



FACULTY OF MEDICINE
SCHOOL OF MEDICAL SCIENCES
DEPARTMENT OF PHYSIOLOGY

NEUROPHYSIOLOGY

NEUR3221

SESSION 2, 2010

COURSE OUTLINE AND PRACTICAL CLASS MANUAL

CONTENTS

Page

Course staff	3
Course information	4
Assessment	7
Academic honesty and plagiarism.....	8
Resources for students	9
Continual course improvement.....	10
Administrative Information.....	10
Practical report guidelines	11
Presentation guidelines	12
In class assignments & online quizzes.....	13
Course schedule	14
Practical classes	
Tactile psychophysics.....	15
Sensory nerve recording	25
DIY practical.....	31
Kinaesthesia	35
Neuroscience (SOMS)	36
Sensory nerve conduction	40
Visual and Auditory psychophysics	44

COURSE STAFF

Course Coordinators

Course Coordinator A/Prof Paul Bertrand
room 301, third floor Wallace Wurth building
phone 9385 3947
e-mail Paul.Bertrand@unsw.edu.au

Course Examiner Dr Richard Vickery
room 308D, third floor Wallace Wurth building
phone 9385 1676
e-mail Richard.Vickery@unsw.edu.au

Consultations

A/Prof Bertrand is responsible for all academic and administrative matters regarding the course. Students should feel free to approach him with any questions or problem concerning the course either before or after scheduled class activities. Outside of these times, students are strongly encouraged to arrange an appointment in advance by email. In A/Prof Bertrand's absence, enquiries can be directed to Dr Vickery who is usually in on Monday, Wednesday and Friday.

Other information of an administrative nature may also be obtained from the School of Medical Sciences Office, Ground Floor, 'M' wing of the Wallace Wurth building.

Other Teaching Staff

Dr Ben Barry	ben.barry@unsw.edu.au
A/Prof Pascal Carrive	p.carrive@unsw.edu.au
Dr Gilles Guillemin	g.guillemin@cfi.unsw.edu.au
Prof Gary Housley	g.housley@unsw.edu.au
Dr Arun Krishnan	arun.krishnan@unsw.edu.au
Prof Margaret Morris	m.morris@unsw.edu.au
Prof Cyndi Shannon-Weickert	c.weickert@powmri.edu.au
Dr Janet Taylor	j.taylor@powmri.edu.au

COURSE INFORMATION

Course Structure and Teaching Strategies

Units of credit: This course is worth 6 units of credit.

Contact hours: The course structure is:

- Three x 1 hour lectures (or tutorials) per week.
- One x 3 hour practical classes (or tutorial/presentation sessions) per week.

Practical Class assignment:

Students are enrolled in a single practical class.

Class Times and Locations:

The course runs on Wednesday, Thursday and Friday.

Lectures run for 1 hour will be held at 11am on Tuesday and 9am on Wednesday in theatre LG02 (Wallace Wurth basement) and 3pm on Friday in theatre Mathews D.

Practical classes are run from 12-3pm on Wednesday in room M210 on the second floor of the Wallace Wurth building. Other venues for tutorials/presentations will be advised in class and on Blackboard.

Course schedule

The course timetable is included at the end of this section. Any updates to the timetable will be announced in lectures and on Blackboard.

Blackboard

This course will rely extensively on Blackboard for communication and resources. To access the course site, point your browser to:

lms-blackboard.telt.unsw.edu.au

At the left enter your UNSW User ID (z<student-number> and your zPass). After logging on to Blackboard, look for the course NEUR3221 on the right. You should have access to it if you are properly enrolled.

Via Blackboard you will be able to access lecture notes, posted shortly before each lecture, as well as iLecture recordings of the lecture (posted after the lecture; audio-only). Students are strongly encouraged to attend the lectures in person instead of relying on notes and recordings.

Blackboard forums are also available for students to discuss the course with each other and with the lecturers and tutors. In particular, specific forums allow lecturers to answer questions about the lecture material. There is also a forum in which students can provide completely anonymous feedback on the course while the course is being conducted. Please use the forum wisely - abusive or offensive posts will be removed and will result in the forum being shut down.

Requirements for Practical Classes

Practicals involving the use of animal specimens are a privilege, and must be treated with respect and professionalism. Students are expected to adhere to NH&MRC guidelines for ethics in animal studies (available at the course site, or via www.nhmrc.gov.au/publications/synopses/_files/ea16.pdf).

Students must take due care with biological and hazardous material and make sure all equipment is left clean and functional. Those unwilling to follow these basic laboratory rules will be marked absent. Enclosed shoes are compulsory in all practical classes. Punctual arrival is expected, and mobile phones must be switched off before entering the class. Practical classes involving your participation as a subject may require you to sign a witnessed, informed consent form.

Attendance Requirements

Attendance at practical classes and presentation sessions is compulsory. Satisfactory completion of the work set for each class is essential. It should be noted that non-attendance for other than documented medical or other serious reasons, or unsatisfactory performance, for more than 1 practical class during the session may result in an additional practical assessment exam or ineligibility to pass the course.

Medical Certificates

Students who miss practical classes due to illness or for other reasons must submit a copy of medical certificates or other acceptable documentation to the course co-ordinator in Room 319. **Certificates should be lodged no more than 7 days after an absence.** Certificates lodged after 7 days will not be accepted. The following details must be attached: Name, Subject number, Group number, Date of the class, Name of class missed.

Official Communication by Email

All students in the course NEUR3221 are advised that e-mail is now the official means by which the School of Medical Sciences at UNSW will communicate with you. All e-mail messages will be sent to your official UNSW e-mail address (e.g. z1234567@student.unsw.edu.au) and, if you do not wish to use the University e-mail system, you MUST arrange for your official mail to be forwarded to your chosen address. The University recommends that you check your mail at least every other day. Facilities for checking e-mail are available in the School of Medical Sciences and in the University library. Further information and assistance is available from the Service Counter on 9385 1777. Free e-mail courses are run by the UNSW Library (Level 2).

Approach to Learning and Teaching

The philosophy underpinning this course and its Teaching and Learning Strategies is based on "Guidelines on Learning that Inform Teaching at UNSW". These guidelines may be viewed at: www.guidelinesonlearning.unsw.edu.au. The teaching of neurophysiology covers both the physiology of neurons and brain function, and how these data were derived, as a full understanding of neurophysiology requires an appreciation of both what is known and of the limitations imposed by our study tools.

Lectures will provide you with the concepts and theory essential for understanding neurophysiology. The practical classes will assist you in the development of research and analytical skills. The practical classes are relatively small and not too tightly structured, so they allow you to engage in more interactive learning than is possible in lectures. The tutorials will be run by someone in addition to the lecturer on the topic, providing you with the opportunity to obtain another perspective on the material under review.

Although the primary source of information for this course is the material delivered in lectures and practical classes, effective learning can be enhanced through self directed use of other resources such as textbooks. Your practical classes will be directly related to the lectures and it is essential to prepare for practical classes before attendance. It is up to you to ensure you perform well in each part of the course; preparing for classes; completing assignments; studying for exams and seeking assistance to clarify your understanding.

Aims of the Course

To gain an understanding of the principles of neurophysiology by:

- using molecular, synaptic and cellular processes to explain brain function
- grasping the relationship between experimental techniques and the data they produce

Student Learning Outcomes

UNSW Learning outcomes:

UNSW aims to provide an environment that fosters students achievement of the following generic graduate attributes:

1. the skills involved in scholarly enquiry
2. an in-depth engagement with the relevant disciplinary knowledge in its interdisciplinary context
3. the capacity for analytical and critical thinking and for creative problem-solving
4. the ability to engage in independent and reflective learning
5. information literacy the skills to appropriately locate, evaluate and use relevant information
6. the capacity for enterprise, initiative and creativity
7. an appreciation of, and respect for, diversity
8. a capacity to contribute to, and work within, the international community
9. the skills required for collaborative and multidisciplinary work
10. an appreciation of, and a responsiveness to, change
11. a respect for ethical practice and social responsibility
12. the skills of effective communication

Not every course addresses all these attributes evenly. Neurophysiology is weighted most heavily towards attributes 1-4; attributes 5, 9 and 12 are also specifically addressed.

Specific Learning outcomes:

By the end of this course students are expected to have gained:

- a demonstrable knowledge of the scope of neurophysiology, and detailed knowledge in some areas including somatosensory system, vision, and synaptic plasticity.
- experience in applying basic physical and physiological principles to resolve questions related to brain and behaviour.
- experience and expertise in critically examining a research paper in the field of Neurophysiology and succinctly presenting their synopsis to an audience of peers.
- experience and expertise in critical enquiry by contributing to scientific discussion.
- by practical experience and critical review, an appreciation of the relationship between the experimental techniques that provide neurophysiological data, and the constraints on interpretation that the techniques impose.

ASSESSMENT

Assessment tasks

Online quizzes	5%
In-class assessments	10%
Mid-session exam (50 minute duration)	15%
Group presentation of a research paper	15%
Practical report	15%
Final exam (2 hour duration)	40%

Material pertaining to the practical classes will be examined in the mid-session and final exams.

The practical report will be submitted electronically as a .DOC or .PDF using Blackboard. In the folder "Extra Stuff" is a Turnitin submission box. Please see the "Practical report guidelines" on page 11 of this manual.

Missed In-Course Assessment

If you unavoidably miss an assessment task in Neurophysiology, you must inform the Course Co-ordinator immediately. You must supply adequate documentation (such as a medical certificate) to be considered for any supplementary assessment.

Missed Exams

If in any circumstances you unavoidably miss an examination, you must inform the Registrar and also contact the Course Co-ordinator immediately. Normally, if you miss an exam (without medical reasons) you will be given an absent fail. If you arrive late for an exam no time extension will be granted. It is your responsibility to check timetables and ensure that you arrive with sufficient time.

PLEASE NOTE that if you miss any examinations for medical reasons you must lodge a medical certificate with New South Q within **3 DAYS** (refer to UNSW Student Gateway @ www.student.unsw.edu.au for further details). Your request for consideration will be assessed and a deferred exam **MAY** be granted. You cannot assume you will be granted supplementary assessment. The deferred exam may include a significant oral element.

Special Consideration

If you believe that your performance in a course, either during session or in an examination, has been adversely affected by sickness or for any other reason, you should notify NewSouth Q and ask for special consideration in the determination of your results. Such requests should be made as soon as practicable after the problem occurs. **Applications made more than three days after an examination in a course will only be considered in exceptional circumstances.** Please refer to myUNSW for further details regarding special consideration.

ACADEMIC HONESTY AND PLAGIARISM

Students should be aware of UNSW's policy on academic and student misconduct: my.unsw.edu.au/student/academiclife/assessment/AcademicMisconductStudentMisconduct.html

Student assignments may be submitted to the Turnitin plagiarism detection engine. In addition students should be familiar with the following:

Plagiarism is the presentation of the thoughts or work of another as one's own. Examples include:*

- *direct duplication of the thoughts or work of another, including by copying work, or knowingly permitting it to be copied. This includes copying material, ideas or concepts from a book, article, report or other written document (whether published or unpublished), composition, artwork, design, drawing, circuitry, computer program or software, web site, Internet, other electronic resource, or another person's assignment without appropriate acknowledgement;*
- *paraphrasing another person's work with very minor changes keeping the meaning, form and/or progression of ideas of the original;*
- *piecing together sections of the work of others into a new whole;*
- *presenting an assessment item as independent work when it has been produced in whole or part in collusion with other people, for example, another student or a tutor; and,*
- *claiming credit for a proportion a work contributed to a group assessment item that is greater than that actually contributed.†*

Submitting an assessment item that has already been submitted for academic credit elsewhere may also be considered plagiarism. The inclusion of the thoughts or work of another with attribution appropriate to the academic discipline does not amount to plagiarism.

Students are reminded of their Rights and Responsibilities in respect of plagiarism, as set out in the University Undergraduate and Postgraduate Handbooks, and are encouraged to seek advice from academic staff whenever necessary to ensure they avoid plagiarism in all its forms.

The Learning Centre website is the central University online resource for staff and student information on plagiarism and academic honesty. It can be located at: www_lc.unsw.edu.au/plagiarism

The Learning Centre also provides substantial educational written materials, workshops, and tutorials to aid students, for example, in:

- *correct referencing practices*
- *paraphrasing, summarising, essay writing, and time management*
- *appropriate use of, and attribution for, a range of materials including text, images, formulae and concepts*

Individual assistance is available on request from The Learning Centre.

Students are also reminded that careful time management is an important part of study and one of the identified causes of plagiarism is poor time management. Students should allow sufficient time for research, drafting, and the proper referencing of sources in preparing all assessment items.

* Based on that proposed to the University of Newcastle by the St James Ethics Centre. Used with kind permission from the University of Newcastle

† Adapted with kind permission from the University of Melbourne.

Student Support Services

Those students who have a disability that requires some adjustment in their teaching or learning environment are encouraged to discuss their study needs with the course co-ordinator prior to, or at the commencement of, their course, or with the Equity Officer (Disability) in the EADU 9385 4734. Issues to be discussed may include access to materials, signers or note-takers, the provision of services and additional exam and assessment arrangements. Early notification is essential to enable any necessary adjustments to be made.

Student Rights and Responsibilities & Appeal Procedures

Refer to UNSW Student Gateway @ www.student.unsw.edu.au

Grievance Resolution Officer

In case you have any problems or grievance about the course, you should try to resolve it with the Course Organizer. If the grievance cannot be resolved in this way, you should contact the School of Medical Sciences Grievance Officer, Dr P. Pandey (9385 2483, P.Pandey@unsw.edu.au).

RESOURCES FOR STUDENTS

Textbook and Reading List

Textbook:

Neuroscience: Exploring the Brain. 3rd edition, 2006
Bear, Connors & Paradiso
Williams & Wilkins

Recommended reading:

Principles of Neural Science
Kandel, Schwartz & Jessell
McGraw-Hill

Medical Physiology, a cellular and molecular approach.
Boron & Boulpaep
Saunders

Neuroscience.
Purves, Augustine, Fitzpatrick et al.
Sinauer

The books are available from the UNSW Bookshop, and limited copies are held by the UNSW library.

CONTINUAL COURSE IMPROVEMENT

Feedback from students about this course is one of the main ways of ensuring the continual development and improvement of this course. We invite students to provide online anonymous course evaluation to academic staff via Blackboard throughout the session to enable immediate feedback. The end-of-session Course and Teaching Evaluation and Improvement [CATEI] process of UNSW is another way in which student feedback is evaluated, and we ask for your assistance in completing this survey at the appropriate time. Part of the CATEI process is to communicate significant changes to the course to subsequent cohorts of students.

Changes to the course for this year based on feedback from 2009 include:

- Many lectures now have a clearer set of learning objectives at the start so the student knows what they will get from the lecture.
- Additional references to the Bear et al. text book have been added to many lectures to provide better integration between lectures and textbook.
- More lectures now have a better review at end of the lecture to help the student understand the important points.
- Many lecture slides now contain more labels and other written information to explain and clarify the image content.

ADMINISTRATIVE INFORMATION

General Information

The Department of Physiology is part of the School of Medical Sciences and is within the Faculty of Medicine. It is located on the lower ground, 2nd and 3rd floors of the Wallace Wurth building. General enquiries can be made at the School of Medical Sciences Reception, located on the Ground Floor in the 'M' wing of the Wallace Wurth building (office hours are 9.00am - 5:00pm).

Professor Gary Housley is Head of Department and appointments may be made through his Administrative Assistant on 9385 2804.

There is are two honours programs available through the School of Medical Sciences. The School of Medical Sciences Honours program is coordinated by Dr Patsie Polly (ph: 9385 8765). In addition, the School of Medical Sciences and the School of Psychology jointly run the Neuroscience Honours program which is coordinated by Dr Richard Vickery (ph: 9385 1676). Any students considering an Honours year should discuss the requirements with the coordinator. Outstanding students may be considered for scholarships offered by the University and School and these are offered annually. Please see:

(medicalsciences.med.unsw.edu.au/somsweb.nsf/page/Honours%20Information%20for%20Students)

Postgraduate research degrees

The School of Medical Sciences offers students the opportunity to enter into a Doctorate (PhD) program in Physiology. For further information contact the Postgraduate Coordinator, A/Prof Pascal Carrive (p.carrive@unsw.edu.au). Please see:

(medicalsciences.med.unsw.edu.au/SOMSWeb.nsf/page/Postgraduate%20Research%20Current%20Students)

Departmental Vacation Scholarships: The Department of Physiology supports several summer vacation scholarships each year to enable good students to undertake short research projects within the department. For further details contact the Research Administrator, Marie Kwok (m.kwok@unsw.edu.au).

The School Student Adviser is able to provide additional information on any courses offered by the School. Please contact Carmen Robinson (9385 2464) or (carmen.robinson@unsw.edu.au).

Practical Report guidelines for Neurophysiology NEUR3221

Requirement: You must submit a practical report based on your third practical entitled "Do-it-yourself practical" that you took part in during the Neurophysiology course.

Contribution to assessment: The Practical Report will contribute **15%** to your final mark for the course.

Due date: The last day on which the prac report can be submitted is Monday 4th of October at midnight. Reports submitted after this time will lose 3% from the Practical Report grade per day (i.e., 0.45% of your final mark/day). Reports can be submitted any time before the deadline.

Where to lodge: Submit your prac report electronically as a .DOC, .DOCX or .PDF. Please don't worry if the generated PDF looks odd (e.g., tables misaligned), I can access the original document that you uploaded and I will use that to mark. In Blackboard, in the folder "Extra Stuff" is a Turnitin submission box. Ensure that your name and student number, number of words, as well as the Course and Convenor are clearly written on the cover page of your report. Contact A/Prof Bertrand (paul.bertrand@unsw.edu.au) if you have any problems submitting your assignment.

Word limit: **2500 words** (excluding tables, figures, figures legends and references).

Format: **Arial font, double-spaced with 2.5 cm margins and four sections: Introduction, Methods, Results, Discussion.** The Introduction should aim to provide the context and rationale for the experiment. Try and write the Methods in your own words, provide enough detail that someone could reproduce your experiment, and clearly describe any differences between your procedures and those in the Prac Manual. Results are usually best conveyed by figures or tables, and should indicate number of repetitions of each measurement. The Discussion should include an attempt to interpret the significance of your results, as well as suggestions for future experiments.

Marking: **Each of the four sections is worth 25% of the Practical Report grade.** We are looking for clarity of thinking (logical consistency, thoroughness, etc) and clarity of expression (clear sequencing, and presentation of information). The data that you obtained in the practical class are important in terms of how you present them, and how they are discussed; this means that "wrong" results you may have obtained are perfectly acceptable provided you present them clearly, and discuss what may have led to these results.

Presentation guidelines for Neurophysiology NEUR3221

Requirement: You must prepare a group presentation on a research paper. The maximum number of people per group is **three**. The set of research papers that you may choose from will go up on Blackboard on Wednesday the 1st of September. You will indicate your choice of paper and up to two partners in a dedicated forum on Blackboard. First come first served: each paper may only be presented by only **one group**.

Aims of the exercise: To help you develop and demonstrate expertise in critically examining research papers in neurophysiology and succinctly presenting synopses to an audience of your peers.

Contribution to assessment: The seminar will contribute 10% to your final mark for the course. All partners in the presentation will receive the same mark. Your group will also be expected to lead the questioning of another group's presentation (assigned by the course coordinator in advance) and you will receive 5% of your mark for how well you promote discussion and ask insightful questions. Together, these exercises contribute **15%** to your final mark.

Due date: The seminars will be delivered during the scheduled prac times in the last week of session. You will be allocated to a time slot in week 12, on Thursday the 14th of October. All students in the course are required to attend the whole session of presentations or marks will be deducted. Attendance will be taken at the beginning and end of the session.

Format: You will work in groups of two to three. The presentation will have you speak for 10 minutes, followed by 5 minutes of questions. Practice your timing beforehand as you will be marked down if your group goes overtime. You are free to decide how the presentation will be managed: you may all speak, or choose one member to speak. Keep in mind that it is easier to assess the group if everyone demonstrates their knowledge at some point. Questions are expected to come from your fellow students, initially from the group assigned to discuss your paper, but assessors (A/Prof Bertrand, Dr Vickery and others) may also ask you questions.

Media: There will be facilities for data projection (PowerPoint from USB flash drive or CD-ROM), overhead projection, and a black or white board.

What to present: You should present the essence of the research paper you have chosen. This will probably mean that you will need to cover Introduction, Methods, Results, Discussion. There is **not** a requirement that you explicitly cover all parts of the paper, or every figure in the paper. Your Introduction should aim to provide the rationale for the work, and may require you to read some additional papers as background to help you understand the context of the research you are presenting. The Methods do not need to be presented in detail - just convey enough to let the audience have a sense of the approach; more detailed questions can be asked and answered in question time. In discussing the paper, you may draw on the issues raised in the paper's discussion plus your own thoughts. A critical examination does not mean that you need to find fault with the paper, it means that you must be able to understand and convey the significance and reliability of the findings.

Marking: You will be marked by 3 or 4 assessors. We are mainly interested in how well you were able to **convey the essential message** of the paper. The skill here is to be able to ignore or summarise the non-essential material, giving the audience time to understand the key message/s. We are also looking for clarity of thinking (logical consistency, assessment of the validity/reliability of the technique) and clarity of expression (clear sequencing, legible visual aids, simple slow spoken presentation). We will provide a mark and feedback through Blackboard.

In-class assignment for Neurophysiology NEUR3221

Requirement: You must write a "long answer" style question of no more than 2 pages for the question given. These assignments are open book and will be completed during normal class hours in weeks 4 and 10.

Aims of the exercise: To help you draw together topics from several lectures. To help prepare you for the Exams.

Contribution to assessment: These assignments will contribute **10%** to your final mark for the course (5% each).

Dates: The in-class assignments will be given during the scheduled lecture times in weeks 4 and 10. Assignments must be completed on Friday 13/8 and 1/10. Only **25 minutes** will be given to complete the in-class assignment.

Format: You will work in alone in class at your desk. You may use any printed materials you bring to class. No computers, phones or online access will be allowed.

What to present: You should answer the question using information given in lecture or from your textbook.

Marking: You will be marked on the content of your answer. Although neatness and legibility are helpful, you will not be marked on your general written language skills. We are interested in how well you can tie together topics from different lectures.

Online quizzes for Neurophysiology NEUR3221

Requirement: You must complete two multiple choice quizzes online. The quizzes will go up on Blackboard on the Monday of week 5 and week 9. You must complete these quizzes by the due date to receive credit.

Aims of the exercise: To help you think about the lecture material in the context of assessment prior to the Exams.

Contribution to assessment: The quizzes will contribute **5%** to your final mark for the course (2.5% each).

Due dates: The quizzes will be due one week after going up on Blackboard. Details will be given online.

Format: The quizzes will be given online and will consist of 5 - 10 multiple choice questions. At the end of the quiz, you will be given feedback on why you were right or wrong. If you did not score 100% correct, then you will then be prompted to try again.

Marking: You will receive the full 5% if you correctly complete all questions on both quizzes. You will not receive any credit if you do not correctly complete the quiz. **You may attempt the quiz as many times as you like in order to achieve a perfect score of 100% correct.**

Neurophysiology NEUR3221 - Timetable 2010

Wk	WEDNESDAY (11 am) Lecture - LG02 WW	THURSDAY (9 am) Lecture - LG02 WW	THURSDAY (12-3 pm) (PRAC or Seminar) - M210 WW	FRIDAY (3 pm) Lecture - Mat D
1	21/7. Welcome (1) BERTRAND and VICKERY	22/7. Neuroscience Methods (2) BERTRAND and VICKERY	22/7. NO PRAC	23/7. Somatosensory: Central (3) VICKERY
2	28/7. Somatosensory: Peripheral (4) VICKERY	29/7. NO CLASS	29/7. PRAC-1 - Tactile psychophysics BERTRAND	30/7. Neurotransmission (5) BERTRAND
3	4/8. Visceral Control (6) BERTRAND	5/8. Pain (7) BERTRAND	5/8. PRAC-2 - Sensory nerve recording combined BERTRAND VICKERY	6/8. Memory (8) BERTRAND
4	11/8. Plasticity (9) BERTRAND	12/8. Taste and smell (10) BERTRAND	12/8. TUTORIAL 1 (Lectures/Pracs 21/7 - 11/8)	13/8. In-class assignment-1 (Lectures/Pracs 21/7 - 11/8. PB)
5 Quiz 1 up	18/8. NO CLASS	19/8. Developing an experiment (11) BERTRAND and VICKERY	19/8. Write your own prac with first 2 setups available BERTRAND VICKERY	20/8. Motor Systems: Neural connections (12) BARRY
6	25/8. Kinaesthesia (13) TAYLOR	26/8. Kinaesthesia (14) TAYLOR	26/8. PRAC-4 - Kinaesthesia TAYLOR	27/8. NO CLASS
7 Papers up	1/9. Glia & Neuro-immunology (15) GUILLEMIN	2/9. NO CLASS	2/9. TUTORIAL 2 (Lectures/Pracs 7/8 - 25/8)	3/9. Mid-session EXAM (Lectures/Pracs 21/7 - 26/8)
-	4th - 12th Sept *	M i d - s e s s i o n	B r e a k	
8	15/9. CNS development (16) SHANNON-WEICKERT	16/9. Neurobiology of mental illness (17) SHANNON-WEICKERT	16/9. VISIT SOMS	17/9. TUTORIAL 3 (MS exam feedback)
9 Quiz 2 up	22/9. Auditory: Central & Binaural (18) HOUSLEY	23/9. Auditory: Cochlear & Hair cells (19) HOUSLEY	23/9. PRAC-5 - Sensory nerve conduction	24/9. Axonal function (20) KRISHNAN
10	29/9. Vision: Central (21) VICKERY	30/9. Vision: Binocular (22) VICKERY	30/9. PRAC-6 - Visual & auditory psychophysics VICKERY	1/10. In-class assignment-2 (Lectures 1/9 - 24/9) PB
11 PRAC REPORT DUE	6/10. Neural control of blood pressure (23) CARRIVE	7/10. Neural control of food intake (24) MORRIS	7/10. Practice seminars - BOOKINGS REQUIRED	8/10. Brain Stimulation 1 (25) BERTRAND
12	13/10. Brain Stimulation 2 (26) VICKERY	14/10. Sleep and Speech (27) VICKERY	14/10. Student seminar-1: BERTRAND and VICKERY	15/10. NO CLASS
13	20/10. NO CLASS	21/10. NO CLASS	21/10. TUTORIAL 4 (Lectures/Pracs 15 - 26)	22/10. NO CLASS

PSYCHOPHYSICS OF TACTILE SENSATION

Introduction

Psychophysics is that area of perceptual psychology dealing with the relationships between sensation and the physical stimuli responsible for the sensation. This discipline had its origins in the 19th century work of Fechner and earlier, Weber, two German psychophysicists who sought to measure sensations and relate those measures to the corresponding physical stimuli.

In sensory physiology one of the aims is to account for subjective sensory capacities, as revealed by psychophysical studies, in terms of the features of neural responses. Thus, the neurophysiologist attempts to correlate stimulus values with differences in neural responses while the psychophysicist tries to correlate stimulus values with sensation magnitude. One of the difficulties for the neurophysiologist is in deciding which neural response is the appropriate one to measure. This can usually only be done by measuring neural activity in a number of ways while the particular stimulus is varied. In this way it may be possible to discover which scale or measure of neural activity provides a relationship with the stimulus variations that matches the relation between the same stimulus variations and psychophysical measures of sensation. Once one finds a functional relation between the neural responses and the stimulus variations of the same form as that relating stimulus to sensation then the neural response may qualify as the neural code for the stimulus attribute under study.

Aspects of psychophysics

Psychophysical studies are normally concerned with one of four aspects of sensory performance:

- (i) Detection
- (ii) Recognition
- (iii) Discrimination
- (iv) Scaling or ranking

Sensory detection

The detection problem deals with the minimum amount of energy necessary for the subject to say that the stimulus is present. Although it was originally thought that this threshold should have a fixed value, it is now known to vary from trial to trial. These variations may be associated with changes in attention, fatigue or other factors. Thus, the neural signals generated by stimuli are presumably superimposed on a background of 'noise' generated by the nervous system. Only when they emerge sufficiently from that noise will they generate a subjective response.

Assessment of detection thresholds

Two ways of assessing threshold are by

- (i) the method of Limits
- (ii) the method of Constant Stimuli

With the method of Limits the stimulus is initially set to a strength which is very faint and undetectable and is gradually increased until the subject says 'I detect it'. On alternate trials the experimenter starts with the stimulus at a high, obviously perceptible level and progressively reduces its intensity until the subject says 'I no longer detect it'. The mean level can then be obtained as the threshold for detection.

The second method relies on a series of fixed stimulus intensities being delivered, usually in random order, and a graph plotted of the proportion detected at each intensity. The Detection Threshold is then usually taken as the value where the probability of detection is 0.5.

Signal detection theory

Because stimuli are at low intensities in detection studies the subject may be uncertain about whether a stimulus has occurred. Different subjects, or even the one subject at different times may react differently in these cases of uncertainty. For example, the subject may indicate that the stimulus was present whenever he/she was uncertain, or at the other extreme may indicate that none was present whenever he/she was uncertain. Thus, the subject's decision-making behaviour will influence the assessment of threshold. This *uncertainty* is the decision process and the variability in the subject's choice of *decision criterion* are recognized in that aspect of psychophysics known as *signal detection theory*.

The uncertainty about the presence of the stimulus is presumably related to moment-to-moment variations in 'noise' level within the sensory system, which may be considered to have a certain *probability distribution* ('signal absent' in Fig. 1). When the stimulus is present it will create a new distribution ('signal present' in Fig. 1) which is a level of activity representing an addition of 'noise' and stimulus-evoked 'signals'. As the two distributions may overlap (Fig. 1) it is clear that there must be some uncertainty about the presence of the stimulus.

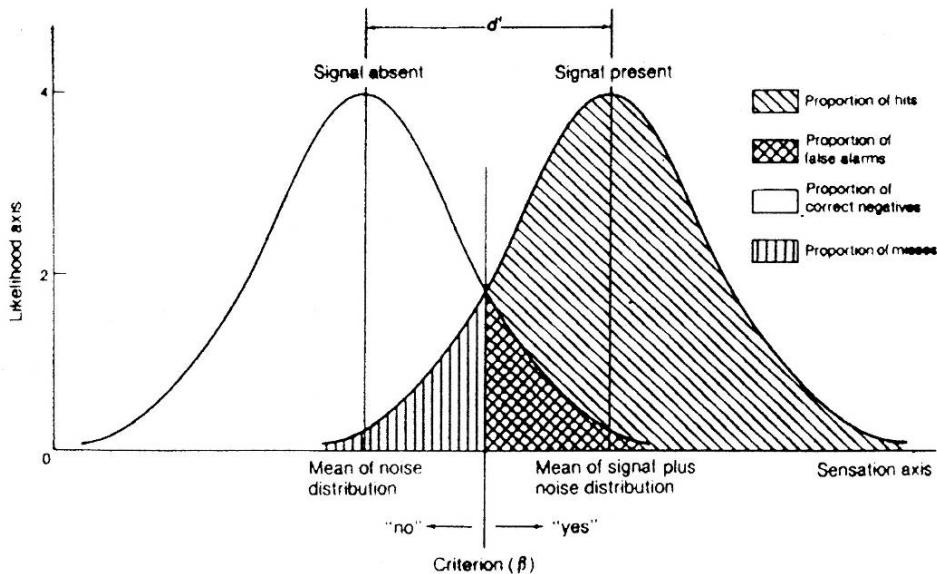


Fig. 1 (from *Sensation and Perception*, Coren et al., 1978, Academic Press)

The subject's *criterion level* (b) determines the proportion of signal-present trials for which the subject gives a correct positive response, represented by the proportion of the 'signal present' distribution that exceeds the criterion level, b . Similarly, the proportion of false alarms is given by how much of the 'signal absent' distribution is over the criterion level.

The subject's placement of the criterion level will be influenced by the context of the detection task and the subject's motivation and expectation. For example a radiologist trying to decide whether an X-ray film shows signs of a tumour should set the criterion low, since this means all cases with a tumour would be investigated. A number of false alarms would arise, but this would be preferable to setting the criterion level too high and missing some actual tumours. The effect of a 'lax' or 'strict' criterion is shown by the distributions of Fig. 2.

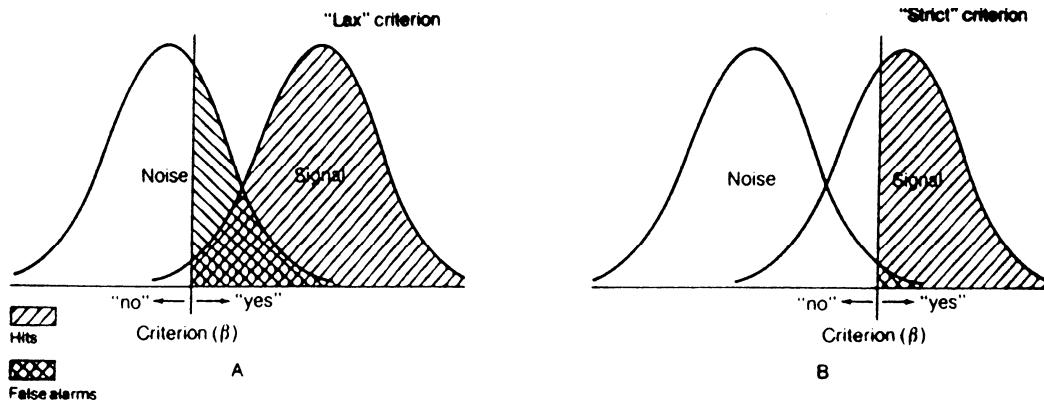


Fig. 2 (from *Sensation and Perception*, Coren et al., 1978, Academic Press)

Recognition of sensory stimuli

Apart from the problem of detecting a stimulus, one of the major tasks for the sensory system is that of *recognition* of the stimulus. This differs from the discrimination task considered below in that the recognition problem involves identification of a particular stimulus from a range of possible stimuli presented whereas in a discrimination task (see below) the subject has to judge whether one stimulus, a *comparison stimulus*, is different from or the same as the *reference stimulus*. The recognition or identification problem is concerned with how many different stimuli within a continuum (for example, recognition of pitch or loudness or brightness) the subject can reliably identify. For any one sensory continuum this turns out to be rather small, usually a set of only about 7 stimuli within the range can be perfectly recognized.

The discrimination task

In a discrimination task the subject is presented with paired stimuli, the first being the *reference stimulus*, the second being the *comparison stimulus*. These differ normally in a single stimulus dimension (for example loudness; brightness; frequency of vibration on the skin). In a *same-different design* the subject is required to decide whether the comparison stimulus is different from or the same as the reference. An alternate experimental design called a *two-alternative forced choice* uses paired stimuli, but the subject is required to say whether the comparison stimulus is greater or less than the reference stimulus. If the comparison stimulus can take a series of values and is presented repeatedly at each of these values the experimenter can then record the proportion of deliveries on which the subject called the comparison stimulus 'different' or 'greater' for each of its different values. A graph can be constructed plotting this proportion (ordinate) against the value (abscissa) of the comparison stimulus. From the resulting curve, often known as a *psychometric function curve*, a quantitative measure of the subject's discriminative ability may be derived. For a same-different design the value of the comparison stimulus that is called 'different' 50% of the time represents the *just noticeable difference*, or JND for the subject for that reference stimulus. In a two-alternative forced choice (2AFC) design, the 50% ordinate value represents chance performance, and the value of the comparison stimulus that results in 75% of responses being called 'greater' is known as the *difference limen*. If the 50% value in a 2AFC experiment occurs at a value where reference stimulus \neq comparison stimulus, the subject exhibits *bias*. Bias need not be deliberate, but represents an inherent tendency of the system or subject towards a particular response, and may be related to the time interval between presenting the reference and comparison stimuli. Subjects in a same-different experiment may also exhibit bias, by using lax or strict criteria for calling 'same' or 'different' for cases where they are unsure.

The stimulus increment needed for discrimination is not a fixed value for different values of the reference stimulus, but rather, as the reference stimulus increases, the JND and difference limen also increase. This relation between the size of the JND and the size of the reference stimulus is called *Weber's Law*, given by:

$$\Delta S = KS$$

where ΔS is the size of the JND
 S is the value of the reference stimulus
 K is a constant, therefore: $K = \Delta S / S$

where $(\Delta S / S)$ is known as the *Weber fraction*. Weber's Law indicates that the increment in the stimulus (ΔS or the JND) needed for discrimination is a function of the reference stimulus intensity. Thus, with a low intensity reference stimulus, a small increment is needed for discrimination; with a more intense stimulus a bigger increment is needed.

Although Weber's Law indicates that the Weber fraction is independent of the stimulus strength this is not true for all sensory continua. One case in which a departure is seen from Weber's Law is for the discrimination of vibration frequency on the skin. For this sensory continuum the capacity for discrimination falls off steeply at higher vibration frequency, so that a plot of the *Weber fraction* $\Delta f/f$, (where f represents the reference vibration frequency and Δf the frequency increment needed for discrimination) against f , the reference frequency, is not a horizontal line as predicted by Weber's Law, but increases at higher values of f . However, for a weight discrimination task, there is a closer adherence to Weber's Law.

Scaling or ranking in psychophysics

In studies of sensation the issue of *scaling* arises where the subject is judging how intense the stimulus is. This problem obviously applies only to those aspects of sensation which vary in intensity or magnitude, such as brightness, weight, pressure, or loudness, but not for sensory continua where changes in the physical stimulus lead to changes in quality rather than quantity, such as colour. A sensory continuum which can change in quantity is known as a *prosthetic continuum*, e.g. changes in pressure or indentation on the skin. A sensory continuum which varies qualitatively, such as the *location* of a skin stimulus, is a *metathetic continuum*.

One of the ways of scaling stimuli along a sensory continuum is by allocating the stimuli to a number of different categories, for example 1 to 8, and plotting the relation between the average category allocation on the ordinate against the actual stimulus intensity on the abscissa. The form of the relation obtained in this type of plot will vary somewhat from one sensory continuum to another but, as demonstrated by Stevens' work the relation is usually described by a *power function* or *power law* relation given by:

$$R = K S^n$$

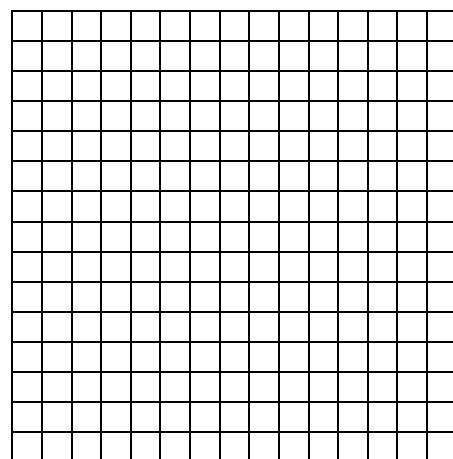
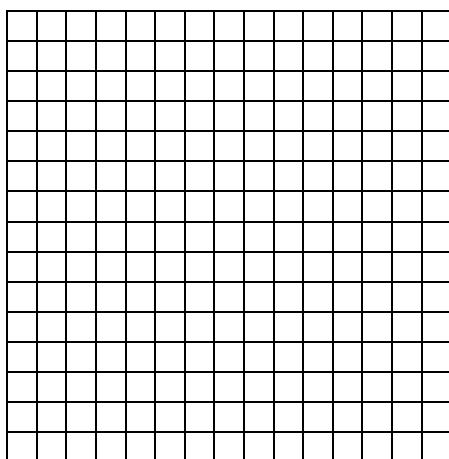
where R represents the subject's scaling estimate, S represents the intensity of the stimulus, K a constant; n is the value of the exponent, which will vary for different sensory continua.

EXERCISE 1: TEXTURE DISCRIMINATION

Design an experiment to test the ability of the subject to discriminate different grades of sandpaper. Factors you might consider in your study include:

- 1) static discrimination (press the finger tip onto the sandpaper) compared with discrimination with movement permitted;
- 2) active versus passive movement (subject moves finger or experimenter moves sandpaper);
- 3) the role of contact force;
- 4) whether a barrier such as a glove or a sheet of paper enhances discrimination.

Protocol:



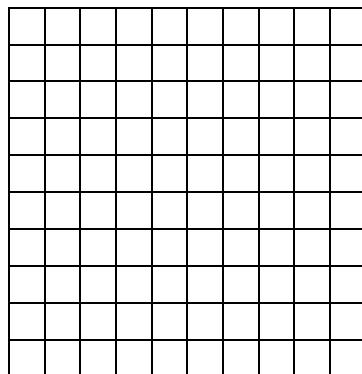
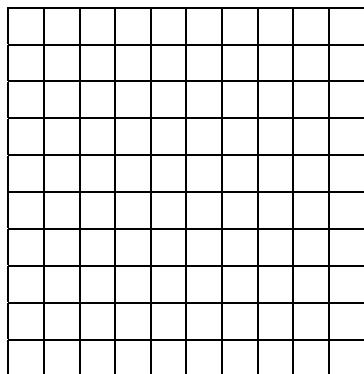
EXERCISE 2: CUTANEOUS SENSIBILITY FOR THERMAL STIMULI

Closely clip the hairs from the back of a subject's hand over an area just bigger than the rubber stamp with the grid pattern used to outline the area of study. The thermal probes are brass rods kept in water of a preset temperature before the tip is placed briefly in contact with the skin.

Design an experiment to test whether:

- 1) there are non-uniformly distributed, thermal receptors in the skin
- 2) there are separate hot and cold receptors in the skin.

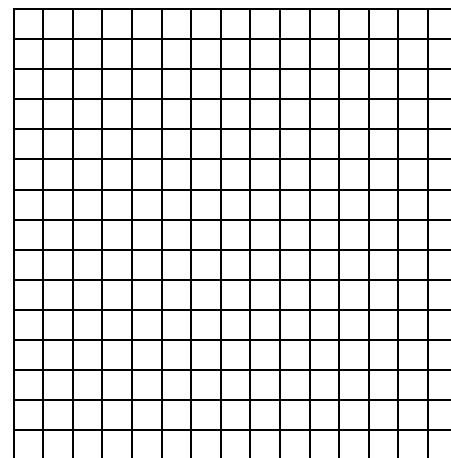
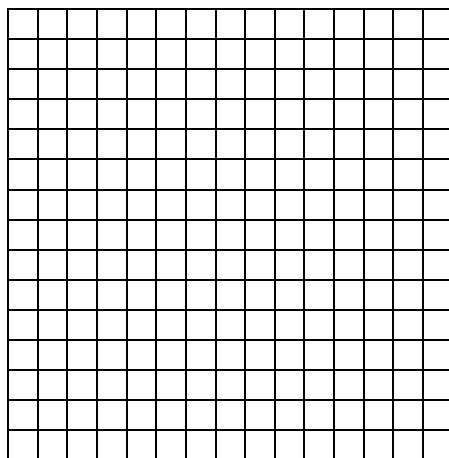
Protocol:



EXERCISE 3: WEIGHT DISCRIMINATION

Design an experiment to test the ability of a subject to discriminate weights held in the hand (small jars with a range of weights are used as the test material). Be careful to specify whether proprio-receptors are intended to contribute to your subject's judgment, and how you will control for this.

Protocol:

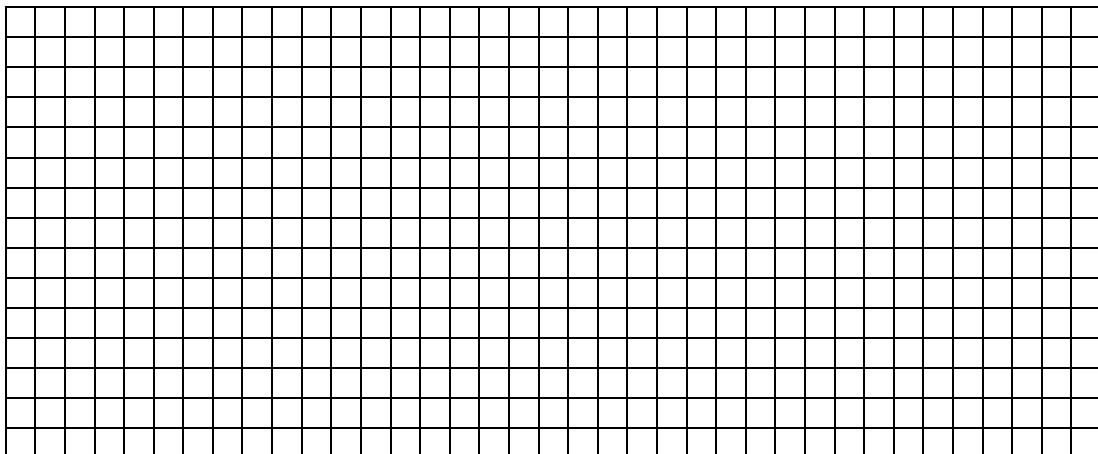


EXERCISE 4: SCALING/RANKING STIMULI ALONG A SENSORY CONTINUUM

Steady indenting stimuli to the skin will be delivered with a graded series of eight von Frey hairs.

Design an experiment to test the subject's magnitude estimation for different intensities of skin indentation.

Protocol:



EXERCISE 5: REGIONAL DIFFERENCES IN TACTILE SPATIAL RESOLUTION: TESTS OF TWO- POINT DISCRIMINATION

Design an experiment to determine the two point discrimination limit at various body sites. The 'two-point' limit measured in mm should plotted as a vertical line on Fig. 3 below.

Protocol:

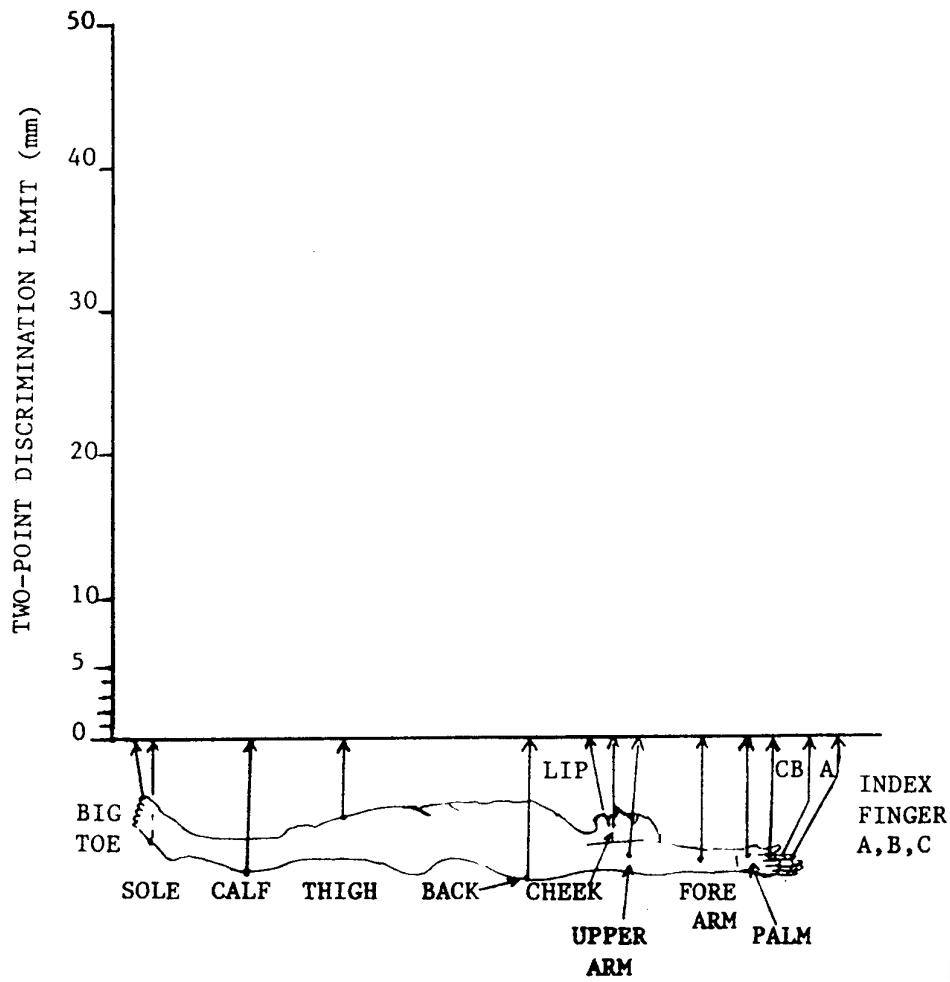


Fig. 3

Neural code underlying the perceptual response

For two of the experiments you have conducted, describe

- 1) the form of the stimulus - response relation?
- 2) the probable neural mechanisms for coding information about the tactile stimulus.

SENSORY NERVE RECORDING

In this experiment you will be recording single action potentials from sensory axons. You will be able to demonstrate the exquisite sensitivity of the tactile system and study how tactile information is coded. The preparation is the cockroach leg, and you will record from joint afferents and from afferents associated with the spines on the cockroach leg.

Equipment

- Computer, PowerLab with BioAmp cable and headphones, 2 leads for grounding
- Retort stand with 2 micromanipulators providing 2 axes of positional control
- Recording electrodes embedded in a rubber stopper, clamped in the arm of the retort stand
- Speaker cone stimulator
- Dissecting microscope with light
- Fine forceps and scissors to dissect cockroach and position leg on recording pins
- Mechanical probe (insect pin), thermal probe (soldering iron shared between groups)
- Pasteur pipettes, 2% sugar solution, 2% salt solution

Set up

The cockroaches will be anaesthetised by cooling them and keeping them in a CO₂ atmosphere for 15 minutes.

Each group will be given a cockroach and you will carefully cut off one of the back legs as close to the abdomen as possible. Then return the cockroach to its storage cage.

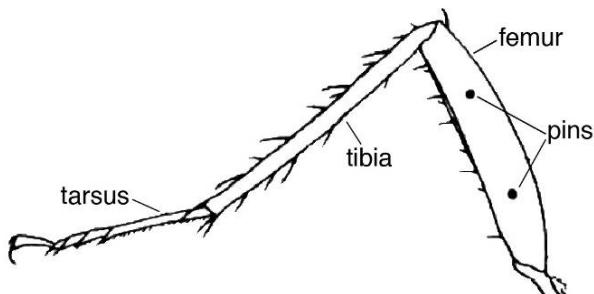


Fig 1 adapted from: *Advan Physiol Educ*, 1992; 262: 18 - 22.

The isolated leg needs to be impaled on the pins as shown in Figure 1. The pins function as extracellular recording electrodes and are connected to the BioAmp, which is a differential input amplifier in the PowerLab. The pins should go right through the leg and should suspend it above the cork. Use the fine forceps to hold the leg while you push it through the pins.

Turn on the PowerLab (switch is on the rear). Then switch on your computer. Under the "Start" button choose the option called "Class Menu". From the Class Menu choose "Data Acquisition", and then choose PowerLab-> Chart Settings -> Sensory nerve. This opens the PowerLab module "Chart" with appropriate parameter settings.

Plug the headphones into the jack on the rear of the PowerLab. Choose "Start" on the PowerLab and you should begin to see and hear your recorded trace, possibly with some clear spontaneous action potentials.

Watch and listen

Electrophysiologists consider it desirable to both hear the amplified signal from a recording electrode, and to see a trace on a screen. Your ears will often discern signals which are not easily picked up on the screen, whereas the visual appearance of action potentials can be used to tell the activity of different cells or fibres apart, even when the APs sound more or less the same.

For each of the following experiments, make sure you listen to the activity through headphones as well as observing the PowerLab traces.

EXPERIMENT 1: AFFERENT FIBRE TYPES

Objective: To characterise the classes of afferent fibres in the cockroach leg

Test the leg for tactile, joint, thermal and chemical receptors.

Run Chart and while watching and listening to the neural response try the following types of stimulation.

- Use an insect pin to carefully move single spines and look for an increase in activity.
- Bend the joint, trying to avoid activating spines if possible.
- Let the soldering iron heat up, then disconnect it and bring it close to the leg to try and activate warm receptors.
- Many insects have sensory hairs or sensillae, some of which have a pore at the top and contain chemosensors. Use the Pasteur pipettes to apply a drop of solution to the leg while trying to avoid tactile activation and determine if there is any change in activity.

How many classes of sensory receptor were you able to confirm?

EXPERIMENT 2: ACTION POTENTIALS OF SENSORY AXONS

Objective: To characterise single axon responses in the cockroach leg, and explain the basis for the shape and size of the recorded action potentials.

Find two spines some distance apart along the leg that each give a good response. Capture a segment of the response to activation of each spine, and then stop Chart.

How big (in mV) are the action potentials in each response?

Are the shapes of the action potentials from one spine all the same?

Are the shapes of the action potentials from the two spines the same?

Explain the size of the action potential (given that each action potential represents a shift in axon membrane potential from about -70 mV to about $+20$ mV) and the differences in shape.

Do any other parameters, such as the maximum action potential rate, differ between the responses recorded from the two spines?

What evidence do you have to support the idea that the action potentials you record when you stimulate a single spine originate from a single axon?

EXPERIMENT 3: DIRECTIONAL CODING

Objective: To use qualitative mechanical stimulation to study the neural coding of tactile information about direction of hair displacement.

Find a spine that gives a good response. Test the response to moving the spine in different directions.

Is the response to an equal sized movement of the spine about the same in each direction of displacement?

If the response differs depending on direction, can you compensate in the weakly stimulating direction by giving a bigger deflection?

EXPERIMENT 4: CONDUCTION VELOCITY

Objective: To determine conduction velocity of cockroach spine sensory afferent fibres.

You have been provided with a mechanical stimulator that uses a speaker cone plugged into the stimulus output of the PowerLab. We will use this to make controlled deflections of a single spine where we can precisely control the timing and size of the stimulus. Close Chart. Under the "Start" button choose the option called "Class Menu". From the Class Menu choose "Data Acquisition", and then choose PowerLab-> **Scope** Settings -> Sensory nerve. This opens the PowerLab module "Scope" with appropriate parameter settings.

Go to the menu options "Set-up -> Stimulator" and familiarise yourself with the stimulus options. Initially you will deliver a single pulse of variable duration and amplitude. Later you will also deliver trains of stimuli.

Use the manipulators holding your cockroach leg to bring a single spine into close contact with the bent pin tip on the stimulator. If you like, you can use a bit of wax or superglue to ensure good contact between the spine and the pin.

Set up a brief, strong (5V) stimulus pulse (1ms) at a latency of 1ms.

Measure the latency of the earliest action potential in response to the stimulus. The latency is taken from the start of the stimulus to the start of the recorded action potential. *Also measure the distance from the spine to the first of your recording pins.*

Using the formula speed = distance / time work out the conduction velocity for your afferent. Remember to express measurements as metres and seconds.

Is the actual conduction velocity likely to be slower or faster than your calculated value? Why?

EXPERIMENT 5: NEURAL CODING

Objective: To use quantitative mechanical stimulation to study the neural coding of tactile information by cockroach spine receptors.

Determine a stimulus response relation by comparing the effectiveness of different stimulus amplitudes in eliciting spikes

stimulus voltage (V)	number of spikes elicited
2	
4	
6	
8	
10	

If all the stimulus voltages elicited a spike, continue decreasing the stimulus until you reach threshold.

What is happening at the receptor when the stimulus is just below threshold?

If you have glued the spine to the pin tip, or if you can slip the tip behind the spine, measure the response of the spine to deflections of the stimulator in the opposite direction.

stimulus voltage (V)	number of spikes elicited
-2	
-4	
-6	
-8	
-10	

Plot your stimulus-response curve on the graph paper at the end of these practical notes.

EXPERIMENT 6: ADAPTATION OF SENSORY SIGNALS

Objective: To use quantitative mechanical stimulation to study adaptation of sensory signals.

Use a stimulus amplitude that elicited several spikes in experiment 5, and vary the stimulus duration to study adaption.

stimulus duration (ms)	number of spikes elicited
1	
10	
50	
100	
500	

Is there a fixed rate of firing of the afferent (i.e. is the number of spikes in 100ms equal to 10 x the number in 10ms)? If not, why not?

Does the rate of firing change throughout the 500ms stimulus?

(Plot the number of spikes in 20 ms bins on the graph paper at the end of these notes.)

How long do you need to stimulate the spine before the afferent ceases to fire?

What is the peak rate of firing you observed? What does this indicate about the refractory period?

Test the effect of using 1ms pulses at 10V to regulate firing – first give a train of 5 impulses at 10 Hz.

How many spikes does each pulse generate?

Now try a train of 20 impulses at 100 Hz.

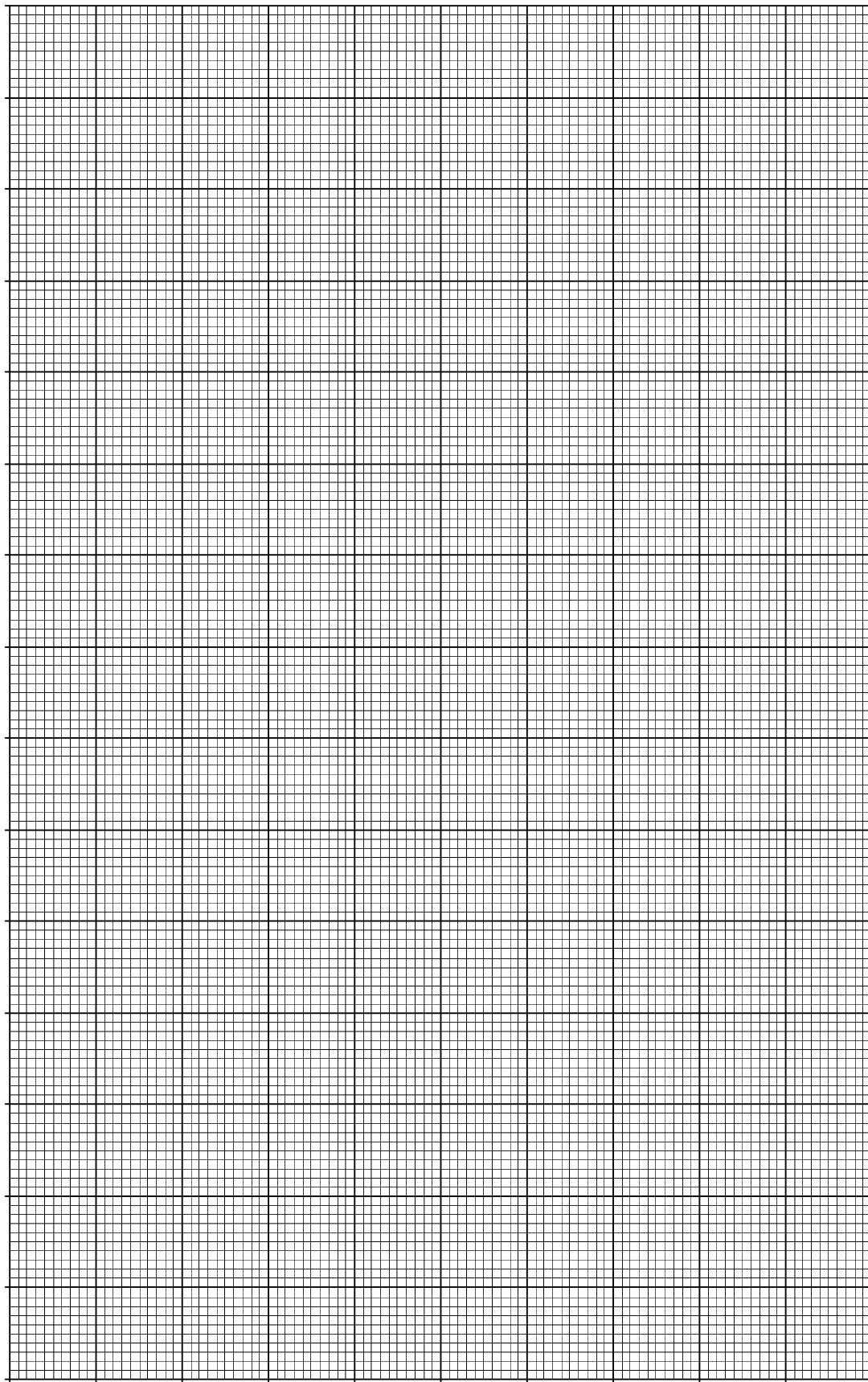
How many spikes does each pulse generate? How does the spike pattern differ from that caused by a steady deflection?

Now try a train of 20 impulses at 500 Hz.

How many spikes does each pulse generate? What is the peak firing rate achieved here?

Repeat the adaptation experiment on a different spine.

Does its rate of adaptation differ from the first spine you tested?



DO-IT-YOURSELF PRACTICAL

The rules for this practical class will be available on Blackboard prior to the scheduled time.

KINAESTHESIA

Proprioception in alignment of elbow joints

This class has been approved by the Committee on Experimental Procedures involving Human Subjects (CEPHIS), and has Project No:99066. STUDENTS ACTING AS SUBJECTS ARE REQUIRED TO SIGN CONSENT FORMS.

TESTS OF PROPRIOCEPTION

The apparatus for this simple test is a perspex screen marked out in degrees. The screen is placed vertically on a table between the subjects elbows. The subject rests his/her elbows on the table top and extends the forearms forward to rest on the table top also. The wrists are kept stiff, and the fingers closed into a loose fist except for the index fingers which point towards the mid-line.

The subject, blindfolded, is instructed to touch the fingertips together at some point on the board. Fine lines are drawn along the tips of the index fingers to aid observations by the experimenters. Choose the placement of the left index finger on the board as an arbitrary reference, and record the placement of the right index finger in degrees of rotation too flexed (positive), too extended (negative), or on target (zero error). Disregard misalignments due to wrist and finger angulations (i.e. misalignments along a radius of the forearm movement).

Always take 10 readings for each experimental situation. Calculate mean, and standard error of the mean.

Experiments

1. An experimenter gently lifts the subject's left hand and places it so that its index finger is against the perspex. Precisely 10 seconds later, the subject moves his/her right hand to the board in an attempt to align the fingers. The subject is not to be hurried in his/her choice, but must not touch the board until alignment is satisfactory. After each reading the subject places the hands back to their starting position on the table top.
 - (a) Is there any difference in the subject's accuracy when attempting alignments in mid-range or at extreme range? (10 readings each).

Why?

Devise another experiment to examine your reasons further.

- (b) Is the subject more accurate when allowed to move both arms voluntarily, and at once, to a self chosen point in the middle of the range of excursion.

Comment:

2.
 - (a) Apply a physiotherapy vibrator firmly over the biceps tendon of the left arm and repeat experiment 1.
 - (b) Take another set of readings with the vibrator over the triceps tendon of the left arm.

Do 2(a) and 2(b) differ from control 1? What might be the mechanism of this?

PERCEPTION OF HEAVINESS

Arrange for a blindfolded subject to lift weights with corresponding body parts on each side of the body. Arbitrarily choose one side as the reference (or experimental) side. Present a weight on that side.

Ask the subject to choose a weight to be lifted by one side of the body (the indicator side), which seems of the same heaviness as that on the experimental side. To permit this choice, present weights on the indicator side and adjust them up or down between lifts in the direction requested by the subject. Always add or subtract as instructed, but "overshoot" from time to time. When both sides seem the same, record the weight on the indicator side as the perceived heaviness of the weight on the reference side.

Make 10 readings, and calculate means and standard errors of the mean. *How accurately can the subject estimate the heaviness of a lifted object?*

Devise an experiment of your own on the perception of heaviness (10 more readings, compare with control).

PROPRIOCEPTIVE ILLUSIONS INDUCED BY MUSCLE VIBRATION

Apply a physiotherapy vibrator over a prominent muscle tendon, and ask your blindfolded subject to align the unvibrated side, with vibrated side. This experiment should reveal a proprioceptive illusion.

Examine and discuss it, with special reference to its possible physiological basis.

How long does it last?

What is it? (an illusory position? an illusory acceleration? an illusory force?)

Does it occur when the stimulus applied to the tendon when the joint is at the end of the range which lengthens the muscle acting through that tendon? If so, what does this tell us about CNS processing?

[A demonstration will be given of the effect of applying vibration to the Achilles tendons of a standing subject].

DISSOCIATION OF PAIN AND TACTILE SENSIBILITY

In an additional experiment, a student volunteer is deprived of sensation and movement by an anoxic/pressure block (sphygmomanometer cuff inflated around the upper arm at above arterial pressure ~ 200mmHg).

In the manoeuvre, sensation in the arm below the cuff is lost gradually over 20 minutes, and motor power declines and then is lost over a similar time period. The experiment illustrates sequential losses of nerve fibre groups of different axonal diameters and physiological functions, and illustrates many important points in human sensation and motor control. Blood flow to the arm is cut off for about 30 minutes, and for no longer than 45 minutes. Upon restoration of blood flow, "pins and needles" are felt for about 1-2 minutes, before complete normal sensory and motor function resumes.

NB: The experiment is under constant supervision by an experienced, qualified practitioner. This procedure is well established in the research literature, and occlusions of up to 2 hours are known to be readily reversed without complications.

Notes

SENSORY NERVE CONDUCTION

Conduction velocity

Axons are classified into several distinct groups (A β , A δ , C among others) based on the conduction velocity of their action potentials. This conduction velocity depends on a number of factors including the axon diameter, myelination, and temperature. Diseases that affect the peripheral nervous system such as carpal tunnel syndrome or peripheral neuropathy may slow action potential conduction, or in severe disease may block conduction.

In this class you will record the compound sensory nerve action potential produced by electrical stimulation of cutaneous afferents in the digital nerves of the index and little fingers (branches of the median and ulnar nerves, respectively). The recording is made using surface electrodes, so the signal comes through the skin. The amplitude and latency of onset of the action potentials will be measured and used to calculate the conduction velocity from the digit-to-wrist and from the wrist-to-elbow.

Further details on this practical will be available on Blackboard prior to the scheduled time.

VISUAL & AUDITORY PSYCHOPHYSICS

Part 1. Visual psychophysics

Stereopsis

The symmetric location of the two eyes on opposite sides of the head of some animals (e.g. sheep and rabbit) allows a panoramic field of vision. The frontal position of the two eyes in humans means that panoramic vision is lost, however a compensating advantage is the binocular depth discrimination (stereopsis) such an anatomical arrangement allows. The visual fields of each eye (monocular visual field) overlap to produce a binocular field of vision that extends for about 120 degrees of visual angle along both the horizontal and vertical meridians. An object positioned anywhere within the binocular visual field is imaged on the retina of both eyes, however, because the two eyes are separated horizontally, the image of the object will fall on slightly different positions of the right and left retinas (binocular parallax). The images on each retina are combined (fused) by central neural mechanisms to produce the perception of a single object localized at a single position in space.

PRACTICAL EXERCISES

1. Stereoscopic Perception of Depth seen in Anaglyphs

The stereoscopic perception of depth requires the image of objects in space to fall on non-corresponding points in each retina which can be simulated for a flat image in a variety of ways.

A stereoscope uses a prism to present each eye with a separate image of the same scene in the form of a *stereoslide*. Stereoslides provide a compelling perception of depth, and work with coloured or monochromatic images. There are only a few stereoscopes in the class, but you should take the opportunity to view the examples of Stereoslides provided.

The cheapest and simplest way to create the stereoscopic illusion of depth is with *anaglyphs*. In an anaglyph, two slightly different grey images are overlaid, but one image is coloured red and one coloured blue. The image is viewed with 3D glasses that have a blue filter on one eye and a red filter on the other. The eye with the red filter will see only the blue-coloured image and the eye with the blue filter will see only the red-coloured image, so the one screen can present the viewer with a separate image for each eye. The disadvantage of this technique is that the pictures must be monochrome.

Look at examples of anaglyphs on these sites:

<http://www.d3.com/gallery.html>

<http://www.rainbowsymphony.com/3dgallery/3dgallery.html>

What is the effect of turning your glasses back-to-front (swap position of red and blue filters)? Why?

Other systems for presenting 3D images on a flat screen include polarizing glasses and synchronized-shutter glasses.

2. Stereoscopic Perception of Depth in Random-Dot Stereograms

The neural mechanism(s) that detect retinal disparity must be able to compare correctly the pairs of images on each retina and find the matching contours. For simple figures against a plain or simple background this is a relatively easy task for the visual system to perform, however, when the objects viewed are part of a 'real scene' consisting of a great deal of detail, the problem for the visual system becomes far more acute. *Random-dot stereograms*, developed by Bela Julesz, consist of nearly identical images of random dot patterns presented separately to each eye. If the patterns are viewed monocularly there are no recognizable features, but when viewed binocularly in a stereoscope, the patterns of the two separate images are matched in the visual cortex and an impression of depth emerges, with the shifted region of each image standing out in depth from the background. The random-dot stereograms illustrate that stereoscopic depth perception does not require monocular cues, nor any binocular cue other than retinal disparity.

View the examples of random-dot stereograms:
http://www.settheory.com/stereo_properties/stereo.html

How is the depth encoded in the random-dot stereogram?

This technique was originally developed to spot camouflaged tanks from the air. What factors would affect how well you were able to spot tanks in the stereo images?

3. Clinical Assessment of Stereopsis

If someone in your group is unable to see the random-dot stereograms you should test them with the clinical tests of stereopsis provided. To administer the tests, hold the picture straight in front of the observer, to maintain the proper axis of polarization. Avoid reflections from the shiny surface. The graded tests are standardized for sixteen inches, but minor variations have little effect on the score. The polarized viewers must be worn when viewing the pictures (over glasses if worn).

Stereotest. This test provides an easily administered check of stereoscopic depth perception. Its purpose is to measure how well the two eyes can discern differences in the distances of objects from the observer. The images are constructed from Polaroid 3-D vectorgraph. Determinants of depth such as different object size, overlapping, of objects and perspective have been excluded from the images. The three tests are each used under different circumstances:

- 1) The House Fly establishes the presence of gross stereopsis, and is especially useful in testing children. Have the observer try to "pinch" the wing of the fly between thumb and forefinger (provides a guide to the extent of stereopsis).
- 2) The Circle patterns provide a finely graded series which tests fine depth discrimination. Within each square are four circles. Only one of the circles should appear forward of the plane of reference for those having normal fusion. (The angles of stereopsis (seconds of arc) at 16 inches subtended by each test circle are: 1 (800 sec), 2 (400 sec), 3 (200 sec), 4 (140 sec), 5 (100 sec), 6 (80 sec), 7 (60 sec), 8 (50 sec) and 9 (40 sec).
- 3) The series of animals facilitates the testing of young children. In each line one of the five animals appears forward of the others.

4. Magic Eye Pictures

Magic Eye pictures or *Single Image Stereograms* as they are more generically known, present a stereoscopic perception of depth without the need for any viewer.

View some examples here (pionet.net/~k0brd/stereo/sirds/index2.html).

Inability to see Single Image Stereograms may relate to problems with stereopsis or with ocular muscle control of gaze. You can test your stereopsis with the clinical test explained in part 3. Gaze control is required because to view the Single Image Stereograms the subject must uncouple their vergence and accommodation.

How is the brain able to reconstruct depth from a flat Magic Eye picture?

Why must accommodation and vergence be uncoupled?

5. Effect of Retinal Illumination on Stereoscopic Depth Perception

Stereoscopic acuity has been shown to be dependent on the level of light adaptation of the eye, such that stereoacuity increases as retinal illumination increases, until high light intensities where the curve relating acuity to retinal illumination asymptotes. An interesting phenomenon occurs with unequal retinal illumination, where darkening of the image in one eye has a marked effect on stereoscopic depth perception. This effect is shown most strikingly by the *Pulfrich stereo-effect*.

dogfeathers.com/java/pulfrich.html

Place the darkest filter in your 3D glasses over one eye (either the blue or the red, not the cyan) and binocularly view the moving white ball (i.e. two eyes open, one eye no glasses, one eye a darkened coloured view). Watch the path of the ball around the post. Place the filter over the other eye. Has the path of the pendulum bob changed in any way?

Can you think of an explanation for your observations?

6. Binocular Rivalry

While fixating an object in the distance, hold a pencil at arms length, with the top of the pencil just below the line of sight. The pencil will be seen as nearer than the distant fixated object, however it will also appear double (diplopia). In everyday visual behaviour many objects exist at different depths to the one(s) we are fixating, however we are rarely aware of diplopia (as in the pencil example). One mechanism that could be involved in preventing, or at least reducing, diplopia of objects in depth is *binocular rivalry*. Binocular rivalry refers to periods of alternating dominance or suppression of one

eye over the other eye brought about by stimulating corresponding retinal elements with dissimilar monocular objects.

View the examples of rivalrous images at
(www.psy.vanderbilt.edu/faculty/blake/Rivalry/Wheatstone.html)

Describe what you perceive while viewing the images.

Does altering the red/blue balance of the monitor affect the duration of either percept?
(or look here: <http://www.psy.vanderbilt.edu/faculty/blake/Rivalry/cononpre.html>)

What do you think would happen if the images suddenly change eyes (the computer shifts the images)? (look here: www.psy.vanderbilt.edu/faculty/blake/Rivalry/EyeSwap.html)

7. MOTION AFTER-EFFECT

One way of studying visual function is to determine the properties of visual after-effects. An after-effect is the perception that results when a visual stimulus has been fixated on and stared at for long enough to produce adaptation. The adaptation may be primarily retinal, as is the case for colour after-effects, but other adaptations are higher level.

dogfeathers.com/java/spirals.html
www.lifesci.sussex.ac.uk/home/George_Mather/Motion/index.html

Stare at the centre of the moving image for 30s. Then look either at someone's face close up or at a textured image (stop the waterfall, or look at the pattern next to the spiral). What do you observe?

Repeat the experiment with one eye closed. Does the motion after-effect transfer to the eye that was not exposed to the stimulus?

Why does the transfer of the phenomenon to the unstimulated eye demonstrate that the adaptation is not a retinal effect?

8. VISUAL ILLUSIONS

Visual illusions are fun, but are also a powerful tool to probe the visual system and learn about its function. Choose two illusions from different categories at
<http://www.michaelbach.de/ot/index.html>

Write brief notes explaining (at least in part) the neural basis of each illusion

Part 2. Auditory psychophysics

STUDIES OF SOUND LOCALIZATION

Introduction ¹

Binaural fusion and lateralization

Sound waves coming from a source on the right side of the head arrive at the right ear before they arrive at the left ear. It might be thought that in this situation one would first hear a sound on the right side and a little later hear a second sound on the left side. Instead, one hears a single sound in the direction of the source. The phenomenon of hearing a single sound when both ears are stimulated is called *binaural fusion* and the process of determining the position of the source is called *localization*.

For any natural sound source to one side of the head, there will be a finite difference between the times of arrival of the sound at the two ears and this could serve as a localization cue. However, this is not the only possible cue. The greater distance to the farther ear and the fact that the sound must diffract around the head into the “head shadow” mean that there will also be a difference between the intensities of sound at the two ears. Any single natural source is associated with both time and intensity differences.

Interaural time differences

The difference in the time the sound reaches the ears (Δt) may be determined by finding the difference in the distance the sound must travel to reach each ear (Δd). If the velocity of the sound is V then the relationship is:

$$t = \frac{\Delta d}{V} \quad \text{where } V = 331 \text{ m.s}^{-1}$$

Determining this time difference thus reduces to a simple geometrical exercise. Imagine a head positioned over a Cartesian reference frame as shown in Figure 1:

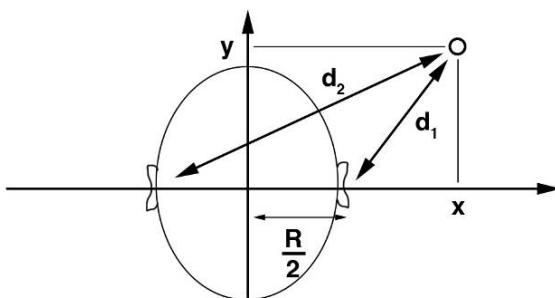


Figure 1: Relationship between spatial location and ear distances.

We can now plot the position of the source for selected time differences as shown in Figure 2.

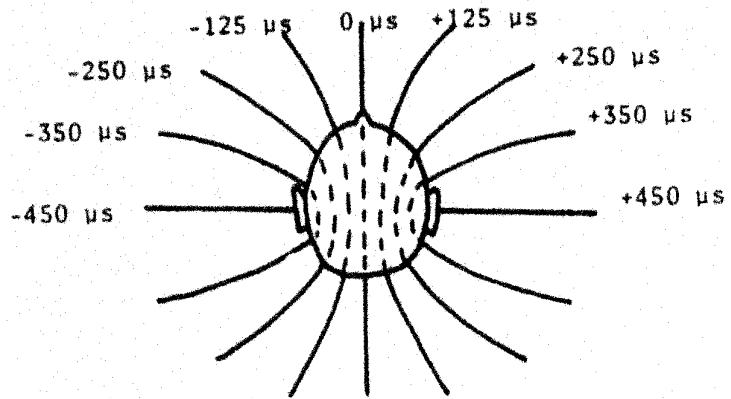


Figure 2: Ears assumed to be 16cm apart; time difference expressed as the lag of left after right. These lines of constant time differences are hyperbolae. Beyond a certain distance they become radially directed with respect to the centre of the head.

Consider the case in which the ears receive a sound from a source which is in a position that gives a time difference of 4-250 μ s. The subject could use this information to tell that the source is to her right, but will have difficulty in determining whether the source is behind or in front, above or below. In an anechoic (non-echo) chamber, the only cue available to distinguish these various directions, all lying on a hyperboloid subtending the same time difference, is that introduced by the presence of the auricle (pinna). Owing to its asymmetric shape, incident sound waves will be reflected to a varying degree from sources located for example, in front, versus the back.

Outside this room, however, she can also make use of the echoes of the source from nearby objects to remove ambiguity. For common sounds such as a person's voice, our experience provides us with a fairly good estimate of the distance of the source from us. A person yelling from some distance away may have the same loudness as a person whispering close by, but the quality of the two will be markedly different. Our estimate of the distance of a source is thus based on its intensity or loudness as well as a judgement, based on experience as to how far away something sounding like that should be to have that intensity.

In summary, binaural localization by the mechanism of time differences is accomplished by localizing the source on some line of constant time difference and estimating its position on this line by a combination of its loudness and subjective experience.

The degree to which the angular orientation of a source may be estimated depends in part on the ability of the ear to detect differences in two time differences. This is illustrated in Figure 3.

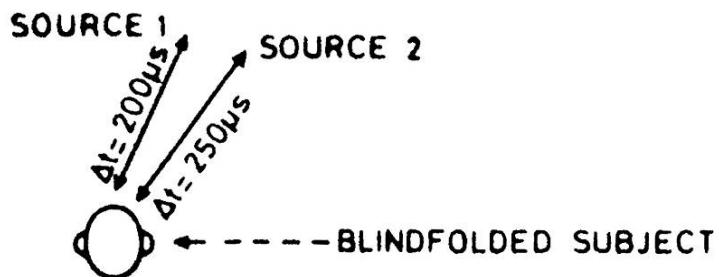


Figure 3

For the subject to be able to tell that source 1 is to the left of source 2, it is necessary for him/her to judge a time difference of only 50 μ s. This is an extremely short time in terms of the rate of operation of the nervous system. For instance, it takes one millisecond (20 times longer) for an action potential to cross over a synapse.

Interaural intensity differences

In addition to time differences a sound source in space will provide sound waves at the two ears which will also be different in pressure, due to the sound shadow cast by the head. Lord Rayleigh, in

1877, calculated the relationship, for a perfect sphere, between the sound pressures at diametrically opposed points and the radius and wavelength of sound (λ). Thus, for:

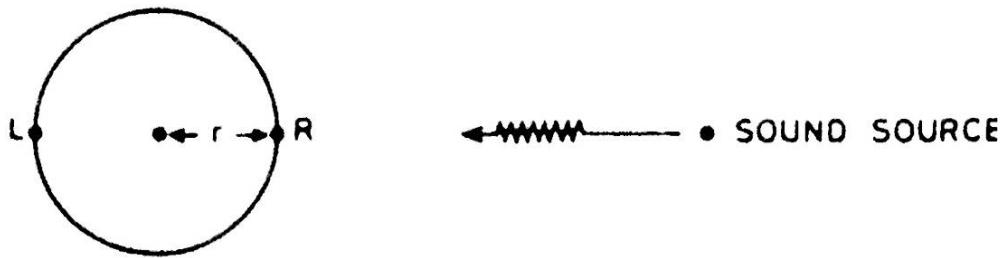


Figure 5.

$$\text{L-R pressure difference (interaural intensity difference)} \propto \frac{2\pi r}{\lambda} \quad \text{Or, since } \lambda = \frac{V}{v} \text{ and } V \approx \text{constant,}$$

$$\text{interaural intensity difference} = \text{constant} \times \text{head radius} \times \text{sound frequency}$$

Owing to the fact that real head shapes plus the pinnae, provide more complex reflectors than do spheres in the sound field, the real interaural intensity difference is a non-linear function of sound frequency. The head becomes an effective shadower at frequencies above about 2kHz, and a maximum attenuation of sound pressure of about 25dB can be achieved with the sound source at 45° to the interaural line, at frequencies of 8kHz and above. The pinna also has a very important role in directionality and in providing amplification when sounds fall on its acoustical axis.

Neural mechanisms of sound localization

If one considers the minimum discriminable spatial angle and converts it into a time or intensity difference, it is clear that very specialized neural mechanisms must be involved in sound localization. It has been shown in the last 15 years that the sound localization cues are encoded by neurones in the lateral and medial superior olfactory nuclei. These nuclei receive binaural connections from the cochlear nuclei of each side, and transmit their impulses to the inferior colliculus. It is likely in some species that the binaural integration they achieve is receded at higher levels and laid out in a highly ordered way as a neural map of auditory space.

EXPERIMENT 1: SEPARATION OF TIME AND INTENSITY CUES IN LOCALIZATION

In order to separate the time and intensity factors for study, electronic apparatus is used to present independent stimuli to the two ears via earphones. By this means, the intensities at the two ears and the time difference between presentations can be varied independently. Stimulation of the two ears results in only a single sound being heard (binaural fusion), but in this case the sound appears to come from inside one's head.

The sensation of the pulse coming from *inside* your head arises because the sound appears very close to your ears with a time delay smaller than that expected by a single source near either ear. With reference to an earlier diagram (figure 2) it thus appears to come from somewhere in the following region in **Figure 6**: and therefore inside your head.

Most recorded music is designed to be played-back through speakers spaced a couple of metres apart. When the same music is played back through headphones, the sound appears to arise in the middle of the head. Some recordings are made with miniature microphones in the external auditory canal of volunteers or acoustic dummies. These recordings already incorporate the effects of the pinna and have the correct spatial separation between the left and right channels for play-back through headphones. A sample tape is provided for you to listen to in class – note how accurate left-right localization is preserved, as well as some sense of the sound's elevation.

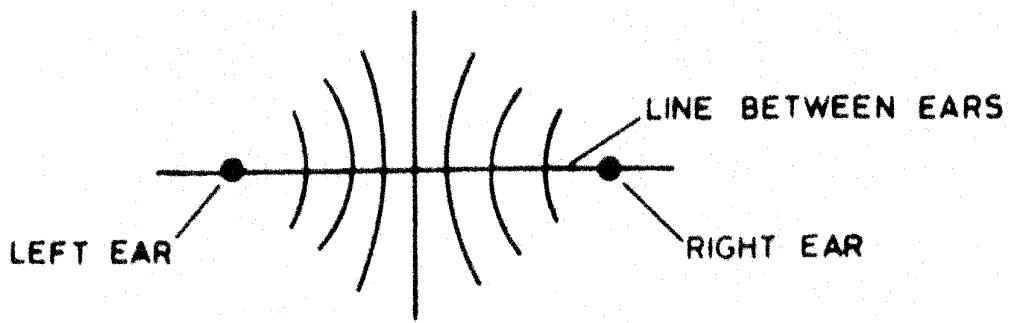


Figure 6

Varying the time or intensity difference moves the sound from side to side within the head. This phenomenon is called *lateralization* to distinguish it from the localization of external sound sources. These phenomena are demonstrated in the following experiment.

The computer program called "sound localization" provides independent control over stimuli presented to each ear. The control panel of this program is shown in Figure 7.

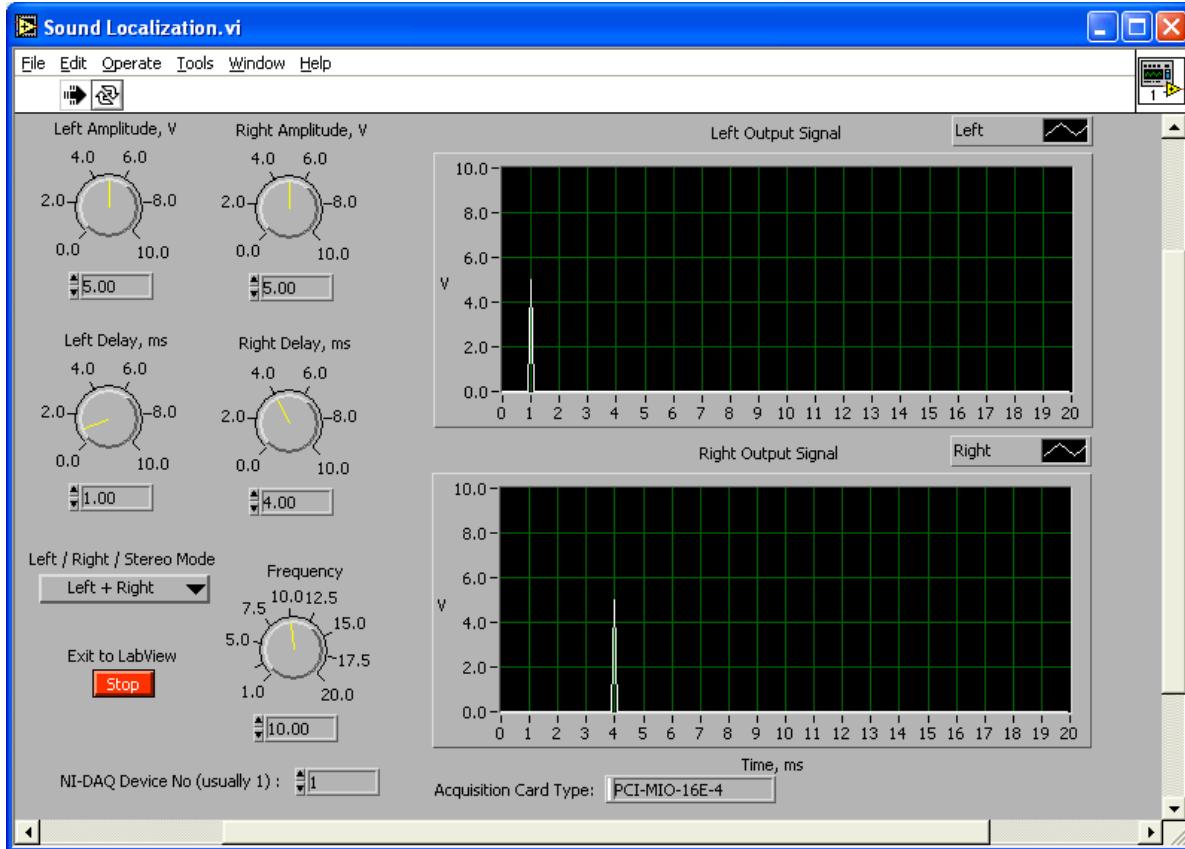


Figure 7

PROCEDURES

The exercises in this section are more easily performed by individuals on themselves than on other subjects.

Exercise 1

On left and right channels set:

Frequency	10Hz
Delay	2 msec
Voltage	~ 1 V
Stereo mode	

1. Use the traces on the screen to measure the duration, amplitude and onset of the two pulses and adjust the stimulator settings so that the two pulses are identical. Use the earphones to check that the loudness is satisfactory.
2. Switch the output to right.
3. Put on the earphones. (It will be easier if you put on the earphones in such a way that what you hear is on the right side).

What do you hear?

4. Switch the output to the left.

What do you hear?

5. Switch to stereo. For each paired delivery of clicks in the train at 10 Hz, do you hear two separate clicks (one in each ear as before), or a single click in the midline of your head? (The latter is an example of *binaural fusion*.)

6. Adjust the delay on one channel so that pulses are applied first to the right ear (say 2 msec apart). (You can identify which pulse goes to which ear by switching from left to right).

Describe any change in the perceived effect. (This is lateralization due to a time difference.)

Toward which side did the clicks appear to move?

Hence, what is the relation between the direction of lateralization and the ear which receives sound first?

7. By moving this delay knob back and forth, observe that the perceived location of the clicks can be moved from side to side.
8. There is a limit to your fusion ability. To experience the failure of binaural fusion, adjust the delay(s) so that the time difference is at least 5 ms.

What do you hear beyond the range of fusion?

9. Determine the maximum time difference for which you can accomplish binaural fusion. (Make the measurement on the screen). Set one channel to 1 msec delay. On the other channel adjust the delay setting in small increments from about 2 msec to 5 msec.

The maximum time difference for binaural fusion is ...

10. Now adjust the delay on both channels so that the pulses occur at the same time (zero time difference) and they are again coincident on the screen.
11. Increase the amplitude of the pulses to the right ear.
What happened to the location of the clicks? (This is lateralization due to an intensity difference.)

Toward which side did the clicks appear to move?

Hence, what is the relation between the direction of lateralization and the ear which receives the greater intensity?

EXPERIMENT 2: ERRORS OF LOCALIZATION USING INTENSITY / TIME DIFFERENCES

A sound appearing to come from the middle of the head is moved away by altering

- i. interaural intensity difference
- ii. interaural time difference

The subject is asked to bring the sound back to the middle of the head by readjusting the parameter under study, and a measure of the error in doing this is obtained. This gives an estimate of the resolution possible using intensity differences and time differences.

With the pulses coincident, adjust the two amplitude controls until the sound appears to come from the middle of your head.

(i) Altering interaural intensity difference

With the coincident pulses appearing to be in the middle of your head you may consider their amplitudes to be equal also. Note the voltage *difference* on the oscilloscope.

left voltage (V_1):

right voltage (V_2):

voltage difference ($V_1 - V_2$):

Now increase the amplitude on *one* of the pulses so that it appears to move towards one ear. Again readjust the voltage so that a centred image is perceived and measure the voltage difference. Repeat this manoeuvre several times until consistency is obtained. Enter your values in Table I and calculate the mean voltage difference and its standard deviation (SD). This will give an estimate of your error in centring the image using intensity as a cue. You may find that different voltage differences occur with different absolute voltages for the pair of clicks.

TABLE I

a) left voltage constant ($V_1 = \quad$):

<i>trial number</i>	1	2	3	4	5
<i>right voltage (V_2)</i>					
<i>voltage difference ($V_1 - V_2$)</i>					

mean voltage difference and SD:

b) right voltage constant ($V_2 =$):

<i>trial number</i>	1	2	3	4	5
<i>left voltage (V_1)</i>					
<i>voltage difference ($V_1 - V_2$)</i>					

mean voltage difference and SD:

Since time delay is zero, what factors might make it necessary to use different pulse voltages for each ear to achieve a centred image?

ii) Altering interaural time difference

With the voltages set to give the average voltage difference for a centred image, (average of a) and b) above) move the time delay knob so that the pulse coming into the left ear occurs before the one coming into the right ear.

Without looking at the face of the oscilloscope screen adjust the position of the delay knob until the pulse again appears to be in the centre of your head. Note the time difference between the two pulses and enter the results in Table II. Repeat this until you obtain a constant result, and then calculate your average time error.

TABLE II

<i>trial number</i>	0	1	2	3	4	5
<i>left delay</i>						
<i>right delay</i>						
<i>time difference</i>	0					

average time difference:

EXERCISE 3: INTERACTIONS OF TIME AND INTENSITY

You have just observed that time differences alone and intensity differences alone can produce lateralization. You will now show that lateralization due to a time difference can be balanced or compensated by lateralization due to an intensity difference. Time information and intensity information are thus said to be “traded”.

1. Equalize and superimpose the two pulses on the screen by setting both delays at 1 ms and both amplitudes at 0.1V.
2. Without changing the delay settings, move the voltage dial of the left channel around in both directions and then bring it back to a position at which the sound is centred in the middle of the head. Measure the amplitude on the left channel (in volts).

$$\text{Left amplitude } (V_1) =$$

At this, and all subsequent intensity pairings, repeat amplitude estimations until a consistent reading is obtained or a reasonable average value is determined.

3. Now increase the delay on the left channel so that there is a 0.5 msec difference between the two (e.g. right delay at 1 msec and left delay at 1.5 msec). By increasing the amplitude on one channel, bring the clicks back to the middle of the head.
4. Measure on the screen the time difference, τ and the amplitudes of the two pulses, V_1 and V_2 (in volts).

$$\tau =$$

$$V_1 =$$

$$V_2 =$$

5. By either increasing the delay on the left stimulator, or decreasing the delay on the right stimulator, increase the time difference between the two pulses to 1.0 ms, 1.5 ms, 2.0 ms, & 2.5 msec. Record, for each of these time differences, the voltage (average of about 5 readings if result not consistent) on the left stimulator required to bring the clicks back to the middle of the head, keeping voltage constant on the right stimulator. Enter your results in Table III.

TABLE III

Increase in left amplitude for an increased left delay (right voltage constant at $V_2 = \text{_____}$)

<i>right delay</i>							
<i>left delay</i>							
<i>time difference</i>	0	0.5	1.0	1.5	2.0	2.5	0
<i>left voltage V_1</i>							
<i>trial 1</i>							
<i>trial 2</i>							
<i>trial 3</i>							
<i>trial 4</i>							
<i>trial 5</i>							
<i>mean</i>							
<i>mean voltage difference (V)</i>							
<i>Mean intensity difference (dB)</i>							

6. Reset zero time difference and check the voltage from the left stimulator for centring the sound images. Note that your measurements for the voltage needed to centre the image may now be different from your original estimates. Why? Repeat this estimation until your amplitude values are consistent with those initially made, and then repeat the above procedure but in this case increasing the time delay at the right ear by 0.5, 1.0, 1.5, 2.0, 2.5 msec. Enter your results in Table IV:

Table IV

Increase in right amplitude for increased right delay (left voltage constant at $V_1 = \text{_____} \mu\text{V}$)

<i>right delay</i>							
<i>left delay</i>							
<i>time difference</i>	0	0.5	1.0	1.5	2.0	2.5	0
<i>right voltage V_2</i>							
<i>trial 1</i>							
<i>trial 2</i>							
<i>trial 3</i>							
<i>trial 4</i>							
<i>trial 5</i>							
<i>mean</i>							
<i>mean voltage difference (V)</i>							
<i>Mean intensity difference (dB)</i>							

For each voltage obtained in these results, calculate the intensity difference between the two ears, in dB:

$$dB = 20 \log \frac{\{ \text{Voltage required (V)} \}}{\{ \text{preset voltage (V}_o \text{) } \}}$$

where "preset voltage" is the voltage which remains unchanged in one ear and "voltage required" is the voltage for the other ear needed to re-centre the image. Acoustic power output from the speaker will be proportional to the electrical power output from the stimulator, and since

Electrical Power = voltage (V) x current (I)
 and V = I x R
 where R = electrical resistance

$$\therefore \text{Power} \quad = \quad I^2 R = \frac{V^2}{R}$$

$$\begin{aligned} \text{Now no. of dB} &= 10 \log \frac{(\text{Power/unit area})}{(\text{Power/unit area})_{\text{reference}}} \\ &= 10 \log \frac{V^2/R}{V_o^2/R} \\ &= 20 \log \frac{V}{V_o} \end{aligned}$$

Plot your results with the time delay for each intensity difference on the abscissa and average intensity difference on the ordinate. What does the slope of this line imply? Can you measure a value in $\mu\text{sec}/\text{dB}$ for the time- intensity trade? Comment on the variability of measurements about the mean, at a given time difference.

Questions

1. The technique of independently stimulating the two ears by means of electronically driven earphones does not produce exactly the same effects as single sound sources do, e.g. the subject hears sounds which appear to come from inside his head instead of from outside. To appraise whether this technique is a useful simulation at all,
 - (a) *compare the direction in which you lateralized a sound due to a time difference (exercise 1, step 6) with the direction you would localize a single source giving the same time difference,*
 - (b) *compare the direction in which you lateralized a sound due to intensity difference (exercise 1, step 11) with the direction you would localize a single source giving the same intensity difference.*
2. *In the programmed text provided in the Appendix you estimated the maximum time difference which could occur for a single natural sound source. Comparing this value with your range of binaural fusion determined above (exercise 1, step 9), is it possible to position a sound source (or to orient one's head) so that binaural fusion fails?*
3. *How could one contrive to make binaural fusion fail when using a single sound source? (Hint: How could the path length around the head be increased?)*

Notes
