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UNIVERSITY OF ESWATINI
MAIN EXAMINATION PAPER 2018/2019

TITLE OF PAPER: BIOSTATISTICS

COURSE CODE: BIO301

TIME ALLOWED: THREE (3) HOURS

INSTRUCTIONS:

1. QUESTION 1 IN SECTION A IS COMPULSORY AND IT CARRIES 50 MARKS
2. ANSWER **ANY TWO** QUESTIONS IN SECTION B
2. EACH QUESTION IN SECTION B CARRIES TWENTY FIVE (25) MARKS
3. USE CLEARLY LABELED DIAGRAMS WHERE APPROPRIATE
4. CLEARLY STATE YOUR NULL AND ALTERNATIVE HYPOTHESES AND YOUR CONCLUSIONS WHERE APPROPRIATE
5. SHOW ALL CALCULATIONS WHERE APPLICABLE

SPECIAL REQUIREMENTS:

1. CALCULATORS (CANDIDATES MUST BRING OWN).
2. GRAPH PAPER WILL BE SUPPLIED.
3. STATISTICAL TABLES (TO BE SUPPLIED WITH THE EXAM PAPER).

THIS PAPER IS NOT TO BE OPENED UNTIL PERMISSION HAS BEEN GRANTED BY THE INVIGILATORS

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SECTION A (Compulsory)

Question 1

(a) The following data are flash durations (in milliseconds) of a sample of 35 male fireflies of the species *Photinus ignites:*

79, 80, 82, 83, 86, 85, 86, 86, 88, 87, 89, 89, 90, 92, 94, 92, 94, 96, 95,

95, 95, 96, 98, 98, 98, 101, 103, 106, 108, 109, 112, 113, 118, 116, 119.

Calculate the following:

(i) range **[1 mark]**

(ii) mean **[3 marks]**

(iii) standard deviation **[3 marks]**

(iv) 95% confidence interval for the population mean **[3 marks]**

(b) Khaya is a nutritionist and he believes that 12 kg boxes of cereal should contain an average of 1.2 kg of bran. He suspects that a popular cereal has a different mean bran content. He carefully analyses the contents of a random sample of twenty 12 kg boxes of the cereal and finds that the mean bran content is 1.16 kg. It is known that the standard deviation of the bran content of all such boxes of cereal is 0.08 kg. Stating your assumptions, determine whether these data provide sufficient evidence to conclude that the mean bran content of all 12 kg boxes of this cereal differs from 1.2 kg at $\alpha = 0.05$ **[10 marks]**

(c) A game poacher kills on the average 3 kudus per week. Use Poisson's law to calculate the probability that in a given week he will kill:

(i) Some kudus. **[5 Marks]**

(ii) Two or more kudus but less than five kudus. **[5 Marks]**

(iii) Assuming that there are five hunting days per week, what is the probability that in a given day he will kill one kudu? **[5 Marks]**

(d) Births in a hospital occur randomly at an average rate of 1.8 births per hour.

(i) What is the probability of observing four births in a given hour at the hospital?

[5 Marks]

(ii) What is the probability of observing more than or equal to two births in a given hour at the hospital? **[5 Marks]**

(e) The population growth of springboks per year is normally distributed among game reserves in Swaziland, with a mean of 1.38% and standard deviation equal to 1.2%. Determine the fraction of game reserves that have a positive (greater than 0) population growth rate. **[5 Marks]**

[Total Marks = 50]

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SECTION B (Answer any two questions in this section)

Question 2

(a) The following table shows the nitrogen concentrations in the soil after harvesting of three crops. The data meet the assumptions of parametric tests.

Nitrogen concentration (mol/l)		
Crop 1	**Crop 2**	**Crop 3**
46.5	47.0	39.1
44.3	46.3	43.2
47.1	44.9	46.1
46.8	47.4	40.7
45.6	45.8	42.7

(b) Using an appropriate statistical test, determine whether the three different crops have significantly different nitrogen concentrations. If you deem it appropriate, perform a multiple comparison to determine any crops that may differ from other crops in nitrogen concentration.

[TOTAL MARKS: 25].

Question 3

It is conjectured that classes that use a statistical computer package, such as Minitab, do better in introductory statistics courses than those who don't use such technology. A random sample of 24 students uses a statistical computer package while taking statistics. Another random sample of 28 students taking the same course uses only hand-held calculators. The final average in the course is recorded for each of these students. The data are as shown below.

Computer

76	93	74	90	90	85	72	81	76	77
69	57	72	100	75	72	86	92	76	79
72	61	80	67						

No computer

74	65	66	85	79	82	80	76	57	75
67	71	55	72	75	89	81	72	88	73
72	64	61	74	63	76	85	72		

Is there sufficient evidence to conclude that students who do not use the computer have lower averages at 95% confidence level?

[TOTAL MARKKS: 25].

Question 4

The following data were collected by a psychologist:

Test score (%)	Time studied (min)
88	120
80	105
76	106
83	108
55	98
62	97
67	99

Determine if there is a significant correlation between the amount of time a student studied and his/her test score. Take α as 0.05. If appropriate, perform a regression analysis and test its significance using a t-test.

[TOTAL MARKS: 25].

Question 5

Bias and sampling error have been observed to reduce accuracy and precision when estimating and testing effects of one variable on another. Discuss experimental procedures that can be used to minimize bias and sampling error.

[TOTAL MARKS: 25]

[TOTAL MARKS: 50]

END OF EXAM PAPER

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UNIVERSITY OF ESWATINI

DEPARTMENT OF BIOLOGICAL SCIENCES

KWALUSENI CAMPUS

Statistical Formulae & Tables for use in Biostatistics Examination

2018 EDITION

PLEASE DO NOT REMOVE FROM THE EXAM ROOM

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Statistical Formulae & Tables for use in Biostatistics Examination

$$\bar{x} = \frac{1}{n}\sum x_i$$

$$\bar{x} = \frac{1}{\sum f}\sum f.x_i$$

$$SS = \sum (x_i - \overline{x})^2 = \sum (x_i^2) - n\overline{x}^2$$

Treatment SS $= \sum n_i (\bar{x}_i - \bar{\bar{x}})^2$

Error SS $= \sum (S_i^2)(df_i)$

$$s^2 = \frac{\sum(x_i - \overline{x})^2}{n-1} = \frac{\sum(x_i^2) - n\overline{x}^2}{n-1}$$

$$s^2 = \frac{\sum f.(x_i - \overline{x})^2}{n-1} = \left(\frac{1}{n-1}\right)\sum_{i=1}^{n} f(x_i - \overline{x})^2$$

$$s^2 = \frac{\sum(fx_i^2) - n\overline{x}^2}{n-1}$$

$$s_p^2 = \frac{(df_1 s_1^2) + (df_2 s_2^2)}{(df_1 + df_2)} = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{(n_1 + n_2 - 2)}$$

$$s = \sqrt{\frac{\sum(x_i - \overline{x})^2}{n-1}} = \sqrt{\frac{\sum(x_i^2) - n\overline{x}^2}{n-1}}$$

$$Cov\,(x, y) = \frac{1}{n-1}\left[\sum (x_i - \overline{x})(y_i - \overline{y})\right] = \frac{1}{n-1}\left[\sum (x_i y_i) - \frac{(\sum x)(\sum y)}{n}\right]$$

$$r_{x,y} = \frac{\sum(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum(x_i - \overline{x})^2}\sqrt{\sum(y_i - \overline{y})^2}} = \frac{\sum xy - \frac{\sum x \sum y}{n}}{\sqrt{\left(\sum x^2 - \frac{(\sum x)^2}{n}\right)\left(\sum y^2 - \frac{(\sum y)^2}{n}\right)}}$$

Statistical Formulae & Tables for use in Biostatistics Examination

$$t = \frac{r}{\sqrt{\frac{1-r^2}{n-2}}}$$

$$t = \frac{(\bar{X}_i - \bar{X}_j)}{\sqrt{MSE\left(\frac{1}{n_i}+\frac{1}{n_j}\right)}}$$

$$b = \frac{\sum(x_i-\bar{x})(y_i-\bar{y})}{\sum(x_i-\bar{x})^2} = \frac{\sum(x_i y_i) - \frac{(\sum x)(\sum y)}{n}}{\sum(x_i^2) - n\bar{x}^2}$$

$$a = \bar{y} - b\bar{x}$$

$$LSD_{1,2} = t_{\alpha/2}\sqrt{MSE\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}$$

$$SE_{\bar{x}} = s_{\bar{x}} = S/\sqrt{n}$$

$$SE_{\bar{x}_1-\bar{x}_2} = \sqrt{s_p^2\left(\frac{1}{n_1}+\frac{1}{n_2}\right)} = \sqrt{\left(\frac{s_1^2}{n_1}+\frac{s_2^2}{n_2}\right)}$$

$$q = (\bar{x}_1 - \bar{x}_2)/SE_{\bar{x}_1-\bar{x}_2} = \frac{(\bar{x}_1-\bar{x}_2)}{\sqrt{\frac{MSE}{n}}}$$

$$\sigma_{\bar{X}} = \frac{\sigma}{\sqrt{n}} =$$

$$\mu_{\bar{x}} = \mu$$

$$Z = (x_i - \mu)/\sigma$$

$$z = \frac{\bar{X} - \mu_{\bar{X}}}{\sigma_{\bar{X}}}$$

$$t = (x_i - \mu)/(s/\sqrt{n})$$

$$t = b/SE_b$$

$$SE_b = \sqrt{\frac{MSE}{\sum(x-\bar{x})^2}}$$

Statistical Formulae & Tables for use in Biostatistics Examination

$$t = \frac{\overline{X} - \mu_{\overline{X}}}{s_{\overline{X}}}$$

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{(s_1^2/n_1) + (s_2^2/n_2)}}$$

$$E = z_c \frac{\sigma}{\sqrt{n}}$$

$$E = t_c \frac{s}{\sqrt{n}}$$

$$CI = \overline{x} \pm (t_{\alpha(2),df})SE_{\overline{x}}$$

$$CI = \overline{x} \pm t_c \frac{s}{\sqrt{n}}$$

$$CI = \overline{x} \pm z_c \sigma_{\overline{X}}$$

$$CI_{(\mu_1 - \mu_2)} = (\overline{X}_1 - \overline{X}_2) \pm t_c \sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}$$

$$s_e = \sqrt{\frac{\Sigma (y - \hat{y})^2}{n-2}} = \sqrt{\frac{\Sigma y^2 - a \Sigma y - b \Sigma xy}{n-2}}$$

$$HSD_\alpha = q_\alpha \sqrt{\frac{MS_W}{n}}$$

$$n = \frac{k}{\sum_{i=1}^{k} \frac{1}{n_i}}$$

$$U = n_1 n_2 + \frac{n_1(n_1+1)}{2} - R_1$$

$$U' = n_1 n_2 - U$$

$$\chi^2 = \sum_{i}^{n} \frac{(O_i - E_i)^2}{E_i}$$

$$\chi^2 = \frac{n(AD - BC)^2}{R_1 R_2 C_1 C_2}.$$

Statistical Formulae & Tables for use in Biostatistics Examination

$$H = \frac{12}{N(N+1)}\left(\sum \frac{R_i^2}{n_i}\right) - 3(N+1)$$

SS Residual = $\sum(y-\hat{y})^2$

SS Regression = $\sum(\hat{y}-\bar{y})^2$

$P(A \text{ or } B) = P(A) + P(B)$ if A, B are mutually exclusive

$P(A \text{ or } B) = P(A) + P(B) - P(A \text{ and } B)$
if A, B are not mutually exclusive

$P(A \text{ and } B) = P(A) \cdot P(B)$ if A, B are independent

$P(A \text{ and } B) = P(A) \cdot P(B|A)$ if A, B are dependent

$P(\overline{A}) = 1 - P(A)$ Rule of complements

${}_nP_r = \frac{n!}{(n-r)!}$ Permutations (no elements alike)

$\frac{n!}{n_1!\, n_2! \ldots n_k!}$ Permutations (n_1 alike, ...)

${}_nC_r = \frac{n!}{(n-r)!\, r!}$ Combinations

$\mu = \Sigma x \cdot P(x)$ Mean (prob. dist.)

$\sigma = \sqrt{[\Sigma x^2 \cdot P(x)] - \mu^2}$ Standard deviation (prob. dist.)

$P(x) = \frac{n!}{(n-x)!\, x!} \cdot p^x \cdot q^{n-x}$ Binomial probability

$\mu = n \cdot p$ Mean (binomial)

$\sigma^2 = n \cdot p \cdot q$ Variance (binomial)

$\sigma = \sqrt{n \cdot p \cdot q}$ Standard deviation (binomial)

$P(x) = \frac{\mu^x \cdot e^{-\mu}}{x!}$ Poisson Distribution
where $e \approx 2.71828$

$$SSB = \sum n_i \, (\bar{x}_i - \bar{\bar{x}})^2, \; MSB = \frac{SSB}{dfN}$$

$$SSw = \sum (n_i - 1) S_i^2, \; MSw = \frac{SSw}{dfD}$$

$$F = \frac{MSB}{MSw}$$

Statistical Formulae & Tables for use in Biostatistics Examination

Index of Useful Statistical Tables

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Statistical Formulae & Tables for use in Biostatistics Examination

Table 1: Standard normal (Z) distribution

z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
0.1	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5753
0.2	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6064	.6103	.6141
0.3	.6179	.6217	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
0.4	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
0.5	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
0.6	.7257	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7517	.7549
0.7	.7580	.7611	.7642	.7673	.7704	.7734	.7764	.7794	.7823	.7852
0.8	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8078	.8106	.8133
0.9	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.0	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.1	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.2	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.9015
1.3	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
1.4	.9192	.9207	.9222	.9236	.9251	.9265	.9279	.9292	.9306	.9319
1.5	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	.9429	.9441
1.6	.9452	.9463	.9474	.9484	.9495	.9505	.9515	.9525	.9535	.9545
1.7	.9554	.9564	.9573	.9582	.9591	.9599	.9608	.9616	.9625	.9633
1.8	.9641	.9649	.9656	.9664	.9671	.9678	.9686	.9693	.9699	.9706
1.9	.9713	.9719	.9726	.9732	.9738	.9744	.9750	.9756	.9761	.9767
2.0	.9772	.9778	.9783	.9788	.9793	.9798	.9803	.9808	.9812	.9817
2.1	.9821	.9826	.9830	.9834	.9838	.9842	.9846	.9850	.9854	.9857
2.2	.9861	.9864	.9868	.9871	.9875	.9878	.9881	.9884	.9887	.9890
2.3	.9893	.9896	.9898	.9901	.9904	.9906	.9909	.9911	.9913	.9916
2.4	.9918	.9920	.9922	.9925	.9927	.9929	.9931	.9932	.9934	.9936
2.5	.9938	.9940	.9941	.9943	.9945	.9946	.9948	.9949	.9951	.9952
2.6	.9953	.9955	.9956	.9957	.9959	.9960	.9961	.9962	.9963	.9964
2.7	.9965	.9966	.9967	.9968	.9969	.9970	.9971	.9972	.9973	.9974
2.8	.9974	.9975	.9976	.9977	.9977	.9978	.9979	.9979	.9980	.9981
2.9	.9981	.9982	.9982	.9983	.9984	.9984	.9985	.9985	.9986	.9986
3.0	.9987	.9987	.9987	.9988	.9988	.9989	.9989	.9989	.9990	.9990
3.1	.9990	.9991	.9991	.9991	.9992	.9992	.9992	.9992	.9993	.9993
3.2	.9993	.9993	.9994	.9994	.9994	.9994	.9994	.9995	.9995	.9995
3.3	.9995	.9995	.9995	.9996	.9996	.9996	.9996	.9996	.9996	.9997
3.4	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9998

Statistical Formulae & Tables for use in Biostatistics Examination

Table 2: Student's *t* distribution

	Level of confidence, *c*	0.50	0.80	0.90	0.95	0.98	0.99
	One tail, α	0.25	0.10	0.05	0.025	0.01	0.005
d.f.	Two tails, α	0.50	0.20	0.10	0.05	0.02	0.01
1		1.000	3.078	6.314	12.706	31.821	63.657
2		.816	1.886	2.920	4.303	6.965	9.925
3		.765	1.638	2.353	3.182	4.541	5.841
4		.741	1.533	2.132	2.776	3.747	4.604
5		.727	1.476	2.015	2.571	3.365	4.032
6		.718	1.440	1.943	2.447	3.143	3.707
7		.711	1.415	1.895	2.365	2.998	3.499
8		.706	1.397	1.860	2.306	2.896	3.355
9		.703	1.383	1.833	2.262	2.821	3.250
10		.700	1.372	1.812	2.228	2.764	3.169
11		.697	1.363	1.796	2.201	2.718	3.106
12		.695	1.356	1.782	2.179	2.681	3.055
13		.694	1.350	1.771	2.160	2.650	3.012
14		.692	1.345	1.761	2.145	2.624	2.977
15		.691	1.341	1.753	2.131	2.602	2.947
16		.690	1.337	1.746	2.120	2.583	2.921
17		.689	1.333	1.740	2.110	2.567	2.898
18		.688	1.330	1.734	2.101	2.552	2.878
19		.688	1.328	1.729	2.093	2.539	2.861
20		.687	1.325	1.725	2.086	2.528	2.845
21		.686	1.323	1.721	2.080	2.518	2.831
22		.686	1.321	1.717	2.074	2.508	2.819
23		.685	1.319	1.714	2.069	2.500	2.807
24		.685	1.318	1.711	2.064	2.492	2.797
25		.684	1.316	1.708	2.060	2.485	2.787
26		.684	1.315	1.706	2.056	2.479	2.779
27		.684	1.314	1.703	2.052	2.473	2.771
28		.683	1.313	1.701	2.048	2.467	2.763
29		.683	1.311	1.699	2.045	2.462	2.756
∞		.674	1.282	1.645	1.960	2.326	2.576

Statistical Formulae & Tables for use in Biostatistics Examination

Table 3: χ^2 distribution

Degrees of freedom	α									
	0.995	0.99	0.975	0.95	0.90	0.10	0.05	0.025	0.01	0.005
1	—	—	0.001	0.004	0.016	2.706	3.841	5.024	6.635	7.879
2	0.010	0.020	0.051	0.103	0.211	4.605	5.991	7.378	9.210	10.597
3	0.072	0.115	0.216	0.352	0.584	6.251	7.815	9.348	11.345	12.838
4	0.207	0.297	0.484	0.711	1.064	7.779	9.488	11.143	13.277	14.860
5	0.412	0.554	0.831	1.145	1.610	9.236	11.071	12.833	15.086	16.750
6	0.676	0.872	1.237	1.635	2.204	10.645	12.592	14.449	16.812	18.548
7	0.989	1.239	1.690	2.167	2.833	12.017	14.067	16.013	18.475	20.278
8	1.344	1.646	2.180	2.733	3.490	13.362	15.507	17.535	20.090	21.955
9	1.735	2.088	2.700	3.325	4.168	14.684	16.919	19.023	21.666	23.589
10	2.156	2.558	3.247	3.940	4.865	15.987	18.307	20.483	23.209	25.188
11	2.603	3.053	3.816	4.575	5.578	17.275	19.675	21.920	24.725	26.757
12	3.074	3.571	4.404	5.226	6.304	18.549	21.026	23.337	26.217	28.299
13	3.565	4.107	5.009	5.892	7.042	19.812	22.362	24.736	27.688	29.819
14	4.075	4.660	5.629	6.571	7.790	21.064	23.685	26.119	29.141	31.319
15	4.601	5.229	6.262	7.261	8.547	22.307	24.996	27.488	30.578	32.801
16	5.142	5.812	6.908	7.962	9.312	23.542	26.296	28.845	32.000	34.267
17	5.697	6.408	7.564	8.672	10.085	24.769	27.587	30.191	33.409	35.718
18	6.265	7.015	8.231	9.390	10.865	25.989	28.869	31.526	34.805	37.156
19	6.844	7.633	8.907	10.117	11.651	27.204	30.144	32.852	36.191	38.582
20	7.434	8.260	9.591	10.851	12.443	28.412	31.410	34.170	37.566	39.997
21	8.034	8.897	10.283	11.591	13.240	29.615	32.671	35.479	38.932	41.401
22	8.643	9.542	10.982	12.338	14.042	30.813	33.924	36.781	40.289	42.796
23	9.260	10.196	11.689	13.091	14.848	32.007	35.172	38.076	41.638	44.181
24	9.886	10.856	12.401	13.848	15.659	33.196	36.415	39.364	42.980	45.559
25	10.520	11.524	13.120	14.611	16.473	34.382	37.652	40.646	44.314	46.928
26	11.160	12.198	13.844	15.379	17.292	35.563	38.885	41.923	45.642	48.290
27	11.808	12.879	14.573	16.151	18.114	36.741	40.113	43.194	46.963	49.645
28	12.461	13.565	15.308	16.928	18.939	37.916	41.337	44.461	48.278	50.993
29	13.121	14.257	16.047	17.708	19.768	39.087	42.557	45.722	49.588	52.336
30	13.787	14.954	16.791	18.493	20.599	40.256	43.773	46.979	50.892	53.672
40	20.707	22.164	24.433	26.509	29.051	51.805	55.758	59.342	63.691	66.766
50	27.991	29.707	32.357	34.764	37.689	63.167	67.505	71.420	76.154	79.490
60	35.534	37.485	40.482	43.188	46.459	74.397	79.082	83.298	88.379	91.952
70	43.275	45.442	48.758	51.739	55.329	85.527	90.531	95.023	100.425	104.215
80	51.172	53.540	57.153	60.391	64.278	96.578	101.879	106.629	112.329	116.321
90	59.196	61.754	65.647	69.126	73.291	107.565	113.145	118.136	124.116	128.299
100	67.328	70.065	74.222	77.929	82.358	118.498	124.342	129.561	135.807	140.169

Table 4: Mann-Whitney U distribution

U, $\alpha = 0.05$

n_1

n_2	3	4	5	6	7	8	9	10
3	-	-	15	17	20	22	25	27
4	-	16	19	22	25	28	32	35
5	15	19	23	27	30	34	38	42
6	17	22	27	31	36	40	44	49
7	20	25	30	36	41	46	51	56
8	22	28	34	40	46	51	57	63
9	25	32	38	44	51	57	64	70
10	27	35	42	49	56	63	70	77

U, $\alpha = 0.01$

n_1

n_2	3	4	5	6	7	8	9	10
3	-	-	-	-	-	-	27	30
4	-	-	-	24	28	31	35	38
5	-	-	25	29	34	38	42	46
6	-	24	29	34	39	44	49	54
7	-	28	34	39	45	50	56	61
8	-	31	38	44	50	57	63	69
9	27	35	42	49	56	63	70	77
10	30	38	46	54	61	69	77	84

When the sample size increases above 10 for either sample, the Z approximation given in the text works reasonably well. Here we give reduced version of the tables for the Mann-Whitney U distribution. Test statistics larger than those given in the table will be significant at the given α level. n_1 and n_2 refer to the sample sizes of the two samples. "-" means that it is not possible to reject a null hypothesis with that α with those sample sizes.

Statistical Formulae & Tables for use in Biostatistics Examination

Table 5: Spearman & Pearson's Correlation coefficients

Critical Values for the Spearman Rank Correlation

n	$\alpha = 0.10$	$\alpha = 0.05$	$\alpha = 0.01$
5	0.900	—	—
6	0.829	0.886	—
7	0.714	0.786	0.929
8	0.643	0.738	0.881
9	0.600	0.700	0.833
10	0.564	0.648	0.794
11	0.536	0.618	0.818
12	0.497	0.591	0.780
13	0.475	0.566	0.745
14	0.457	0.545	0.716
15	0.441	0.525	0.689
16	0.425	0.507	0.666
17	0.412	0.490	0.645
18	0.399	0.476	0.625
19	0.388	0.462	0.608
20	0.377	0.450	0.591
21	0.368	0.438	0.576
22	0.359	0.428	0.562
23	0.351	0.418	0.549
24	0.343	0.409	0.537
25	0.336	0.400	0.526
26	0.329	0.392	0.515
27	0.323	0.385	0.505
28	0.317	0.377	0.496
29	0.311	0.370	0.487
30	0.305	0.364	0.478

Critical Values for the Pearson Correlation Coeffic:

n	$\alpha = 0.05$	$\alpha = 0.01$
4	0.950	0.990
5	0.878	0.959
6	0.811	0.917
7	0.754	0.875
8	0.707	0.834
9	0.666	0.798
10	0.632	0.765
11	0.602	0.735
12	0.576	0.708
13	0.553	0.684
14	0.532	0.661
15	0.514	0.641
16	0.497	0.623
17	0.482	0.606
18	0.468	0.590
19	0.456	0.575
20	0.444	0.561
21	0.433	0.549
22	0.423	0.537
23	0.413	0.526
24	0.404	0.515
25	0.396	0.505
26	0.388	0.496
27	0.381	0.487
28	0.374	0.479
29	0.367	0.471
30	0.361	0.463
35	0.334	0.430
40	0.312	0.403
45	0.294	0.380
50	0.279	0.361
55	0.266	0.345
60	0.254	0.330
65	0.244	0.317
70	0.235	0.306
75	0.227	0.296
80	0.220	0.286
85	0.213	0.278
90	0.207	0.270
95	0.202	0.263
100	0.197	0.256

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Table 6: Tukey's q distribution

Critical Points for the Studentized Range q-Statistic at $\alpha = 0.05$																			
Degrees of freedom (error)	K																		
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
5	3.64	4.60	5.22	5.67	6.03	6.33	6.58	6.80	6.99	7.17	7.32	7.47	7.60	7.72	7.83	7.93	8.03	8.12	8.21
6	3.46	4.34	4.90	5.30	5.63	5.90	6.12	6.32	6.49	6.65	6.79	6.92	7.03	7.14	7.24	7.34	7.43	7.51	7.59
7	3.34	4.16	4.68	5.06	5.36	5.61	5.82	6.00	6.16	6.30	6.43	6.55	6.66	6.76	6.85	6.94	7.02	7.10	7.17
8	3.26	4.04	4.53	4.89	5.17	5.40	5.60	5.77	5.92	6.05	6.18	6.29	6.39	6.48	6.57	6.65	6.73	6.80	6.87
9	3.20	3.95	4.41	4.76	5.02	5.24	5.43	5.59	5.74	5.87	5.98	6.09	6.19	6.28	6.36	6.44	6.51	6.58	6.64
10	3.15	3.88	4.33	4.65	4.91	5.12	5.30	5.46	5.60	5.72	5.83	5.93	6.03	6.11	6.19	6.27	6.34	6.40	6.47
11	3.11	3.82	4.26	4.57	4.82	5.03	5.20	5.35	5.49	5.61	5.71	5.81	5.90	5.98	6.06	6.13	6.20	6.27	6.33
12	3.08	3.77	4.20	4.51	4.75	4.95	5.12	5.27	5.39	5.51	5.61	5.71	5.80	5.88	5.95	6.02	6.09	6.15	6.21
13	3.06	3.73	4.15	4.45	4.69	4.88	5.05	5.19	5.32	5.43	5.53	5.63	5.71	5.79	5.86	5.93	5.99	6.05	6.11
14	3.03	3.70	4.11	4.41	4.64	4.83	4.99	5.13	5.25	5.36	5.46	5.55	5.64	5.71	5.79	5.85	5.91	5.97	6.03
15	3.01	3.67	4.08	4.37	4.59	4.78	4.94	5.08	5.20	5.31	5.40	5.49	5.57	5.65	5.72	5.78	5.85	5.90	5.96
16	3.00	3.65	4.05	4.33	4.56	4.74	4.90	5.03	5.15	5.26	5.35	5.44	5.52	5.59	5.66	5.73	5.79	5.84	5.90
17	2.98	3.63	4.02	4.30	4.52	4.70	4.86	4.99	5.11	5.21	5.31	5.39	5.47	5.54	5.61	5.67	5.73	5.79	5.84
18	2.97	3.61	4.00	4.28	4.49	4.67	4.82	4.96	5.07	5.17	5.27	5.35	5.43	5.50	5.57	5.63	5.69	5.74	5.79
19	2.96	3.59	3.98	4.25	4.47	4.65	4.79	4.92	5.04	5.14	5.23	5.31	5.39	5.46	5.53	5.59	5.65	5.70	5.75
20	2.95	3.58	3.96	4.23	4.45	4.62	4.77	4.90	5.01	5.11	5.20	5.26	5.36	5.43	4.49	5.55	5.61	5.66	5.71
24	2.92	3.53	3.90	4.17	4.37	4.54	4.68	4.81	4.92	5.01	5.10	5.16	5.25	5.32	5.38	5.44	5.49	5.55	5.59
30	2.89	3.49	3.85	4.10	4.30	4.46	4.60	4.72	4.82	4.92	5.00	5.08	5.15	5.21	5.27	5.33	5.38	5.43	5.47
40	2.86	3.44	3.79	4.04	4.23	4.39	4.52	4.63	4.73	4.82	4.90	4.98	5.04	5.11	5.16	5.22	5.27	5.31	5.36
60	2.83	3.40	3.74	3.98	4.16	4.31	4.44	4.55	4.65	4.73	4.81	4.88	4.94	5.00	5.06	5.11	5.15	5.20	5.24
120	2.80	3.36	3.68	3.92	4.10	4.24	4.36	4.47	4.56	4.64	4.71	4.78	4.84	4.90	4.95	5.00	5.04	5.09	5.13
∞	2.77	3.31	3.63	3.86	4.03	4.17	4.29	4.39	4.47	4.55	4.62	4.68	4.74	4.80	4.85	4.89	4.93	4.97	5.01

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Table 7: F distribution

$d.f._D$: Degrees of freedom, denominator	α = 0.05																		
	$d.f._N$: Degrees of freedom, numerator																		
	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	∞
1	161.4	199.5	215.7	224.6	230.2	234.0	236.8	238.9	240.5	241.9	243.9	245.9	248.0	249.1	250.1	251.1	252.2	253.3	254.3
2	18.51	19.00	19.16	19.25	19.30	19.33	19.35	19.37	19.38	19.40	19.41	19.43	19.45	19.45	19.46	19.47	19.48	19.49	19.50
3	10.13	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81	8.79	8.74	8.70	8.66	8.64	8.62	8.59	8.57	8.55	8.53
4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00	5.96	5.91	5.86	5.80	5.77	5.75	5.72	5.69	5.66	5.63
5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77	4.74	4.68	4.62	4.56	4.53	4.50	4.46	4.43	4.40	4.36
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06	4.00	3.94	3.87	3.84	3.81	3.77	3.74	3.70	3.67
7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.64	3.57	3.51	3.44	3.41	3.38	3.34	3.30	3.27	3.23
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39	3.35	3.28	3.22	3.15	3.12	3.08	3.04	3.01	2.97	2.93
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.14	3.07	3.01	2.94	2.90	2.86	2.83	2.79	2.75	2.71
10	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.98	2.91	2.85	2.77	2.74	2.70	2.66	2.62	2.58	2.54
11	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.90	2.85	2.79	2.72	2.65	2.61	2.57	2.53	2.49	2.45	2.40
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80	2.75	2.69	2.62	2.54	2.51	2.47	2.43	2.38	2.34	2.30
13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71	2.67	2.60	2.53	2.46	2.42	2.38	2.34	2.30	2.25	2.21
14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65	2.60	2.53	2.46	2.39	2.35	2.31	2.27	2.22	2.18	2.13
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59	2.54	2.48	2.40	2.33	2.29	2.25	2.20	2.16	2.11	2.07
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54	2.49	2.42	2.35	2.28	2.24	2.19	2.15	2.11	2.06	2.01
17	4.45	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.49	2.45	2.38	2.31	2.23	2.19	2.15	2.10	2.06	2.01	1.96
18	4.41	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.46	2.41	2.34	2.27	2.19	2.15	2.11	2.06	2.02	1.97	1.92
19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42	2.38	2.31	2.23	2.16	2.11	2.07	2.03	1.98	1.93	1.88
20	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39	2.35	2.28	2.20	2.12	2.08	2.04	1.99	1.95	1.90	1.84
21	4.32	3.47	3.07	2.84	2.68	2.57	2.49	2.42	2.37	2.32	2.25	2.18	2.10	2.05	2.01	1.96	1.92	1.87	1.81
22	4.30	3.44	3.05	2.82	2.66	2.55	2.46	2.40	2.34	2.30	2.23	2.15	2.07	2.03	1.98	1.94	1.89	1.84	1.78
23	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.37	2.32	2.27	2.20	2.13	2.05	2.01	1.96	1.91	1.86	1.81	1.76
24	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.30	2.25	2.18	2.11	2.03	1.98	1.94	1.89	1.84	1.79	1.73
25	4.24	3.39	2.99	2.76	2.60	2.49	2.40	2.34	2.28	2.24	2.16	2.09	2.01	1.96	1.92	1.87	1.82	1.77	1.71
26	4.23	3.37	2.98	2.74	2.59	2.47	2.39	2.32	2.27	2.22	2.15	2.07	1.99	1.95	1.90	1.85	1.80	1.75	1.69
27	4.21	3.35	2.96	2.73	2.57	2.46	2.37	2.31	2.25	2.20	2.13	2.06	1.97	1.93	1.88	1.84	1.79	1.73	1.67
28	4.20	3.34	2.95	2.71	2.56	2.45	2.36	2.29	2.24	2.19	2.12	2.04	1.96	1.91	1.87	1.82	1.77	1.71	1.65
29	4.18	3.33	2.93	2.70	2.55	2.43	2.35	2.28	2.22	2.18	2.10	2.03	1.94	1.90	1.85	1.81	1.75	1.70	1.64
30	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21	2.16	2.09	2.01	1.93	1.89	1.84	1.79	1.74	1.68	1.62
40	4.08	3.23	2.84	2.61	2.45	2.34	2.25	2.18	2.12	2.08	2.00	1.92	1.84	1.79	1.74	1.69	1.64	1.58	1.51
60	4.00	3.15	2.76	2.53	2.37	2.25	2.17	2.10	2.04	1.99	1.92	1.84	1.75	1.70	1.65	1.59	1.53	1.47	1.39
120	3.92	3.07	2.68	2.45	2.29	2.17	2.09	2.02	1.96	1.91	1.83	1.75	1.66	1.61	1.55	1.50	1.43	1.35	1.25
∞	3.84	3.00	2.60	2.37	2.21	2.10	2.01	1.94	1.88	1.83	1.75	1.67	1.57	1.52	1.46	1.39	1.32	1.22	1.00