UNIVERSITI SAINS MALAYSIA

First Semester Examination
Academic Session 2005/2006

November 2005

BOI 109E/4 – Biostatistics
[Biostatistik]

Duration : 3 hours
[Masa: 3 jam]

Please ensure that this examination paper contains TEN printed pages and NINE pages of Attachment before you begin the examination.

Answer FIVE out of SIX questions, in English or Bahasa Malaysia.

Each question carries 20 marks.

Sila pastikan bahawa kertas peperiksaan ini mengandungi SEPULUH muka surat yang bercetak dan SEMBILAN muka surat Lampiran sebelum anda memulakan peperiksaan ini.

Jawab LIMA daripada ENAM soalan yang diberikan dalam Bahasa Inggeris atau Bahasa Malaysia.

Tiap-tiap soalan bernilai 20 markah.

1. [a] The following data represents the volume of mice erythrocytes (in cubic microns) taken from normal (diploid) and inter-sex individuals (triploid). Using an appropriate statistical test, compare the volume of erythrocytes between the two groups of individuals.

(15 marks)

Normal	Inter-sex
240	262
255	271
239	250
245	285
260	260
251	259
249	282
254	251
269	265
236	274
248	
250	

[b] Write a short note on nonparametric statistics.

(5 marks)

[a] Data berikut merupakan isipadu (dalam unit mikron padu) eritrosit tikus yang diambil daripada individu normal (diploid) dan individu interjentina (intersex - triploid). Dengan menggunakan ujian statistik yang sesuai bandingkan isipadu eritrosit bagi dua kumpulan individu ini.

(15 markah)

Normal	Inter-sex
240	262
255	271
239	250
245	285
260	260
251	259
249	282
254	251
269	265
236	274
248	
250	

[b] Tulis nota ringkas mengenai statistik nonparametrik

(5 markah)

...3/-

2. For both cases below, describe how you would conduct the study and following that describe the appropriate statistical test that would be used to analyse the data. For the statistical test, include the hypotheses, the calculations to determine the test statistics, the rejection region or critical value and the conclusion should H_o be rejected.

[a] You are given 12 sea-bass (siakap) and are required to determine which, among the muscle, the kidney and liver tissues, can store more organochlorine pesticides.

(10 marks)

[b] You are provided with 2 varieties of soybean seeds. You are asked to grow the beans in order to determine which variety will give a better harvest. To conduct the study you are provided with 6 plots of land each with an area of approximately 1 hectare.

(10 marks)

2. *Bagi kedua-dua kes di bawah, huraikan bagaimana anda akan menjalankan kajian berkenaan dan seterusnya huraikan juga kaedah statistik yang sesuai bagi menganalisis data yang akan dihasilkan. Bagi penghuraian statistik, sertakan hipotesis, pengiraan bagi menentukan statistik ujian, kawasan tolak atau nilai genting dan kesimpulan sekiranya H_o ditolak.*

[a] Anda diberi 12 ekor ikan siakap dan diminta untuk menentukan yang mana antara tisu otot, ginjal dan hati berupaya mengumpulkan lebih banyak pestisid organoklorin.

(10 markah)

[b] Anda diberi dua jenis biji kacang soya. Anda diminta menanam biji-biji kacang tersebut untuk menentukan yang mana memberi hasil yang lebih. Untuk kajian tersebut, anda diberi 6 plot tanah dengan luas kawasan lebih kurang 1 hektar setiap satunya.

(10 markah)

...4/-

3. A student from the School of Biological Sciences conducted a study to determine the organic content of coastal bottom sediments around Penang Island. Six replicates of bottom sediment were obtained from 5 locations and the organic contents (in mg/g) determined. The mean values for the 6 replicates are as follows:

Location	**Organic Content**
Teluk Aling	131
Jelutong	295
Bayan Lepas	217
Gertak Sanggul	323
Balik Pulau	259

Upon running ANOVA test, the following results were obtained:

Source of Variation	**SS**
Between Locations	42,431
Within Locations	54,650

Continue the statistical test to enable you to compare the organic contents of the coastal bottom sediment from the 5 locations.

(20 marks)

Seorang pelajar dari Pusat Pengajian Sains Kajihayat menjalankan suatu kajian untuk menentukan kandungan bahan organik bagi sedimen dasar kawasan pantai Pulau Pinang. Enam replikat sedimen dasar telah diambil dari 5 lokasi dan kandungan bahan organiknya (dalam unit mg/g) ditentukan. Min bagi 6 replikat tersebut adalah seperti di bawah.

Lokasi	***Kandungan Organik***
Teluk Aling	131
Jelutong	295
Bayan Lepas	217
Gertak Sanggul	323
Balik Pulau	259

...5/-

Setelah menjalankan ANOVA hasil berikut didapati:

Sumber Variasi	SS
Antara Lokasi	42,431
Dalam Lokasi	54,650

Teruskan ujian statistik ini untuk membolehkan anda membezakan kandungan organik bagi sedimen dasar lima lokasi ini.

(20 markah)

4. [a] One of the possible side effects on a woman using oral contraceptive (ie taking birth control pills) is increase in blood pressure. In a study to confirm this possibility, the systolic blood pressures of 15 women volunteers were measured before and after 6 months of taking the pills. Based on these results and **assuming that these data do not come from populations that are normally distributed,** run an appropriate statistical test to show whether or not it is true that taking the pills will in fact increase one's blood pressure.

Volunteer	Before Taking Pill	While Taking Pills
1	125	127
2	119	118
3	130	134
4	125	130
5	106	111
6	108	108
7	121	120
8	134	140
9	115	121
10	107	115
11	111	114
12	117	123
13	113	118
14	110	115
15	119	117

(12 marks)

[b] When running a statistical test we need to indicate either the α or the p values. Explain these values ?

(8 marks)

...6/-

4. [a] *Satu daripada kesan sampingan yang mungkin berlaku jika seseorang wanita itu mengamalkan kontraseptif oral (mengambil pil pencegah kehamilan) ialah peningkatan tekanan darah. Dalam suatu kajian untuk menentukan kebenaran dakwaan ini, tekanan darah sistoli bagi 15 orang sukarela wanita telah diambil sebelum dan selepas mengamalkan kontraseptif oral bagi jangka masa 6 bulan.* ***Dengan andaian data ini tidak datang dari populasi yang bertaburan normal****, jalankan ujian statistik yang sesuai bagi menentukan sama ada betul atau tidak tekanan darah seseorang itu boleh meningkat jika mengamalkan memakan pil tersebut?*

Sukarela	*Sebelum Mengambil Pil*	*Setelah Mengambil Pil*
1	125	127
2	119	118
3	130	134
4	125	130
5	106	111
6	108	108
7	121	120
8	134	140
9	115	121
10	107	115
11	111	114
12	117	123
13	113	118
14	110	115
15	119	117

(12 markah)

[b] *Semasa menjalankan ujian statistik kita perlu menyatakan nilai α atau p. Huraikan mengenai nilai-nilai ini.*

(8 markah)

5. A study was carried out to determine the potency of a kind of rat poison. It was felt that the size of a rat plays a significant role in determining how fast the animal will die after taking the poison. For this particular experiment 16 rats of different sizes were given the poison and the lengths of time it took them to die were monitored. The results are as follows:

Weight (kg)	Length of Time It Took the Animals to Die (h)
0.46	36
0.43	36
0.40	35
0.47	39
0.44	34
0.39	34
0.51	44
0.55	46
0.44	36
0.55	44
0.41	32
0.35	27
0.26	24
0.30	28
0.41	29
0.34	30

[a] Is there a linear relationship between size of rat and time it took them to die from the poisoning?

[b] Show this relationship in the form of a mathematical equation.

[c] How strong is this relationship?

[d] Suppose you administer the poison to a rat that weighs 0.59 kg, what would be the estimated time before this rat will die. Would you consider your estimate to be good? Why?

(20 marks)

...8/-

5. *Suatu kajian telah dijalankan bagi menentukan kepotenan (kemujaraban) satu jenis racun tikus. Pengkaji merasakan saiz tikus berperanan penting dalam menentukan berapa cepat tikus akan mati selepas memakan racun tersebut. Bagi kajian ini 16 ekor tikus pelbagai saiz telah diberi racun tersebut dan jangkamasa untuk tikus mati direkodkan. Keputusannya adalah seperti berikut.*

Berat (kg)	*Jangkamasa tikus mati setelah memakan racun (j)*
0.46	36
0.43	36
0.40	35
0.47	39
0.44	34
0.39	34
0.51	44
0.55	46
0.44	36
0.55	44
0.41	32
0.35	27
0.26	24
0.30	28
0.41	29
0.34	30

(a) *Adakah terdapat pertalian linear antara saiz tikus dan jangkamasa tikus mati setelah memakan racun?*
(b) *Tunjukkan pertalian ini dalam bentuk persamaan matematik.*
(c) *Berapa kuatkah pertalian ini?*
(d) *Andaikan anda memberi racun kepada tikus bersaiz 0.59 kg, berapakah anggaran jangkamasa sebelum tikus itu mati?Adakah anggaran ini dianggap baik? Kenapa?*

(20 markah)

6. [a] A study was conducted in Batu Ferringhi, Penang to determine the distribution of the animals associated with the seagrass *Sargassum* at different distances from the shoreline. Sample of *Sargassum* was taken at 5, 10, an 15 m from the shore and these were examined for amphipods and isopods. The observations are recorded below. Is the distribution of organisms associated with *Sargassum* the same at all three distances? Clearly explain your results.

Distance (m)	**Amphipods**	**Isopods**
5	5	13
10	29	18
15	51	25

(10 marks)

[b] Based on the Mendel's model, the progeny of inbreeding a particular flower will result in red, pink and white flowers in the ratio of 1:2:1. A total of 240 progenies were produced with 55 bearing red flowers, 132 with pink flowers and 53 with white flowers. Do the data fit Mendel's model?

(10 marks)

...10/-

6. [a] *Suatu kajian telah dijalankan di Batu Feringghi, Pulau Pinang, untuk menentukan taburan haiwan yang dikaitkan dengan rumpai laut Sargassum pada jarak yang berbeza dari pinggir pantai. Sampel Sargassum telah diambil pada jarak 5, 10 dan 15 m dari pantai dan sampel tersebut dikaji untuk menentukan kehadiran haiwan amfipod dan isopod. Cerapan tersebut direkod seperti di bawah. Adakah taburan organisma yang berkait dengan Sargassum sama bagi 3 jarak tersebut? Huraikan jawapan dengan jelas.*

Jarak (m)	Amphipods	Isopods
5	5	13
10	29	18
15	51	25

(10 markah)

[b] *Berasaskan model Mendel, progeni kacukan dalaman bagi sejenis bunga akan menghasilkan bunga merah, merah jambu dan putih dalam nisbah 1:2:1. Sejumlah 240 progeni telah dihasilkan dengan 55 bunga merah, 132 bunga merah jambu, dan 53 bunga putih. Adakah data ini secocok dengan model Mendel?*

(10 markah)

- ooo O ooo -

FORMULA THAT MAY BE REQUIRED

A. $Z = \frac{\bar{y} - u_0}{\sigma_{\bar{y}}}$

B. $t = \frac{(\bar{y}_1 - \bar{y}_2)}{s\sqrt{(1/n_1) + (1/n_2)}}$

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

D. $z = \frac{y - 0.5n}{\sqrt{0.25n}}$

E. $t = \frac{\bar{d}}{s_d/\sqrt{n}}$

F. $s = \sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}}$

G. $|t'| = \frac{(t_1 s_1^2/n_1) + (t_2 s_2^2/n_2)}{(s_1^2/n_1) + (s_2^2/n_2)}$

H. $\chi^2 = \frac{\Sigma(n_{ij} - E_{ij})^2}{E_{ij}}$

I $s_d^2 = \frac{1}{n-1}\left[\Sigma d_1^2 - \frac{(\Sigma d_i)^2}{n}\right]$

J **Wilcoxon Test**

1) $\mu_T = \frac{n(n+1)}{4}$

2) $\sigma_T = \sqrt{\frac{n(n+1)(2n+1)}{24}}$

3) $z = \dfrac{T - \mu_T}{\sigma_T}$

K **Mann–Whitney Test**

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

2) $U' = n_1 n_2 - U$

L. **Completely Randomized Block**

1) $TSS = \Sigma\Sigma Y_{ij}^2 - \dfrac{G^2}{n}$

2) $SST = \Sigma\Sigma \dfrac{Ti^2}{b} - \dfrac{G^2}{n}$

3) $SSB = \Sigma\Sigma \dfrac{B_j^2}{t} - \dfrac{G^2}{n}$

M. **Latin Square Design**

1) $SST = \Sigma\Sigma \dfrac{T_i^2}{t} - \dfrac{G^2}{n}$

2) $SSR = \Sigma\Sigma \dfrac{R_j^2}{t} - \dfrac{G^2}{n}$

3) $SSC = \Sigma\Sigma \dfrac{C_k^2}{t} - \dfrac{G^2}{n}$

N. **Factorial Design**

1) $$SSA = \Sigma\Sigma \frac{A_i^{\,2}}{n_A} - \frac{G^2}{n}$$

2) $$SSB = \Sigma\Sigma \frac{B_j^{\,2}}{n_B} - \frac{G^2}{n}$$

3) $$\Sigma\Sigma \frac{(AB)_{ij}^2}{n_{AB}} - SSA - SSB - \frac{G^2}{n} = SSAB$$

O. **Completely Random Design**

1) $$SSB = \Sigma\Sigma \frac{T_i^{\,2}}{n_i} - \frac{G^2}{n}$$

P. **Regression**

i) $SS_{xx} = \Sigma x^2 - \frac{(\Sigma x)^2}{n}$

ii) $SS_{xy} = \Sigma xy - \frac{\Sigma x \Sigma y}{n}$

iii) $r = \frac{SS_{xy}}{\sqrt{SS_{xx}\, SS_{yy}}}$

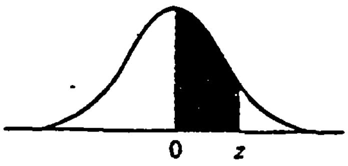
iv) $\frac{SS_{xy}}{SS_{xx}}$

Q **Multiple Comparison**

i) $LSD = t_{\alpha/2} \sqrt{MSE\left(\frac{1}{n_i} + \frac{1}{n_j}\right)}$

ii) $W_r = q_\alpha(r, v)\sqrt{\frac{MSE}{n}}$

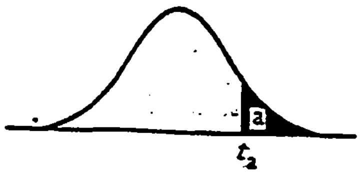
Table 1: Normal Curve Areas



z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.0000	.0040	.0080	.0120	.0160	.0199	.0239	.0279	.0319	.0359
0.1	.0398	.0438	.0478	.0517	.0557	.0596	.0636	.0675	.0714	.0753
0.2	.0793	.0832	.0871	.0910	.0948	.0987	.1026	.1064	.1103	.1141
0.3	.1179	.1217	.1255	.1293	.1331	.1368	.1406	.1443	.1480	.1517
0.4	.1554	.1591	.1628	.1664	.1700	.1736	.1772	.1808	.1844	.1879
0.5	.1915	.1950	.1985	.2019	.2054	.2088	.2123	.2157	.2190	.2224
0.6	.2257	.2291	.2324	.2357	.2389	.2422	.2454	.2486	.2517	.2549
0.7	.2580	.2611	.2642	.2673	.2704	.2734	.2764	.2794	.2823	.2852
0.8	.2881	.2910	.2939	.2967	.2995	.3023	.3051	.3078	.3106	.3133
0.9	.3159	.3186	.3212	.3238	.3264	.3289	.3315	.3340	.3365	.3389
1.0	.3413	.3438	.3461	.3485	.3508	.3531	.3554	.3577	.3599	.3621
1.1	.3643	.3665	.3686	.3708	.3729	.3749	.3770	.3790	.3810	.3830
1.2	.3849	.3869	.3888	.3907	.3925	.3944	.3962	.3980	.3997	.4015
1.3	.4032	.4049	.4066	.4082	.4099	.4115	.4131	.4147	.4162	.4177
1.4	.4192	.4207	.4222	.4236	.4251	.4265	.4279	.4292	.4306	.4319
1.5	.4332	.4345	.4357	.4370	.4382	.4394	.4406	.4418	.4429	.4441
1.6	.4452	.4463	.4474	.4484	.4495	.4505	.4515	.4525	.4535	.4545
1.7	.4554	.4564	.4573	.4582	.4591	.4599	.4608	.4616	.4625	.4633
1.8	.4641	.4649	.4656	.4664	.4671	.4678	.4686	.4693	.4699	.4706
1.9	.4713	.4719	.4726	.4732	.4738	.4744	.4750	.4756	.4761	.4767
2.0	.4772	.4778	.4783	.4788	.4793	.4798	.4803	.4808	.4812	.4817
2.1	.4821	.4826	.4830	.4834	.4838	.4842	.4846	.4850	.4854	.4857
2.2	.4861	.4864	.4868	.4871	.4875	.4878	.4881	.4884	.4887	.4890
2.3	.4893	.4896	.4898	.4901	.4904	.4906	.4909	.4911	.4913	.4916
2.4	.4918	.4920	.4922	.4925	.4927	.4929	.4931	.4932	.4934	.4936
2.5	.4938	.4940	.4941	.4943	.4945	.4946	.4948	.4949	.4951	.4952
2.6	.4953	.4955	.4956	.4957	.4959	.4960	.4961	.4962	.4963	.4964
2.7	.4965	.4966	.4967	.4968	.4969	.4970	.4971	.4972	.4973	.4974
2.8	.4974	.4975	.4976	.4977	.4977	.4978	.4979	.4979	.4980	.4981
2.9	.4981	.4982	.4982	.4983	.4984	.4984	.4985	.4985	.4986	.4986
3.0	.4987	.4987	.4987	.4988	.4988	.4989	.4989	.4989	.4990	.4990

This table is abridged from Table I of *Statistical Tables and Formulas*, by A. Hald (New York: John Wiley & Sons, 1952). Reproduced by permission of A. Hald and the publishers, John Wiley & Sons.

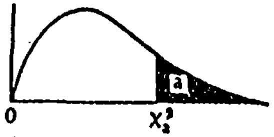
Table 2: Percentage Points of the t Distribution



df	a = .10	a = .05	a = .025	a = .010	a = .005
1	3.078	6.314	12.706	31.821	63.657
2	1.886	2.920	4.303	6.965	9.925
3	1.638	2.353	3.182	4.541	5.841
4	1.533	2.132	2.776	3.747	4.604
5	1.476	2.015	2.571	3.365	4.032
6	1.440	1.943	2.447	3.143	3.707
7	1.415	1.895	2.365	2.998	3.499
8	1.397	1.860	2.306	2.896	3.355
9	1.383	1.833	2.262	2.821	3.250
10	1.372	1.812	2.228	2.764	3.169
11	1.363	1.796	2.201	2.718	3.106
12	1.356	1.782	2.179	2.681	3.055
13	1.350	1.771	2.160	2.650	3.012
14	1.345	1.761	2.145	2.624	2.977
15	1.341	1.753	2.131	2.602	2.947
16	1.337	1.746	2.120	2.583	2.921
17	1.333	1.740	2.110	2.567	2.898
18	1.330	1.734	2.101	2.552	2.878
19	1.328	1.729	2.093	2.539	2.861
20	1.325	1.725	2.086	2.528	2.845
21	1.323	1.721	2.080	2.518	2.831
22	1.321	1.717	2.074	2.508	2.819
23	1.319	1.714	2.069	2.500	2.807
24	1.318	1.711	2.064	2.492	2.797
25	1.316	1.708	2.060	2.485	2.787
26	1.315	1.706	2.056	2.479	2.779
27	1.314	1.703	2.052	2.473	2.771
28	1.313	1.701	2.048	2.467	2.763
29	1.311	1.699	2.045	2.462	2.756
inf.	1.282	1.645	1.960	2.326	2.576

From "Table of Percentage Points of the *t*-distribution." Computed by Maxine Merrington, *Biometrika*, Vol. 32 (1941), p. 300. Reproduced by permission of the *Biometrika* Trustees.

Table 3: Percentage Points of the Chi Square Distribution



df	a = .995	a = .990	a = .975	a = .950	a = .900	a = .10	a = .05	a = .025	a = .010	a = .005	df
1	0.0000393	0.0001571	0.0009821	0.0039321	0.0157908	2.70554	3.84146	5.02389	6.63490	7.87944	1
2	0.0100251	0.0201007	0.0506356	0.102587	0.210720	4.60517	5.99147	7.37776	9.21034	10.5966	2
3	0.0717212	0.114832	0.215795	0.351846	0.584375	6.25139	7.81473	9.34840	11.3449	12.8381	3
4	0.206990	0.297110	0.484419	0.710721	1.063623	7.77944	9.48773	11.1433	13.2767	14.8602	4
5	0.411740	0.554300	0.831211	1.145476	1.61031	9.23635	11.0705	12.8325	15.0863	16.7496	5
6	0.675727	0.872085	1.237347	1.63539	2.20413	10.6446	12.5916	14.4494	16.8119	18.5476	6
7	0.989265	1.239043	1.68987	2.16735	2.83311	12.0170	14.0671	16.0128	18.4753	20.2777	7
8	1.344419	1.646482	2.17973	2.73264	3.48954	13.3616	15.5073	17.5346	20.0902	21.9550	8
9	1.734926	2.087912	2.70039	3.32511	4.16816	14.6837	16.9190	19.0228	21.6660	23.5893	9
10	2.15585	2.55821	3.24697	3.94030	4.86518	15.9871	18.3070	20.4831	23.2093	25.1882	10
11	2.60321	3.05347	3.81575	4.57481	5.57779	17.2750	19.6751	21.9200	24.7250	26.7569	11
12	3.07382	3.57056	4.40379	5.22603	6.30380	18.5494	21.0261	23.3367	26.2170	28.2995	12
13	3.56503	4.10691	5.00874	5.89186	7.04150	19.8119	22.3621	24.7356	27.6883	29.8194	13
14	4.07468	4.66043	5.62872	6.57063	7.78953	21.0642	23.6848	26.1190	29.1413	31.3193	14
15	4.60094	5.22935	6.26214	7.26094	8.54675	22.3072	24.9958	27.4884	30.5779	32.8013	15
16	5.14224	5.81221	6.90766	7.96164	9.31223	23.5418	26.2962	28.8454	31.9999	34.2672	16
17	5.69724	6.40776	7.56418	8.67176	10.0852	24.7690	27.5871	30.1910	33.4087	35.7185	17
18	6.26481	7.01491	8.23075	9.39046	10.8649	25.9894	28.8693	31.5264	34.8053	37.1564	18
19	6.84398	7.63273	8.90655	10.1170	11.6509	27.2036	30.1435	32.8523	36.1908	38.5822	19
20	7.43386	8.26040	9.59083	10.8508	12.4426	28.4120	31.4104	34.1696	37.5662	39.9968	20
21	8.03366	8.89720	10.28293	11.5913	13.2396	29.6151	32.6705	35.4789	38.9321	41.4010	21
22	8.64272	9.54249	10.9823	12.3380	14.0415	30.8133	33.9244	36.7807	40.2894	42.7956	22
23	9.26042	10.19567	11.6885	13.0905	14.8479	32.0069	35.1725	38.0757	41.6384	44.1813	23
24	9.88623	10.8564	12.4011	13.8484	15.6587	33.1963	36.4151	39.3641	42.9798	45.5585	24
25	10.5197	11.5240	13.1197	14.6114	16.4734	34.3816	37.6525	40.6465	44.3141	46.9278	25
26	11.1603	12.1981	13.8439	15.3791	17.2919	35.5631	38.8852	41.9232	45.6417	48.2899	26
27	11.8076	12.8786	14.5733	16.1513	18.1138	36.7412	40.1133	43.1944	46.9630	49.6449	27
28	12.4613	13.5648	15.3079	16.9279	18.9392	37.9159	41.3372	44.4607	48.2782	50.9933	28
29	13.1211	14.2565	16.0471	17.7083	19.7677	39.0875	42.5569	45.7222	49.5879	52.3356	29
30	13.7867	14.9535	16.7908	18.4926	20.5992	40.2560	43.7729	46.9792	50.8922	53.6720	30
40	20.7065	22.1643	24.4331	26.5093	29.0505	51.8050	55.7585	59.3417	63.6907	66.7659	40
50	27.9907	29.7067	32.3574	34.7642	37.6886	63.1671	67.5048	71.4202	76.1539	79.4900	50
60	35.5346	37.4848	40.4817	43.1879	46.4589	74.3970	79.0819	83.2976	88.3794	91.9517	60
70	43.2752	45.4418	48.7576	51.7393	55.3290	85.5271	90.5312	95.0231	100.425	104.215	70
80	51.1720	53.5400	57.1532	60.3915	64.2778	96.5782	101.879	106.629	112.329	116.321	80
90	59.1963	61.7541	65.6466	69.1260	73.2912	107.565	113.145	118.136	124.116	128.299	90
100	67.3276	70.0648	74.2219	77.9295	82.3581	118.498	124.342	129.561	135.807	140.169	100

Table 5: Critical Values of the Wilcoxon Signed-Rank Test

n = 5(1)50

One-sided	*Two-sided*	*n* = 5	*n* = 6	*n* = 7	*n* = 8	*n* = 9	*n* = 10	*n* = 11	*n* = 12	*n* = 13	*n* = 14	*n* = 15	*n* = 16
.05	.10	1	2	4	6	8	11	14	17	21	26	30	36
.025	.05		1	2	4	6	8	11	14	17	21	25	30
.01	.02			0	2	3	5	7	10	13	16	20	24
.005	.01				0	2	3	5	7	10	13	16	19

One-sided	*Two-sided*	*n* = 17	*n* = 18	*n* = 19	*n* = 20	*n* = 21	*n* = 22	*n* = 23	*n* = 24	*n* = 25	*n* = 26	*n* = 27	*n* = 28
.05	.10	41	47	54	60	68	75	83	92	101	110	120	130
.025	.05	35	40	46	52	59	66	73	81	90	98	107	117
.01	.02	28	33	38	43	49	56	62	69	77	85	93	102
.005	.01	23	28	32	37	43	49	55	61	68	76	84	92

One-sided	*Two-sided*	*n* = 29	*n* = 30	*n* = 31	*n* = 32	*n* = 33	*n* = 34	*n* = 35	*n* = 36	*n* = 37	*n* = 38	*n* = 39
.05	.10	141	152	163	175	188	201	214	228	242	256	271
.025	.05	127	137	148	159	171	183	195	208	222	235	250
.01	.02	111	120	130	141	151	162	174	186	198	211	224
.005	.01	100	109	118	128	138	149	160	171	183	195	208

One-sided	*Two-sided*	*n* = 40	*n* = 41	*n* = 42	*n* = 43	*n* = 44	*n* = 45	*n* = 46	*n* = 47	*n* = 48	*n* = 49	*n* = 50
.05	.10	287	303	319	336	353	371	389	408	427	446	466
.025	.05	264	279	295	311	327	344	361	379	397	415	434
.01	.02	238	252	267	281	297	313	329	345	362	380	398
.005	.01	221	234	248	262	277	292	307	323	339	356	373

From *Some Rapid Approximate Statistical Procedures* (Revised) by Frank Wilcoxon and Roberta A. Wilcox (Pearl River, N.Y.: Lederle Laboratories, 1964), Table 2. Reproduced by permission of Lederle Laboratories, a division of American Cyanamid Company.

Table 6: Percentage Points of the Duncan New Multiple Range Test

Error df	α	r = number of ordered steps between means: 2	3	4	5	6	7	8	9	10	12	14	16	18	20
1	.05	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0
	.01	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
2	.05	6.09	6.09	6.09	6.09	6.09	6.09	6.09	6.09	6.09	6.09	6.09	6.09	6.09	6.09
	.01	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
3	.05	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50
	.01	8.26	8.5	8.6	8.7	8.8	8.9	8.9	9.0	9.0	9.0	9.1	9.2	9.3	9.3
4	.05	3.93	4.01	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02
	.01	6.51	6.8	6.9	7.0	7.1	7.1	7.2	7.2	7.3	7.3	7.4	7.4	7.5	7.5
5	.05	3.64	3.74	3.79	3.83	3.83	3.83	3.83	3.83	3.83	3.83	3.83	3.83	3.83	3.83
	.01	5.70	5.96	6.11	6.18	6.26	6.33	6.40	6.44	6.5	6.6	6.6	6.7	6.7	6.8
6	.05	3.46	3.58	3.64	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68
	.01	5.24	5.51	5.65	5.73	5.81	5.88	5.95	6.00	6.0	6.1	6.2	6.2	6.3	6.3
7	.05	3.35	3.47	3.54	3.58	3.60	3.61	3.61	3.61	3.61	3.61	3.61	3.61	3.61	3.61
	.01	4.95	5.22	5.37	5.45	5.53	5.61	5.69	5.73	5.8	5.8	5.9	5.9	6.0	6.0
8	.05	3.26	3.39	3.47	3.52	3.55	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56
	.01	4.74	5.00	5.14	5.23	5.32	5.40	5.47	5.51	5.5	5.6	5.7	5.7	5.8	5.8
9	.05	3.20	3.34	3.41	3.47	3.50	3.52	3.52	3.52	3.52	3.52	3.52	3.52	3.52	3.52
	.01	4.60	4.86	4.99	5.08	5.17	5.25	5.32	5.36	5.4	5.5	5.5	5.6	5.7	5.7
10	.05	3.15	3.30	3.37	3.43	3.46	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.48
	.01	4.48	4.73	4.88	4.96	5.06	5.13	5.20	5.24	5.28	5.36	5.42	5.48	5.54	5.55
11	.05	3.11	3.27	3.35	3.39	3.43	3.44	3.45	3.46	3.46	3.46	3.46	3.46	3.47	3.48
	.01	4.39	4.63	4.77	4.86	4.94	5.01	5.06	5.12	5.15	5.24	5.28	5.34	5.38	5.39
12	.05	3.08	3.23	3.33	3.36	3.40	3.42	3.44	3.44	3.46	3.46	3.46	3.46	3.47	3.48
	.01	4.32	4.55	4.68	4.76	4.84	4.92	4.96	5.02	5.07	5.13	5.17	5.22	5.23	5.26
13	.05	3.06	3.21	3.30	3.35	3.38	3.41	3.42	3.44	3.45	3.45	3.46	3.46	3.47	3.47
	.01	4.26	4.48	4.62	4.69	4.74	4.84	4.88	4.94	4.98	5.04	5.08	5.13	5.14	5.15
14	.05	3.03	3.18	3.27	3.33	3.37	3.39	3.41	3.42	3.44	3.45	3.46	3.46	3.47	3.47
	.01	4.21	4.42	4.55	4.63	4.70	4.78	4.83	4.87	4.91	4.96	5.00	5.04	5.06	5.07
15	.05	3.01	3.16	3.25	3.31	3.36	3.38	3.40	3.42	3.43	3.44	3.45	3.46	3.47	3.47
	.01	4.17	4.37	4.50	4.58	4.64	4.72	4.77	4.81	4.84	4.90	4.94	4.97	4.99	5.00
16	.05	3.00	3.15	3.23	3.30	3.34	3.37	3.39	3.41	3.43	3.44	3.45	3.46	3.47	3.47
	.01	4.13	4.34	4.45	4.54	4.60	4.67	4.72	4.76	4.79	4.84	4.88	4.91	4.93	4.94
17	.05	2.98	3.13	3.22	3.28	3.33	3.36	3.38	3.40	3.42	3.44	3.45	3.46	3.47	3.47
	.01	4.10	4.30	4.41	4.50	4.56	4.63	4.68	4.72	4.75	4.80	4.83	4.86	4.88	4.89
18	.05	2.97	3.12	3.21	3.27	3.32	3.35	3.37	3.39	3.41	3.43	3.45	3.46	3.47	3.47
	.01	4.07	4.27	4.38	4.46	4.53	4.59	4.64	4.68	4.71	4.76	4.79	4.82	4.84	4.85
19	.05	2.96	3.11	3.19	3.26	3.31	3.35	3.37	3.39	3.41	3.43	3.44	3.46	3.47	3.47
	.01	4.05	4.24	4.35	4.43	4.50	4.56	4.61	4.64	4.67	4.72	4.76	4.79	4.81	4.82
20	.05	2.95	3.10	3.18	3.25	3.30	3.34	3.36	3.38	3.40	3.43	3.44	3.46	3.46	3.47
	.01	4.02	4.22	4.33	4.40	4.47	4.53	4.58	4.61	4.65	4.69	4.73	4.76	4.78	4.79
22	.05	2.93	3.08	3.17	3.24	3.29	3.32	3.35	3.37	3.39	3.42	3.44	3.45	3.46	3.47
	.01	3.99	4.17	4.28	4.36	4.42	4.48	4.53	4.57	4.60	4.65	4.68	4.71	4.74	4.75
24	.05	2.92	3.07	3.15	3.22	3.28	3.31	3.34	3.37	3.38	3.41	3.44	3.45	3.46	3.47
	.01	3.96	4.14	4.24	4.33	4.39	4.44	4.49	4.53	4.57	4.62	4.64	4.67	4.70	4.72
26	.05	2.91	3.06	3.14	3.21	3.27	3.30	3.34	3.36	3.38	3.41	3.43	3.45	3.46	3.47
	.01	3.93	4.11	4.21	4.30	4.36	4.41	4.46	4.50	4.53	4.58	4.62	4.65	4.67	4.69
28	.05	2.90	3.04	3.13	3.20	3.26	3.30	3.33	3.35	3.37	3.40	3.43	3.45	3.46	3.47
	.01	3.91	3.08	4.18	4.28	4.34	4.39	4.43	4.47	4.51	4.56	4.60	4.62	4.65	4.67
30	.05	2.89	3.04	3.12	3.20	3.25	3.29	3.32	3.35	3.37	3.40	3.43	3.44	3.46	3.47
	.01	3.89	4.06	4.16	4.22	4.32	4.36	4.41	4.45	4.48	4.54	4.58	4.61	4.63	4.65
40	.05	2.86	3.01	3.10	3.17	3.22	3.27	3.30	3.33	3.35	3.39	3.42	3.44	3.46	3.47
	.01	3.82	3.99	4.10	4.17	4.24	4.30	4.34	4.37	4.41	4.46	4.51	4.54	4.57	4.59
60	.05	2.83	2.98	3.08	3.14	3.20	3.24	3.28	3.31	3.33	3.37	3.40	3.43	3.45	3.47
	.01	3.76	3.92	4.03	4.12	4.17	4.23	4.27	4.31	4.34	4.39	4.44	4.47	4.50	4.53
100	.05	2.80	2.95	3.05	3.12	3.18	3.22	3.26	3.29	3.32	3.36	3.40	3.42	3.45	3.47
	.01	3.71	3.86	3.93	4.06	4.11	4.17	4.21	4.25	4.29	4.35	4.38	4.42	4.45	4.48
∞	.05	2.77	2.92	3.02	3.09	3.15	3.19	3.23	3.26	3.29	3.34	3.38	3.41	3.44	3.47
	.01	3.64	3.80	3.90	3.98	4.04	4.09	4.14	4.17	4.20	4.26	4.31	4.34	4.38	4.41

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Table 7: Critical Values of the Mann-Whitney Test

n_1	n_2	α(2): 0.20 α(1): 0.10	α(2): 0.10 α(1): 0.05	α(2): 0.05 α(1): 0.025	α(2): 0.02 α(1): 0.01	α(2): 0.01 α(1): 0.005	α(2): 0.005 α(1): 0.0025	α(2): 0.002 α(1): 0.001	α(2): 0.001 α(1): 0.0005
8	38	198	210	220	232	240	247	255	260
	39	203	215	226	238	246	253	261	267
8	40	208	221	231	244	252	259	268	273
9	9	56	60	64	67	70	72	74	76
	10	62	66	70	74	77	79	82	83
	11	68	72	76	81	83	86	89	92
	12	73	78	82	87	90	93	96	98
	13	79	84	89	94	97	100	103	106
	14	85	90	95	100	104	107	111	113
	15	90	96	101	107	111	114	118	120
	16	96	102	107	113	117	121	125	128
	17	101	108	114	120	124	128	132	135
	18	107	114	120	126	131	135	139	142
	19	113	120	126	133	138	142	146	150
	20	118	126	132	140	144	149	154	157
	21	124	132	139	146	151	155	161	166
	22	130	138	145	153	158	162	168	172
	23	135	144	151	159	164	169	175	179
	24	141	150	157	166	171	176	182	186
	25	147	156	163	172	178	183	189	193
	26	152	162	170	179	185	190	196	201
	27	158	168	176	185	191	197	203	208
	28	164	174	182	192	198	204	211	215
	29	169	179	188	198	205	211	218	222
	30	175	185	194	205	212	218	225	230
	31	180	191	201	211	218	224	232	237
	32	186	197	207	218	225	231	239	244
	33	192	203	213	224	232	238	246	251
	34	197	209	219	231	238	245	253	259
	35	203	215	226	237	245	252	260	266
	36	209	221	232	244	252	259	267	273
	37	214	227	238	250	258	256	275	280
	38	220	233	244	257	265	273	282	288
	39	225	239	250	263	272	280	289	295
9	40	231	245	257	270	275	286	296	302
10	10	68	73	77	81	84	87	90	92
	11	74	79	84	88	92	94	98	100
	12	81	86	91	96	99	102	106	108
	13	87	93	97	103	108	110	113	116
	14	93	99	104	110	114	117	121	124
	15	99	106	111	117	121	125	129	132
	16	106	112	118	124	125	133	137	140
	17	112	119	125	132	135	140	145	148
	18	118	125	132	139	143	148	153	156
	19	124	132	138	146	151	155	161	164
	20	130	138	145	153	158	163	168	172
10	21	137	145	152	160	166	170	176	180