1. In an experiment to study the effects of sleep deprivation on hand steadiness, 32 subjects were randomly divided into four groups and four levels of sleep deprivation, 12, 24, 36 and 48 hours, were randomly assigned to the four groups. The response variable is an index on hand steadiness. The data of the experiment is given below:

	Deprivation levels			
	1	2	3	4
	3	4	7	7
	6	5	8	8
	3	4	7	9
	3	3	6	8
	1	2	5	10
	2	3	6	10
	2	4	5	9
	2	3	6	11
Mean	2.75	3.50	6.25	9.00
sd	1.49	0.93	1.04	1.31

(i) Compute the following ANOVA table:

Source	df	SS	MS	F ratio
Between groups				
Within groups				

(ii) Based on the ANOVA table computed in (i), test whether there is significant difference in the effects of the four deprivation levels at level $\alpha = 0.05$.

(iii) Suppose the following hypotheses are of interest:

$$\mu_2 - \mu_1 = \mu_3 - \mu_2 \quad \text{and} \quad \mu_3 - \mu_2 = \mu_4 - \mu_3,$$

where μ_j denote the expected response with deprivation level j. Give the appropriate test statistics. Test the above hypotheses using appropriate multiple comparison criterion to control the overall error rate at level 0.05. The following critical values are for your reference: $t_{28,0.0125} = 2.3685$, $F_{3,28,0.05} = 2.29$, Tukey's $q_{4,28,0.05} = 3.864$, Dunnett's $d_{3,28,0.05} = 2.483$.

2. **(i)** The following table gives the serum total cholesterol (X) of two groups of patients with heart disease.

Group 1		Group 2	
Patient	X	Patient	X
1	194	1	215
2	330	2	281
3	334	3	209
4	171	4	180
5	388	5	234
6	283	6	240
7	315	7	216
		8	182
		9	298

Using Mann-Whitney-Wilcoxon test to test whether the two groups have significant difference in their expected serum total cholesterol at level $\alpha = 0.05$. ($\chi_1^2(0.05) = 3.841$.)

(ii) The following table gives the results of a reliability study comparing DMFS scores (number of decayed, missing, and filled surfaces of a patient's permanent teeth) by three examiners on six patients.

	Examiner		
Patient	1	2	3
1	8	7	10
2	12	11	15
3	1	0	2
4	3	6	9
5	13	14	17
6	19	23	27

Using Kruskal-Wallis test to test whether the examiner's scores are consistent with each other, i.e., whether their expected scores are the same, at level $\alpha = 0.05$. ($\chi_2^2(0.05) = 5.991$.)

3. The following table is the layout of the data from a complete random blocks design:

	Treatment				
Block	1	$\cdots$	j	$\cdots$	g
1	X_{11}	$\cdots$	X_{1j}	$\cdots$	X_{1g}
$\vdots$					
i	X_{i1}	$\cdots$	X_{ij}	$\cdots$	X_{ig}
$\vdots$					
n	X_{n1}	$\cdots$	X_{nj}	$\cdots$	X_{ng}

(i) Define dummy variables for the blocks and treatments. Write the linear model in terms of the dummy variables for the description of the data above.

(ii) Give interpretations on the meanings of the parameters in the linear model which you write in (i).

(iii) State the hypothesis of no treatment difference in terms of the parameters.

(iv) In the following ANOVA table, fill in the degrees freedom associated with various sums of squares:

Source	df	SS
Treatments		TSS
Blocks		BSS
Residuals		RSS
Total		TTSS

(v) Give the formulas for TSS and RSS in the ANOVA table above, provide the definition for your notations.

4. In the table below, each block represents a different subject, the units within blocks are four blood samples from each subject, and four treatments were randomly assigned to the blood samples within each set. The values are the clotting times of plasm, in minutes.

	Treatment			
Block	1	2	3	4
1	8.4	9.4	9.8	12.2
2	12.8	15.2	12.9	14.4
3	9.6	9.1	11.2	9.8
4	9.8	8.8	9.9	12.0
5	8.4	8.2	8.5	8.5
6	8.6	9.9	9.8	10.9
7	8.9	9.0	9.2	10.4
8	7.9	8.1	8.2	10.0

The following R-code is used for the computation:

```
y = c(8.4,12.8,9.6,9.8,8.4,8.6,8.9,7.9,
         9.4,15.2,9.1,8.8,8.2,9.9,9.0,8.1,
         9.8,12.9,11.2,9.9,8.5,9.8,9.2,8.2,
        12.2,14.4,9.8,12.0,8.5,10.9,10.4,10)
tmt=factor(c(rep(1,8),rep(2,8),rep(3,8),rep(4,8)))
blk=factor(rep(1:8,4))
options(contrasts=c("contr.treatment","contr.poly"))
lm.fit= lm(y~tmt+blk)
```

The computation produces the following results:

```
          Df Sum Sq Mean Sq F value    Pr(>F)
tmt        3 13.016   4.339   6.615  0.002550 **
blk        7 78.989  11.284  17.204 2.197e-07 ***
Residuals 21 13.774   0.656

Intercept   tmt2   tmt3   tmt4  blk2   blk3
     9.256  0.413  0.638  1.725 3.875 -0.025
     blk4    blk5    blk6    blk7   blk8
     0.175   -1.550  -0.150  -0.575 -1.400
```

The variance-covariance matrix for the parameters corresponding to `tmt2 tmt3 tmt4` is extracted as

	tmt2	tmt3	tmt4
tmt2	0.164	0.082	0.082
tmt3	0.082	0.164	0.082
tmt4	0.082	0.082	0.164

(i) Test the null hypothesis that there is no difference in the effects of the four treatments at level 0.01. Give the value of the test statistic and your conclusion.

(ii) Test the following contrasts at level $\alpha = 0.05$. Use an appropriate multiple comparison criterion to control the overall error rate.

$$\mu_1 - \mu_4;\ \mu_2 - \mu_4;\ \mu_3 - \mu_4;$$

where μ_j denotes the expected effect of treatment j. The following critical values are for your reference: $t_{21,0.05/6} = 2.6014$, $F_{3,21,0.05} = 3.072$, Tukey's $q_{4,21,0.05} = 3.945$, Dunnett's $d_{3,21,0.05} = 2.53$.

END OF PAPER