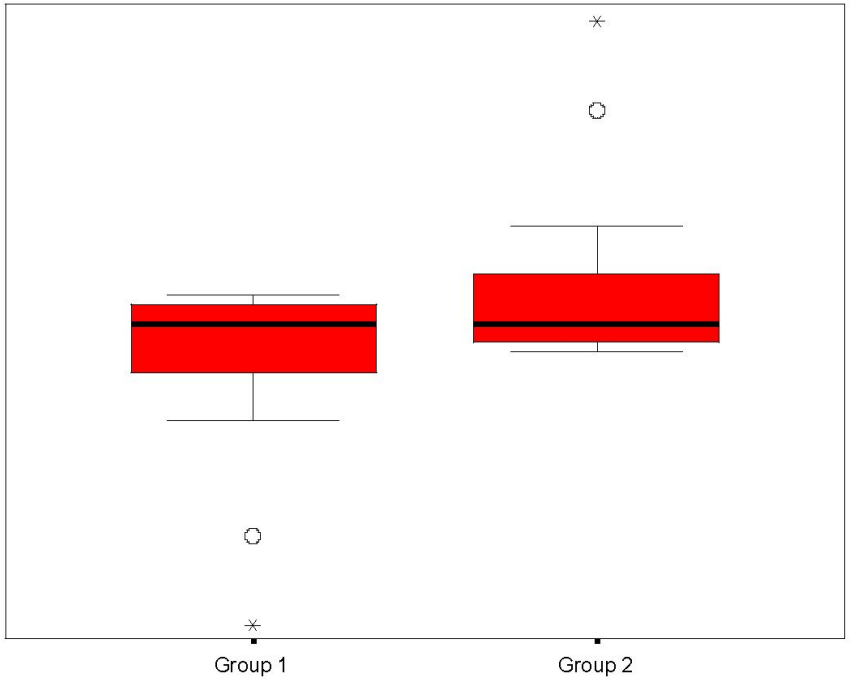
Mann-Whitney U test

- Also called the Wilcoxon Rank Sum test
- Assumptions:
  - Two independent groups
  - At least ordinal dependent variable
  - Randomly selected observations
  - Population distributions same shape
- Hypotheses:
  - H_0: populations have the same median
  - H_0: populations have the same spread and shape

Misunderstood test



Statistics	Group 1	Group 2
Minimum	9.03	0.40
Median	9.94	9.94
Maximum	19.48	10.85
Mann-Whitney U	U=303, p=0.03	

Mann-Whitney U Test

Method:

- Pool the whole sample
- Rank observations from smallest to largest
  (assign average rank to ties)
- Calculate sum of ranks for each group
- Calculate U test statistic
- Compare U to critical value in the tables

Mann-Whitney U Test

- Coronary artery surgery study (Fisher's book)
- Exercise times in seconds for 2 groups:
  - Control and 3-Vessel Disease group
- Is there a difference in exercise times between the two groups?

- H_0 : distributions of both populations are equal

Mann-Whitney U Test

Control: 1014 684 810 990 840 978 1002 1110

3-Vessel: 864 636 638 708 786 600 1320 750 594 750

Mann-Whitney U Test

Control: 1014 684 810 990 840 978 1002 1110

3-Vessel: 864 636 638 708 786 600 1320 750 594 750

Data: 1014 684 810 990 840 978 1002 1110 864 636 638 708 786 600 1320 750 594 750

Mann-Whitney U Test

Control: 1014 684 810 990 840 978 1002 1110

3-Vessel: 864 636 638 708 786 600 1320 750 594 750

Data:	1014	684	810	990	840	978	1002	1110	864	636	638	708	786	600	1320	750	594	750
Sorted:	594	600	636	638	684	708	750	750	786	810	840	864	978	990	1002	1014	1110	1320

Mann-Whitney U Test

Control:	1014	684	810	990	840	978	1002	1110	
3-Vessel:	864	636	638	708	786	600	1320	750	594	750

Data:	1014	684	810	990	840	978	1002	1110	864	636	638	708	786	600	1320	750	594	750
Sorted:	594	600	636	638	684	708	750	750	786	810	840	864	978	990	1002	1014	1110	1320
Ranks:	1	2	3	4	5	6	7.5	7.5	9	10	11	12	13	14	15	16	17	18

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Rank-sums:

Control: 101

3-Vessel: 70

Test statistics:

U_1: 65

U_2: 15

Mann-Whitney U Test

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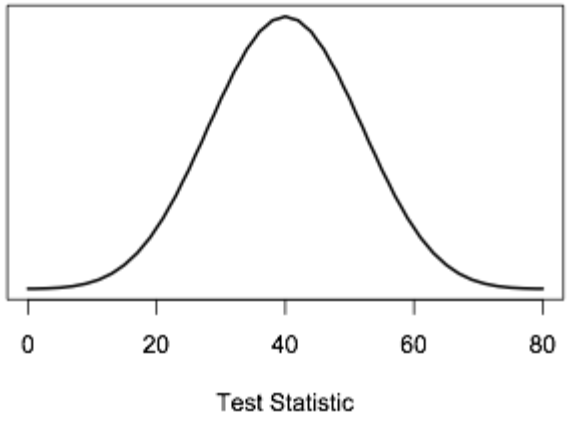

Mann-Whitney U Test

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3-Vessel: 864 636 638 708 786 600 1320 750 594 750

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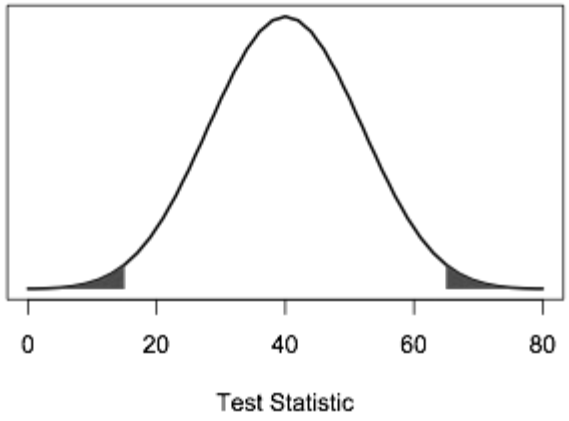

P-value = 0.026

Advantages and limitations

- Almost as powerful as t-test
  - almost as likely as t-test to reject H_0 if false
- Sensitive to central tendencies of scores
- Often misinterpreted:
  - Difference in medians if same shape distributions
  - Otherwise tests for a combination of differences between the distributions, including spread and shape

Summary: One Sample

- **One-sample t-test**:

Compares mean to a proposed value, providing the data can be assumed to be Normally distributed.

- **One-sample Sign test**:

Compares the median to a proposed value.

Summary: Two Independent Samples

- **Two-sample t-test**:

Compares means, providing the data can be assumed to be Normally distributed.

- **Mann-Whitney U test (Wilcoxon Rank Sum test)**:

Compares medians in two independent groups, without assuming Normality. However, does assume similarity of distributions. Otherwise, compares the shape and spread of the two groups, leading to potential misinterpretation of results.

Summary: Paired Groups

- **Paired t-test**:

Compares means, providing paired differences can be assumed to be Normally distributed.

- **Wilcoxon Signed Rank test**:

Compares means, providing the distribution of differences is symmetric.

- **Two-sample Sign test**:

Compares the medians between matched pairs.