First-year Statistics for Psychology Students through Worked Examples

4. The Independent Samples *t*-test and the Mann-Whitney *U*-Test

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Acknowledgements

I am grateful to the following for comments and guidance at various points in the evolution of this tutorial: Dr Fabian Wadel, Dr Paul Griffiths, and Professor David Popplewell.

I am also indebted to Andrew Legge for help with the formatting of mathematical formulae and symbols.

Most recently, I have become much indebted to Dr Ed Knorr, who very kindly read through the complete typescript and made numerous suggestions and corrections, both large and small.

Any remaining errors or omissions are my responsibility. I would be pleased to receive information from anyone who spots any error, mathematical or otherwise. I can be contacted via e-mail at:

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I should also be pleased to hear from anyone who finds this tutorial helpful, either for themselves or for their students.

Charles McCreery

General Introduction[1]

There are usually three complementary methods for mastering any new intellectual or artistic task; these are, in ascending order of importance:

- reading books about it
- observing how other people do it
- actually doing it oneself

These tutorials focus on the second of these methods. They are based on handouts that I developed when teaching first-year psychology students at Magdalen College, Oxford. The core of each tutorial is a worked example from an Oxford University Prelims Statistics examination paper. I have therefore placed this section in prime position; however, in teaching the order of events was different, and more nearly corresponded to the three-fold hierarchy of methods given above:

1. Students were invited to read one of the chapters on the Recommended Reading list, given at the end of each tutorial. They were also expected to attend a lecture on the topic in question at the Department of Experimental Psychology.

2. Students would attend a tutorial, in which we would go through the worked example shown here. They would take away the handouts printed as Appendices at the end of each chapter, which were designed to give structure to the topic and help them when doing an example on their own.

3. They would be given another previous examination question to take away and do in their own time, which would be handed in later for marking.

I am strongly in favour of detailed worked examples; following one is the next best thing to attempting a question oneself. Even better than either method is doing a statistical test on data which one has collected oneself, and which therefore has some personal significance to one, but that is not usually practicable in a first-year course.

[1] This is a general introduction to a series of six tutorials available here: http://www.celiagreen.com/charlesmccreery.html

I list three books in the General Bibliography at the end of this tutorial which give worked examples. One of these is Spiegel (1992), in which each chapter has numerous ‘solved problems’ on the topic in question. These worked problems occupy more than half of each chapter. However, the solutions to the individual problems are not as detailed and discursive as the ones I give here.

Another book which is based on worked examples on each of the topics covered is Greene and D’Oliveira (1982), also listed in the General Bibliography. Their examples are as detailed as those I give here. However, they do not cover probability and Bayes’ theorem or Analysis of Variance.

Finally, I strongly recommend the *Introductory Statistics Guide* by Marija Norusis, designed to accompany the statistical package *SPSS-X*, and based on worked examples throughout. Even if the student does not have access to a computer with the *SPSS-X* package on it, this instruction manual contains excellent expositions of all the basic statistical concepts dealt with in my own examples.

The Independent Samples *t*-Test and the Mann-Whitney *U* Test

Contents

1 The question[2]

Briefly state the advantages and disadvantages of nonparametric statistical tests.

The data below are from a study investigating the possible increased levels of stress caused by working in an *Open-plan*, as against *Closed*, office. Two groups of workers were asked to rate their levels of stress on a scale from 1 to 10, where 1 represented very little stress and 10 represented high levels of stress. Plot the data on a single graph and comment. Carry out an appropriate parametric and nonparametric statistical test to compare the stress levels in the two groups. Comment on the outcome of the tests.

Open-plan: 9 8 7 6 7 9 10 6 5 8

Closed: 7 4 6 7 3 4 5 4 7

2 The answer

Non-parametric tests make fewer assumptions than parametric ones about the nature of the test data. With non-parametric tests there is no assumption of normality in the underlying data distribution from which the test data are selected, so they are suitable even if the underlying distribution is known to be skewed.

For a non-parametric test to be appropriate, the data itself need not be interval data, but need only be capable of being ranked (i.e. ordinal). Also the results of non-parametric tests are less affected by outliers in the data set.

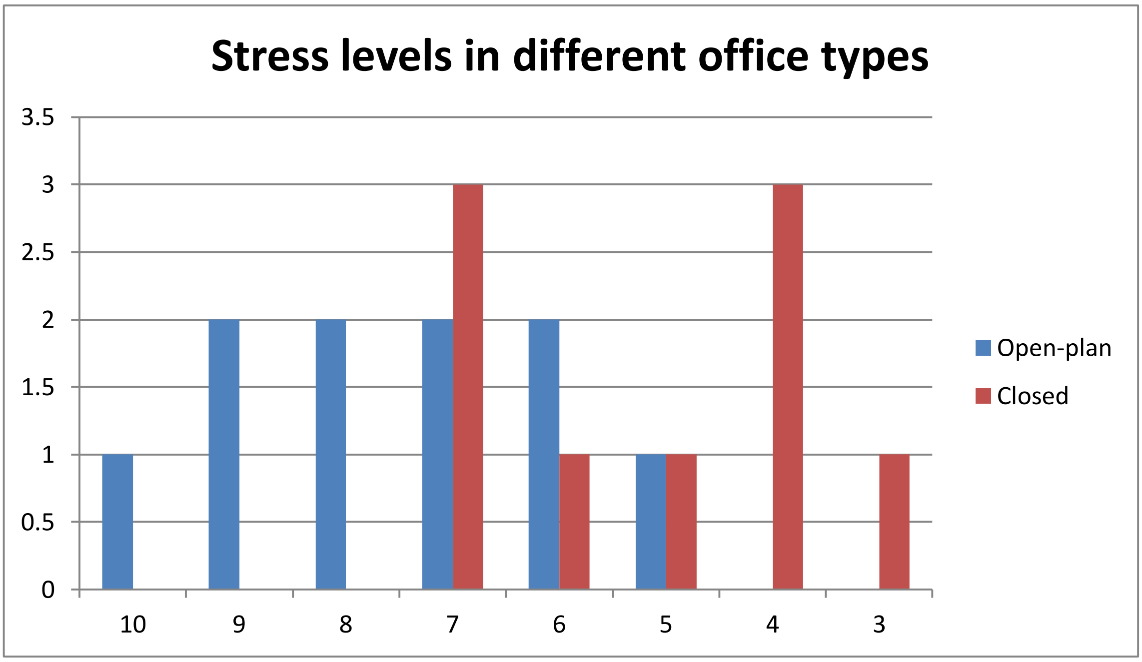
Against these largely practical advantages must be set the fact that parametric statistical tests, such as the *t*-test, tend to have more power than their non-parametric counterparts, because they utilize more of the information in the data, provided such information is available.

[We will see by the end of this tutorial that the present question illustrates this disadvantage of non-parametric tests. In the present case the parametric test (Student's *t*-test[3]) will produce a more significant result than the non-parametric one (the Mann-Whitney).

[2] The question is taken from the Prelims Statistics paper for first-year psychology students at Oxford University, March, 1995.

[3] 'Student' was the *nom de plume* of William Sealy Gosset (1876-1937), who developed the *t*-test.

Note also that this question requires us to use the independent-samples version of the *t*-test, not the matched pairs version; the number of members in the two groups, Open-plan and Closed, are different (10 in the first case and 9 in the second), so they could not in principle form matched pairs.]



2.1 Comments on the graph

The distribution of self-rating scores in neither the Open-plan group nor the Closed group is notably normal in shape. This may be a function of the relatively small number of subjects in each group (10 in the first group and 9 in the second). For the *t*-test to be appropriate, therefore, we have to assume that the two groups each represent a small sample from a much larger potential population, which *would* display normality in their self-rating scores.

The two distributions only overlap for the three central scores, so we may expect to find a statistically significant difference between them.

2.2 Applying the independent samples *t*-test to the data

[The first step is to work out the two group means.]

Mean of first group:
Sum of Open-plan group's ratings = $\Sigma x = 75$
Number of observations = $n_1 = 10$
Mean = $\bar{x} = \Sigma x / n_1 = 75/10 = 7.50$

Mean of second group:
Sum of Closed group's ratings = $\Sigma y = 47$`
Number of observations = $n_2 = 9$
Mean = $\bar{y} = \Sigma y / n_2 = 47/9 = 5.22$

[Next we work out the variance of each group separately.]

2.3 Calculation of the variance of the Open-plan group

Group mean	Individual score	Difference of score from mean	Square of difference
7.5	9	1.5	2.25
7.5	8	0.5	0.25
7.5	7	-0.5	0.25
7.5	6	-1.5	2.25
7.5	7	-0.5	0.25
7.5	9	1.5	2.25
7.5	10	2.5	6.25
7.5	6	-1.5	2.25
7.5	5	-2.5	6.25
7.5	8	0.5	0.25
Sum:	**75**		**22.5**

[I have laid out the preliminary calculations for the variance in this detail for heuristic purposes; i.e. to make what is being done as perspicuous as possible. In the Oxford University Psychology Prelims examination students are allowed the use of a hand calculator, and are not expected to show their workings in this detail.

Nevertheless, I recommend 'eye-balling' the results of any calculations you do on a calculator in an examination as you go along, and thinking, 'Do they make intuitive sense?' Under the stress of an examination one might, for example, accidentally add a nought to one of the data points as one enters it, and the calculator is not going to flag your mistake for you.

We now divide the sum of squares by $n - 1$, where n is the number of observations (in this case 10), to find the variance.]

Variance $= s_1^2 = \Sigma(x - \bar{x})^2/(n_1 - 1)$

$= 22.5/9$

$= 2.5$

2.4 Calculation of the variance of the Closed group

Group mean	Individual score	Difference of score from mean	Square of difference
5.2	7	1.80	3.24
5.2	4	-1.20	1.44
5.2	6	0.80	0.64
5.2	7	1.80	3.24
5.2	3	-2.20	4.84
5.2	4	-1.20	1.44
5.2	5	-0.20	0.04
5.2	4	-1.20	1.44
5.2	7	1.80	3.24
Sum:	**47**		**19.56**

Variance $= s_2^2 = \Sigma(y - \bar{y})^2/(n_2 - 1)$

$= 19.56/8$

$= 2.44$

2.5 Working out the pooled/combined variance of the two groups

[This is done using the formula below. Oxford students are given this formula, and the formula for calculating Student's *t*, both found in the 'Definitions and Formulae' booklet, which they are allowed to take into the Prelims exam.]

$$\text{Pooled variance} = s^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}$$

where n_1 is the number of workers in the first group (Open-Plan), n_2 is the number of workers in the second group (Closed), s_1^2 is the variance of the first group, and s_2^2 is the variance of the second group.

$$\therefore\ s^2 = \frac{(10-1)2.5+(9-1)2.44}{10+9-2}$$

$$\therefore\ s^2 = \frac{22.5+19.52}{17}$$

$$\therefore\ s^2 = 2.47$$

2.6 Working out the value of *t*

[To work out the value of *t*, we use the following formula for a test involving independent groups, as in the present case:]

$$t = \frac{\bar{x} - \bar{y}}{s\sqrt{\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

[Here the top line of the formula represents the difference between the two group means. In the bottom line the standard deviation, *s*, is the *square root* of the pooled variance above, and n_1 and n_2 are the numbers of subjects in the first and second groups respectively.]

Therefore:

$$t = \frac{7.50 - 5.22}{1.57\sqrt{\left(\frac{1}{10} + \frac{1}{9}\right)}}$$

$$= \frac{2.28}{1.57\sqrt{(0.21)}}$$

$$= \frac{2.28}{1.57 \text{ x } 0.46}$$

$$= \frac{2.28}{0.722}$$

$$= 3.15$$

[In the Oxford Prelims exam the student is not required to show his or her workings in this way. However, I have shown my work explicitly in case the reader comes to a different numerical conclusion in the first instance and wishes to see where his/her path diverged from mine. (Small differences may be due to the number of significant figures retained in intermediate calculations.)

Next we work out the degrees of freedom from the following formula:]

Degrees of freedom = $(n_1 - 1) + (n_2 - 1)$

= (10 – 1) + (9 – 1)

= 17

[Finally, we look up the significance or otherwise of the *t*-value we obtained, namely 3.185, given there are 17 degrees of freedom. This can be done using any table that gives Student's *t* distribution, for example Table V in Hoel, 1976, p.334. The value we have obtained needs to be *greater than* whatever value we find in the table.]

The critical value of t for significance at the 1% level, given 17 degrees of freedom = 2.898.

$3.15 > 2.898$

∴ The observed difference between the two group means is significant at the 0.01 level.

3 Applying a non-parametric test to the same data

We will use the Mann-Whitney rank sum test for two independent samples as the non-parametric alternative to the *t*-test.

[The Mann-Whitney is an appropriate test when we are dealing with two separate sets of subjects whose relevant values (in this case stress levels) were measured under unrelated conditions. In this instance one set of 10 subjects was measured under the Open-plan condition and a different set of 8 subjects was measured under the Closed condition. None of the 18 subjects was measured under both conditions, as might happen in a repeated measures experiment.]

Step 1:

(a) Rank the stress level score from both groups as a single series, regardless of which group they come from, and *ranking them from low to high*.

(b) Assign a rank number to each subject.

[For clarity, I have highlighted the Open-plan subjects in Table A below in grey.

How to assign a rank number to each subject:

Note that there are ties for every Stress level rank except the first and the last (Stress levels 10 and 3). The way to assign one rank number to each member of a tie is as follows:

(1) We count the number of subjects tied on a given Stress level score.

(2) We sum the position numbers (first line of Table A) of each of these subjects.

(3) We divide this sum of position numbers by the total number of the subjects occupying this position.
(4) We assign the resulting number to *each* of these subjects.

For example, to assign a rank number to each of the two subjects tied on the Stress level score of 9, we do the following: we sum the two position numbers they occupy, namely 2 and 3, which give us 5; we then divide this sum of 5 by 2; result: 2.5

Similarly, to assign a rank number to the five subjects who all had a score of 7, we sum the five position numbers they occupy (i.e. 6, 7, 8, 9 and 10, to get 40), and then divide this sum by 5 (to get 8).

It may seem counter-intuitive to be assigning fractional rank numbers in some cases of ties. In most real-life contexts we would assign both members of a tie the first position number; for example, if two horses in a horse race were tied for second position because the camera could not separate them, then we would allocate them both position number 2, not position 2.5.

However, in the present context the horse-race practice would introduce an element of arbitrariness into the rank numbers of tied subjects: subjects whose Stress scores happened to be tied with a relatively large number of other subjects would have an artificially distorted rank number.]

Table A:

Position number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Stress level score	3	4	4	4	5	5	6	6	6	7	7	7	7	7	8	8	9	9	10
Rank number	1	3	3	3	5.5	5.5	8	8	8	12	12	12	12	12	15.5	15.5	17.5	17.5	19

Open-plan subjects

Step 2:
Sum the rank numbers found in Step 1 separately for the two groups:

Open-plan	9	8	7	6	7	9	10	6	5	8
Rank number	17.5	15.5	12	8	12	17.5	19	8	5.5	15.5
Closed	7	4	6	7	3	4	5	4	7	
Rank number	12	3	8	12	1	3	5.5	3	12	

[The first row consists of the raw data for the Stress level scores of the Open-plan group. These are given in the order in which they are presented in the exam question at the start of this tutorial.

The second row consists of the rank numbers of those scores, which we found in Step 1.

Rows three and four repeat the process for the Closed group.]

Summing the rank numbers of the Open-plan group (the second row of the table) gives a total (T_1) of 130.5.

Summing the rank numbers of the Closed group (the fourth row of the table) gives a total (T_2) of 59.5.

[Note that just by 'eye-balling' the data in the 'Step 2' table above it looks as though the average rank number of the Closed group is higher than that of the Open-plan group, as we would expect from inspection of the graph at the start of our answer.]

Next we calculate U, the Mann-Whitney statistic, using the following formula:

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

In this formula T_x is always the larger of the two rank scores for the groups; i.e. the Open-plan group in this instance, whose rank scores summed to 130.5.

n_1 and n_2 are the numbers of subjects in the two groups, Open-plan and Closed.

n_x is the number of subjects in the group with the higher total rank score — in this case the Open-plan (more stressed) group.

We therefore fill in the formula as follows:

$$U = 9 \times 10 + \frac{10 \times 11}{2} - 130.5$$

$$= 90 + 55 - 130.5$$
$$= 14.5$$

Finally, we look up the critical value which U must *less than* to be significant, where the group sizes are 10 and 9 and the test is two-tailed (because we did not predict the direction of any difference that might be found – see Appendix 3).

Referring to Table B(1) on p. 162 of Greene and D'Oliveira (1982), for example, we find that our U value of 14.5 is *greater* than the required value of 13 *or less* for significance at the 0.01 level, given group sizes of 10 and 9 (which is our case). So our result fails to reach significance at this level.

However, referring to Table B(2) on p. 163 of Greene and D'Oliveira (1982), for example, we find that the required value for significance at the 0.02 level, given our group sizes, is 16 *or less*. Our value is 14.5, which meets this criterion and is therefore significant at the 1 in 50 level.

[It is noteworthy that the non-parametric Mann-Whitney test, which utilizes less of the information contained in the data than does the *t*-test, only meets the less demanding criterion of significance of the 1 in 50 level, whereas the result of the *t*-test was significant at the 1 in 100 level.]

4 Comment on the outcome of the tests

At first sight it is somewhat surprising, given the relatively small degree of overlap of the scores of the two groups shown by the plot, that the Mann-Whitney test fails to give a significant result at the 1 in 100 level, while the *t*-test does. The finding may reflect the greater power of the *t*-test, and the relatively small number of subjects used in both groups. The greater power of the *t*-test results from the fact that it uses quantitative information in the data, which is lost when the scores are merely ranked.

The result suggests that it is preferable to use the parametric test rather than the non-parametric one when the assumptions of the *t*-test can reasonably be assumed to be met.

The main assumptions of the *t*-test are:

(1) that the distributions of the two underlying populations of scores, of which the present data are samples, are both *reasonable approximations to the normal distribution*; and

(2) that the two underlying populations would be found to have *reasonably similar variances*.

5 Recommended reading

Greene, Judith and D'Oliveira, Manuela (1982). *Learning to Use Statistical Tests in Psychology.* Milton Keynes: Open University Press, Chapter 8.

Appendix 1

Summary of steps in the independent samples *t*-test

1. (a) Work out the mean of the first group
(b) Work out the mean of second group

2. (a) Work out the variance of the first group:

(i) Find the difference of each observation from the mean worked out in 1 (a)
(ii) Square each of these differences
(iii) Sum these squares
(iv) Divide this sum by (n −1), where n is the number of observations in the group

(b) Work out the variance of the second group

3. Work out the pooled/combined variance of the two groups:

Plug your two sample variances into the combined (pooled) variance formula:

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

where s^2 is the combined variance, n_1 is the number of observations in the first sample, n_2 is the number of observations in the second sample, $s_1{}^2$ is the variance of the first sample, and $s_2{}^2$ is the variance of the second sample.

4. (a) Plug the results of l(a) and l(b) into the top line of the *t*-test formula (independent samples version):

$$t = \frac{\bar{x} - \bar{y}}{s\sqrt{\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

(b) Plug the square root of the combined variance into the bottom line of the formula, where it says s.

(c) Plug n_1 and n_2 into the bottom line also.

5. Compute the resulting *t*-value.

6. Look up the significance or otherwise of this *t*-value in a table giving the critical values of Student's *t* distribution.

   N.B. degrees of freedom = $(n_1 - 1) + (n_2 - 1)$

Appendix 2

Parametric versus non-parametric tests

	Parametric	Non-parametric
Differences:	Assume normality in underlying population distribution	No assumptions about nature of underlying distribution
	Deal with means	Deal with medians
	Deal with intervals	Deal with ranks
Advantages:	More power	Fewer assumptions (good for skewed distributions, for example)
		Less affected by outliers (regarding mean and variance)
		Simpler to calculate
Disadvantages:	Mean and variance disproportionately affected by outliers	Less power (because they use less information)
	Affected by skewness	

CORRESPONDING TESTS

Parametric	Non-parametric
t-test, independent samples	Mann-Whitney (‘Rank Sum’) Median (less powerful than Mann-Whitney)
t –test, matched pairs	Wilcoxon for matched pairs Sign (less powerful than Wilcoxon)
ANOVA (one-way)	Kruskal-Wallis (generalization of Wilcoxon)
ANOVA (2-factor)	Friedman
Chi-square	Kolmogorov-Smirnov
Product-Moment Correlation	Spearman’s Rank Correlation

Appendix 3

One-tailed versus Two-tailed Tests

Synonyms: - one-sided vs. two-sided
- directional vs. non-directional

	One-tailed	**Two-tailed**
Definitions:	We are seeking to reject H_0 (the null hypothesis) in only one tail of a distribution .	We are seeking to reject H_0 in both tails.
Context in which applicable:	We have made a prediction concerning the *direction* of the effect under H_0.	We have made no prediction about the direction of the effect.
Typical criterion of significance:	5% at one end of the distribution constitutes the rejection region for H_0.	2.5% at each end

N.B. If you have looked up the significance of your result in a table of values for two-tailed tests but had in fact made a prediction, then you should divide by 2 the probability you find in the table.

General Bibliography

Textbooks of the kind listed below are usually updated every few years. If the reader finds there is an edition later than the one listed here, he or she is recommended to buy the latest version.

Greene, Judith and D'Oliveira, Manuela (1982). *Learning to Use Statistical Tests in Psychology*. Milton Keynes: Open University Press.

Hays, William L. (1994). *Statistics* (5th edition). Orlando, Florida: Harcourt Brace.

Hoel, Paul G. (1976). *Elementary Statistics* (4th edition). New York: Wiley.

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Norusis, Marija J. (1988). *SPSS-X Introductory Statistics Guide, for SPSS-X Release 3*. Chicago, Illinois: SPSS Inc.

Spiegel, Murray R. (1992). *Schaum's Outline of Theory and Problems of Statistics* (2nd edition). New York: McGraw-Hill.

Tabachnick, Barbara G. and Fidell, Linda S. (1983). *Using Multivariate Statistics*. London: Pearson Education Ltd.

Charles McCreery is a Research Director at Oxford Forum, an independent association of academics, set up to research and publish in currently neglected areas of psychology, theoretical physics, philosophy and economics.

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https://celiagreen.blogspot.co.uk/

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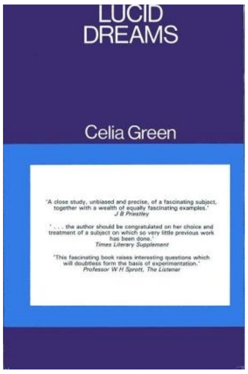
They are available from Amazon UK and Amazon USA.

Celia Green

Lucid Dreams

Foreword by Professor H.H. Price, FBA



The original pioneering study of lucid dreams: dreams in which the subject is aware that he or she is dreaming, and sometimes able to control the course of the dream.

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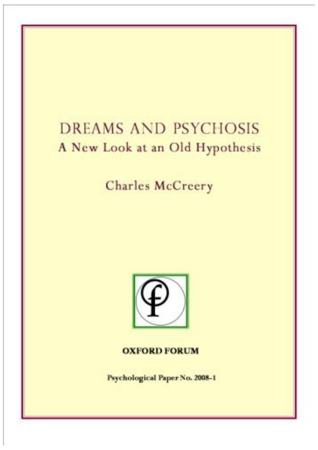
"[Lucid dream research] rests almost entirely on the meticulous descriptions and classifications of types and subtypes put forward by Green in her initial publications ... All of us 'second generation' researchers have found ourselves continuously in her debt."
Professor Harry Hunt, Brock University

Hamish Hamilton, reissued by Institute of Psychophysical Research

ISBN 978 09000760 08 (hardback)

Charles McCreery

Dreams and Psychosis
A new look at an old hypothesis



This paper proposes a theory of psychosis based on a link between sleep and hyperarousal. It is argued that the phenomenological similarities between psychosis and dreams arise from the fact that sleep can occur, not only in states of deafferentation and low arousal, but also in states of hyperarousal resulting from extreme stress.

It is proposed that both schizophrenic and manic-depressive patients are people who are prone to episodes of hyperarousal. Various sorts of electrophysiological evidence are adduced for this proposition, drawn from the fields of electroencephalography, studies of the galvanic skin response and studies of smooth pursuit eye movements. In addition, it is suggested that a key finding is the apparently paradoxical one that catatonic patients can be aroused from their seeming stupor by the administration of sedatives rather than stimulants.

It is proposed that a tendency to hyperarousal leaves certain individuals vulnerable to 'micro-sleeps' in everyday life, with the attendant phenomena of hallucination and other sorts of reality-distortion. Delusional thinking may follow as an attempt to rationalise these intrusions of dream-phenomena into daylight hours.

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Price £4.95; 34 pages
ISBN 978 09536772 83

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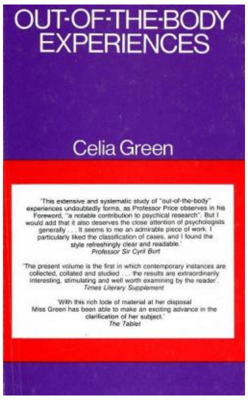
Out-of-the-Body Experiences

Foreword by Professor H.H. Price, FBA



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The Tablet

Hamish Hamilton,
reissued by Institute of Psychophysical Research

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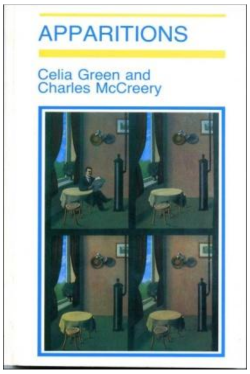
Apparitions



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The authors advance the hypothesis that some, or even all, apparitional experiences are 'metachoric', meaning the whole of the visual field is hallucinatory.

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"Enthralling"
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"A fascinating and thought-provoking book."
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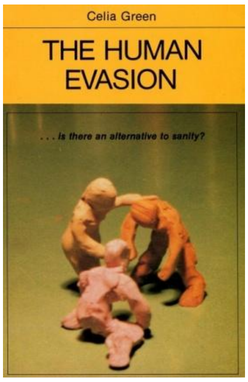
Foreword by R.H. Ward



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"Few books, long or short, are great ones; this book is short and among those few."
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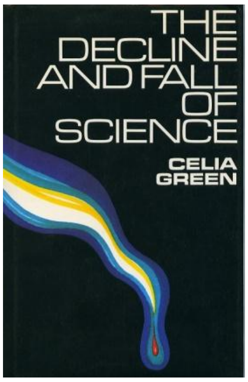
Celia Green

The Decline and Fall of Science



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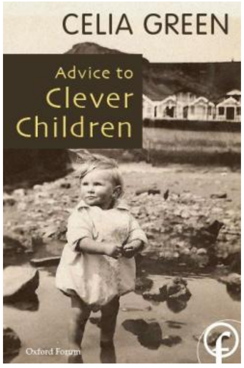

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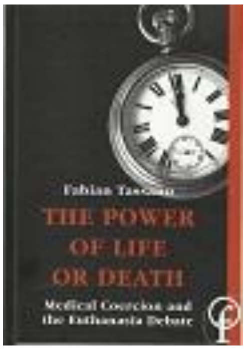

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Celia Green

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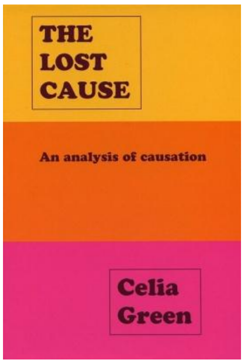
Foreword by Professor Howard Robinson



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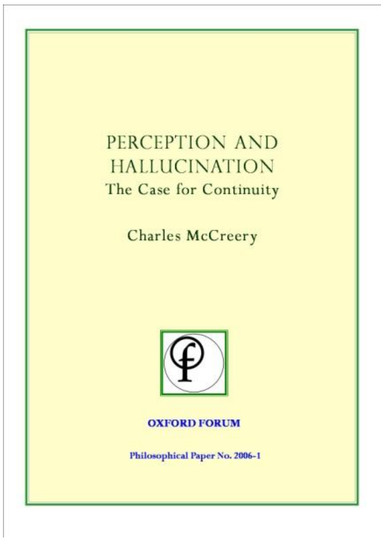

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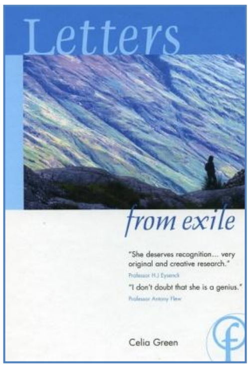

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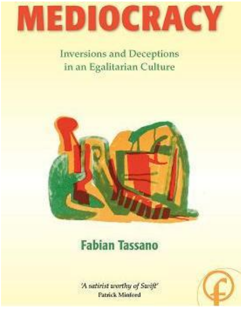

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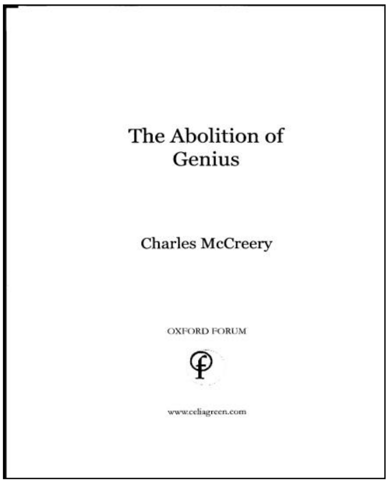

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