8
Psychophysiological Methods

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AIMS

This chapter aims to provide the reader with an understanding of the breadth of possibilities in psychophysiological work. The tone of this chapter is less discursive and more didactic than many of the other chapters in this book. It is intended to whet the appetite of those readers who may wish to pursue this kind of research.

Key terms

electrocardiography
electrodermal activity
electroencephalography
electromyography
electro-oculography
evoked potential electroencephalography
diastole
galvanic skin response
photoplethysmograph
PQRST complex
pupillary response
skin potentials
skin resistance
sphygmomanometer
systole
transducers

8.1 WHAT IS PSYCHOPHYSIOLOGY?

Specifically, the field of psychophysiology is concerned with the manipulation of psychological variables and their corresponding observed effects on physiological processes. Thus, psychophysiology is concerned with observing the interactions between physiological and psychological phenomena. More generally, psychophysiology can be said to encompass both the study of behavioural consequences of physiological properties of the body at a biochemical and anatomical level, and the effects of behaviour on these same physiological properties.

Much of psychophysiological investigation is concerned with examining the concepts of emotion, behavioural states, stress, cognitive task performance, personality and intelligence. In each case, the relationships between psychological factors, stimulus perception and recognition, situational indices and physiological response are used in an attempt to shed light on the initiation, execution, maintenance and termination of behavioural events. Ultimately, the field can be partitioned into six major areas of endeavour as follows.

Social psychophysiology Social psychophysiology is the study of the interactions between physiology and behaviour's when those behaviours are involved in social processes. For example, interpersonal phenomena and group dynamics may be investigated by observing the interplay between various behaviours and each individual's dynamic physiological changes such as pupil size, muscle tone and skin electrical resistance (e.g. Birnbaumer & Ohman, 1993; Blascovich & Kelsey, 1990; Diamond, 2001; Wagner & Manstead, 1989).

Developmental psychophysiology This is the study of the ageing process, looking specifically at how changing properties of physiological systems and anatomical structures affect behaviour (e.g. van der Molen & Molenaar, 1994). In addition, the nature of the interaction between the psychological and physiological factors during development is examined. For example, research may use measures of brain activity (e.g. event-related potentials) to examine ongoing brain function during early development (Ridderinkhof & van der Stelt, 2000; Steinschneider, Kurtzberg & Vaughan, 1992).

Cognitive psychophysiology This concerns the relationship between information processing and physiology (see Jennings & Coles, 1991). That is, it examines the relationships between cognitive task performance and physiological events. For example, it looks at how perception, movement, attention, language and memory may be associated with particular features of brain electrical and magnetic activity (see Kutas & Dale, 1997; Zani & Proverbio, 2002).

Clinical psychophysiology This is the study of psychological disorders and their relationship with physiological functioning and malfunctioning (e.g. Halliday, Butler & Paul, 1987; Magina, 1997). In addition, this area is concerned with the examination of the effectiveness of treatment regimes and drug effects on the

psychological behaviour and affect of the individual. For example, in looking at chronic depression, it is sometimes useful to look at the benefits of any treatment applied in terms of both the behavioural outcomes and the changed nature of physiological parameters such as brain activity, sympathetic nervous system responsivity and biochemical substance assays (Carlson *et al.*, 2004).

Applied psychophysiology This area is involved with the application of psychophysiological techniques and findings to occupational, recreational, clinical and other areas of interest. For example, the monitoring of certain physiological activity within an individual, and providing instant and appropriate feedback of this activity, is known as biofeedback. This technique is used as an aid for relaxation therapy, stuttering, respiration control and a variety of other practical problems whose treatment may be amenable to self-control therapeutic techniques (Schwartz & Andrasik, 2003).

Individual differences This area looks specifically at the relation of physiological processes and anatomical structures to measures of personality and intelligence (generally defined by psychometric measures, e.g. Cooper, 2002; Gale & Eysenck, 1993). These measures may be of typically dynamic psychophysiological form, such as the relationship between the overall amplitude of brain-evoked potentials to varying levels of stimulation, and introversion–extroversion (the augmenting–reducing phenomenon), or may quantify aspects of anatomical physiology and relate these to the psychometric or psychological indices. For example, from histological surveys of human cadavers, the number of dendrites and their length correlate positively with the level of education attainment within individuals.

8.2 THE PRINCIPAL AREAS OF PHYSIOLOGICAL DATA ACQUISITION

This section is a brief summary of important facts and information surrounding the quantification of parameters describing the function of particular physiological structures and systems. It is not intended to be a comprehensive overview but rather is a snapshot of the diversity and richness of the measurement process in psychophysiology.

8.2.1 Muscle activity

electromyography

transducers

Assessing muscle activity is carried out by a technique known as **electromyography**, in which the electrical potentials that are associated with contractions of muscle fibres are measured. These potentials are brief impulses lasting between 1 and 5 milliseconds (ms), detected using devices known as **transducers**. These vary from invasive needle electrodes inserted into muscle tissue and recording individual fibre potentials, to non-invasive surface electrodes that are fixed to the skin above the particular muscle of interest, recording the mass action of muscle fibre groups.

The amplitude of recorded signals can vary between about 1 and 1000 microvolts (μV), although recordings of less than 20 μV are difficult to obtain. The frequency of the electrical impulses can be anywhere between 20 and 1000 hertz (Hz). The quantitative measures available will vary depending upon the focus of investigation. For example, when one is looking at the behaviour of a single nerve fibre or a homogeneous group of fibres, the single or compound (many fibres) action potential may be measured in response to a precise, targeted stimulus such as a small electric shock. Measures extracted from this potential include those of impulse amplitude and nerve conduction velocity. Alternatively, when looking at the long-term activity of muscle fibres, the integrated amplitude, frequency of nerve firing (impulses) and gradients of frequency responses may be examined.

One interesting example of electromyograph recordings was reported by Surakka and Hietanen (1998) who assessed muscular activity on the face in response to other peoples' facial expressions of emotion. Their research has revealed that people show different muscular reactions to real (Duchenne) as opposed to deliberate (false) smiles. Also, Winkielman and Cacioppo (2001) showed that electromyographic activity is associated with real smiles when conducting easier mental tasks.

8.2.2 Sweat gland activity

electrodermal activity
galvanic skin response

Assessing the activity of the sweat glands relies upon measuring electrical activity on the surface of the skin, a procedure known variously as **electrodermal activity** or **galvanic skin response**. What is actually measured are the electrical properties of the skin that are associated with eccrine sweat gland activity. This activity is responsive to changes in emotionality and cognitive activity in general, and is often used as a general measure of arousal.

skin potentials
skin resistance

Measuring electrodermal activity requires the placement of two non-invasive, metallic, surface electrodes either on the palm or the fingers of one hand. Two types of measure can be recorded: **skin potentials** and **skin resistance**. Skin potentials are recorded by measuring the voltage potential between an electrode over an 'active' site and a reference electrode on an inert site. Alternatively, skin resistance is measured by imposing a constant voltage between the electrodes, across the surface of the skin. The current between these electrodes can be measured, and this provides information about the conductivity of the skin between the two electrodes. In short, sweaty palms are better conductors of current than dry ones and the equipment is designed to register any changes in sweat production. An alternative strategy sometimes used is to maintain a constant current between the two electrodes by constantly adjusting the voltage: this voltage adjustment measures skin resistivity. Both momentary fluctuations (phasic) and relatively stable measures (tonic) can be recorded.

If measuring skin potentials, the voltage amplitude between the two electrodes is recorded, and this normally ranges between about 1 and 6 millivolts (mV). If

measuring skin resistance, then variation of electrical resistance around a baseline is recorded. Given a relatively stable level of resistance of, say, 100 kilohms (kΩ), to the passage of electric current through the surface of the skin, variability of resistance around this baseline value can reach up to 50 (kΩ) or more in magnitude.

Skin conductance is generally measured in microsiemens (μS), where 1 seimens equals $1\,\Omega^{-1}$. Given a baseline level of conductivity of 10 μS, conductivity can be seen to vary generally between about 8 μS and 20 μS. A typical response duration would be between about 1 and 3 seconds. Of course, these example values will be heavily dependent on the type of experimental conditions used to elicit changes in potential, resistivity and conductivity.

The quantitative measures derived from electrodermal activity are generally measures of response waveform amplitude and latency, rise/fall times, and frequency of responses. In addition, gradients over time of these measures can be analysed, as in the case of habituation of response amplitude to repetitive stimuli.

Measures of electrodermal activity have been widely used to indicate level of arousal from almost any conceivable stimulus. For instance, Blair, Jones, Clerk and Smith (1997) found that psychopathic individuals show a lower electrodermal response to distress cues in others than a group of matched controls (see also Lorber, 2004).

8.2.3 Eye movements – pupillary response

Pupillary response describes the dilation of the pupil of the eye, while **electro-oculography** describes the measurement of eye movement. In addition, eye-blink rate and duration can be measured.

Pupillary response
electro-orulography

To measure pupillary response, an individual's eyes are illuminated by low-level infrared light and a low-light-level video camera is used to record pupil size, with digital signal processing of the video images to provide a continuous measurement of pupil diameter. Pupil diameter changes can be measured over a 0.5 mm to 10 mm range. Spontaneous, continuous pupil size changes vary around 1 mm or so. Typically, pupillary response measures encompass pupil diameter and rate of change in diameter in response to either a specific stimulus or a longer-term emotional state.

Electro-oculography is concerned with assessing muscular activity around the eye, and evaluating the change in voltage potential between the positively charged cornea and negatively charged retinal segment of the eye. It uses non-invasive pairs of electrodes placed around the eye. Electrodes placed at the side of the eye record horizontal movement, those placed above and below the eye record vertical movement. Electro-oculographic amplitude varies between about 0.4 and 1 mV. Currently, electro-oculographic signals can record movement up to 70° from a central position, with a resolution of 1°. Eye-blink duration is generally seen to fall between 100 and 400 ms, with rates heavily dependent upon specific situational factors. Electro-oculographic measures encompass eye movement speed, direction, type (smooth pursuit as in tracking tasks, or fast saccades as in reading or examining a static stimulus).

Pupillary dilation is considered to be indicative of heightened interest and arousal, while electro-oculograms are regularly used in sleep research, for instance, as one indicator of entry to the phase of sleep known as REM (rapid eye movement) sleep, which is characterized by the eyes making rapid darting movements (see Carlson, 2004).

8.2.4 Cardiac response, blood pressure and blood volume

Electrocardiography

Electrocardiography refers to the recording of the electrical potentials generated by the heart muscles over the period of one heartbeat. The electrical waveform produced by the sequence of contractile responses in a heartbeat is referred to as the

PQRST complex

PQRST complex. The P wave is the small change in potential caused by the initial excitation of the atrial (upper heart chambers) muscles just prior to their contraction. The QRS complex represents the contraction of the left and right ventricular (lower chambers of the heart) muscles that pump blood from the ventricular chambers to the lungs and rest of the body. The R wave is the point of maximum ventricular excitation. The T wave indicates repolarization of ventricular muscle.

systole
diastole

The term **systole** is used to describe the atrial and ventricular contraction phases (P–S) and **diastole** to describe the relaxation phase (T–P) of the passive filling of the atria and ventricles. Blood pressure measurement is based upon the measurement of the systolic and diastolic phase wavefronts in the blood moving through the arteries. Blood volume measurement (plethysmography) assesses the amounts of blood that are present in various areas of the body during particular activities.

To make an electrocardiograph measurement, surface electrodes can be placed on the wrist, ankle, neck or chest. For the measurement of blood pressure, a

sphygmomanometer

sphygmomanometer (pressure cuff) and stethoscope are used to detect the systolic and diastolic pressures. For blood volume measurements, conventionally a

photoplethysmograph

photoplethysmograph is used to detect the amount of blood passing in tissue directly below the sensor (using the principle of light absorption characteristics of blood). This device is normally placed on a fingertip or an earlobe.

The most popular quantitative measures in electrocardiography are of heart rate (counting the number of R waves over a minute) and heart period (the duration between R waves). The average heart rate is around 75 bpm, beats per minute which is equivalent to a cardiac cycle of 800 ms, during which the heart is in ventricular systole for 200–250 ms and in diastole for 550–600 ms. However, with a multi-component waveform as in the PQRST complex, and the physiological processes that underlie the waveform, meaningful measures can be generated from many combinations of latencies or amplitudes between and within the PQRST complex. The measurement of blood pressure yields simple pressure indices; however, the ratio between the systolic and diastolic pressure values is of significance, as is the absolute value of each pressure parameter. Normal systolic blood pressure (measured in millimetres of mercury displacement (mmHg)) ranges from 95 to 140 mmHg, with about 120 mmHg as the average pressure.

Normal diastolic blood pressure ranges from 60 to 90 mmHg, with about 80 mmHg as the average pressure. Blood volume measures are always relative to some baseline within an individual. The signal is generally an amplified analogue voltage that indexes light absorption by the photoelectric sensor.

Measures such as heart rate variability have been widely used to indicate the mental workload (a concept that reflects information processing demands and complexity) imposed by a variety of tasks, such as those involved in flying aircraft (e.g. Backs, 1998; Sammer, 1998).

8.2.5 Respiration

To assess respiration, measures of the breathing and gas-exchange process are made. More specifically, oximetry examines the arterial blood oxygen (O_2) levels and infrared capnometry examines the lung carbon dioxide (CO_2) levels. Abdominal and thoracic respiration rate and depth may also be measured.

Oximetry measures are made using a specially calibrated photoplethysmograph, with output calibrated as percentage of saturated haemoglobin. For capnometry, a nasal catheter is inserted about 6 mm into a nostril and held in place with some tape on the upper lip. CO_2 expiration pressure (PCO_2) and end-tidal CO_2 ($PETCO_2$: the concentration of CO_2 in expired air) can be measured. For abdominal and thoracic breathing measurement, pneumography and strain gauges are most often used.

The different methods of respiration assessment produce analogue voltages, digital values or direct pressure manometer readings that index the gases or strains being measured. There are up to 50 measures that can be extracted from an examination of the output from oximetry, capnography and pneumography. These vary from measures of volume displacement, frequency and pressure, to proportionate fractionation of gases in expired air and oxygenation of the blood. The analysis of respiration has inexplicably been neglected in psychophysiology. However, the book by Fried and Grimaldi (1993) is a remarkable testament to the richness of relationships between respiration and psychological factors, and to the theoretical importance of respiration to conventional models of arousal and physiological functioning.

An interesting finding from the analysis of respiration has been that individuals suffering from panic disorder have greater irregularity and complexity in their breathing patterns, which may make them more vulnerable to panic attacks (e.g. Caldirola, Bellodi, Caumo, Migliarese & Perna, 2004).

8.2.6 Electrical potentials of the brain

The electrical activity generated by the mass action of neurons within the cortex and midbrain structures is measured using a technique known as **electroencephalography**. In addition, since electrical currents generate magnetic fields, these can be measured by magnetoencephalography. Electroencephalograph (EEG) recordings can be made using either invasive needle electrodes, placed directly into the exposed cortex or deeper structures, or non-invasive electrodes placed upon the surface of the scalp

Electroencephalography

(up to more than 300 with high-density EEG recording). These electrodes are used to record voltage differences between one or more cortical sites and a relatively electrically inactive area (such as an earlobe). For magnetoencephalograph recording, superconducting quantum interfering devices (SQUIDs) are used to detect the minute dynamically fluctuating magnetic fields within the brain. Unlike EEG electrodes, SQUIDs do not have to be in contact with the scalp or cortical tissue as there is no reliance on electrical conductivity of electrons through body tissues.

The electrical signals emanating from the brain are very small (of the order of microvolts). Spontaneous electroencephalography is the term used to describe the continuous stream of activity that is always present within the brain. This activity can be characterized as patterns of oscillatory waveforms that have conventionally been subdivided in terms of their frequency into four main bands: delta (low frequency, 0.5–4 Hz; amplitude 20–200 μV), theta (low frequency, 4–7 Hz; amplitude 20–100 μV), alpha (dominant frequency, 8–13 Hz; amplitude 20–60 μV) and beta (high frequency, 13–40 Hz; amplitude 2–20 μV). Electroencephalography has frequently been used to study levels of arousal from deep sleep, where delta activity predominates, through to alert attentiveness, where beta activity predominates.

evoked potential electroencephalography

If, instead of recording the spontaneous activity of the brain, a brain response is evoked by a quantifiable stimulus, then it is possible to examine the change in electrical activity in direct response to a known stimulus. This technique is known as **evoked potential electroencephalography**. Some of these evoked potentials can last less than 10 ms (such as the brain-stem auditory evoked potential generated by subcortical brain tissues) or up to a second or longer as in the case of the *Bereitschaftspotential* or readiness potential (a slow shift in voltage that is observed as preceding voluntary or spontaneous movement within an individual). Generally, because of the low level of brain response over and above the normal background electroencephalographic activity, many evoked responses are collected and then summed to produce an average evoked response (AER), also known as an average evoked potential (AEP). The basis for this summation is that activity in the waveform that is not generated in response to the stimulus will be almost random and hence sum to near zero over occasions, while activity that is related to the stimulus will be enhanced by adding these stimulus-generated signals together.

For spontaneous EEG data, the most popular method of analysis is based around a mathematical technique known as Fourier analysis. This decomposes the complex EEG waveform into simple separate oscillating components each having a particular frequency of oscillation and magnitude. Following this, the amount of electrical energy accounted for by each particular frequency that could possibly make up the complex waveform provides direct, quantitative measures that index signal power at certain frequencies. More recent methods of analysis have re-expressed multi-electrode output as a spatial contour map – the topographical EEG map. This is a method of interpolating activity between electrodes in order to produce a set of smoothed gradients that can be 'mapped' over the surface of the

scalp, encompassing all electrode positions and the intervening spaces between electrodes. In addition, chaos theory (non-linear dynamic analysis or fractal dimensionality analysis) has very recently been applied to the background EEG as a method for determining the 'complexity' of the EEG. For AEP research, measures invariably focus on peaks and troughs in the waveform, characterizing these components by their amplitude and latency from the point of stimulation. Some work has also focused on the spectral composition of the AEP. Particularly promising has been analysis that uses the wavelet transform, which allows a multi-resolution analysis of time-varying signals and which is especially suited to locating the time interval within which a high-frequency signal, such as the brainstem auditory evoked potential, occurs (see Samar, Swartz & Raghuveer, 1995).

Contemporary EEG work frequently uses high-density recording (see Oostenveld & Praamstra, 2001) where many electrodes are placed on the scalp, yielding a relatively high-resolution topographical map. Using this type of recording, Huber, Ghilardi, Massimini and Tononi (2004) have been able to show that slow wave sleep may be crucial to learning new tasks. Specifically, they found that learning a new task may trigger an increase in slow wave sleep activity in the relevant brain area, which in turn may enhance task performance.

However, despite advances in the topographic mapping of EEG data its spatial resolution is still relatively poor. Fortunately, complementary techniques for measuring brain activity, such as functional magnetic resonance imaging (see Box 8.1), have relatively good spatial resolution. When used together, these techniques make an especially particularly powerful combination to measuring the brain activity associated with psychological processes.

Box 8.1 Functional magnetic resonance imaging

Functional magnetic resonance imaging (fMRI) is currently the fastest-growing method for relating brain activity to psychological processes and behaviour. Whilst the hardware and facilities required are extremely expensive, they are becoming increasingly available to researchers working in psychology departments, with a number of departments having their own fMRI facilities.

Functional magnetic resonance imaging works by detecting the radiofrequency energy emitted by the nuclei of atoms as they align with a strong magnetic field. Participants in fMRI studies are placed inside a scanner, which fundamentally comprises a large, high-strength magnet, various coils that make local adjustments to the static magnetic field generated by the large magnet, and radiofrequency transmitting and receiving coils. The participants are stimulated in some way, for instance, by presentation of visual stimuli, whilst their brain activity is measured as described next.

Essentially, a radiofrequency pulse is used to flip the nuclei out of alignment with the magnetic field and then, as they move back into alignment, they emit radiofrequency energy – the magnetic resonance signal – that is measured by a receiver

(Continued)

Box 8.1 (Continued)

coil. Because increased neural processing requires increased oxygen consumption, and because the magnetic resonance signal from deoxygenated blood is reduced relative to oxygenated blood, changes in the blood oxygen level dependent (BOLD) response are related to changes in underlying neural activity in a given brain area. Statistical analysis of fMRI BOLD data attempts to relate changes in stimulation applied by the experimenter to changes in the BOLD response in different brain areas. From this type of analysis various types of deduction can be made including those about the functional role of different brain areas, about the interactions between brain areas, about the mechanisms of learning in the brain and about the modulation of brain activity by factors such as task.

In recent years there has been an explosion of fMRI-based research. To take one example, by using fMRI, researchers have been able to identify brain areas that seem to be associated with psychological cravings (Myrick *et al*., 2004).

8.3 QUANTIFYING BIOSIGNAL DATA

8.3.1 Level of measurement

As can be seen from the information presented in Section 8.2, the measurements made from psychophysiological data are almost always at true ratio level – that is, they behave like interval level measurements and possess a true zero (see Chapter 3). However, despite the high level of precision of psychophysiological measurements, the psychologist using these measures faces a significant problem. She must determine the psychological meaningfulness of any change in the biosignal. For instance, returning to the earlier example of using heart rate variability as a measure of mental workload, a statistically significant change in heart rate variability may not necessarily signify a psychologically meaningful change in mental workload. Thus, the interpretation of psychophysiological data is often more qualitative than the precision of the measures might seem to imply.

8.3.2 Hardware, signal processing and data volume

Having established that the scale of measurement is superior to that of nearly all psychological data, it is apparent that many issues in the quantification of parameters that bedevil psychology fade into insignificance in this area. However, the price of this philosophical simplicity is computational and methodological complexity. The measures made are invariably electrically based, exact to a predetermined level of accuracy defined by the properties of the sensors and any amplification used, and prone to levels of noise that can utterly distort any parameter or signal. So, in order to attempt to measure any physiological parameter from any part of the human body, fairly detailed knowledge is required of the underlying physiology to be assessed, the physical properties of the sensors or transducers to be

applied, the properties of the signals thus generated (electrical engineering and digital signal processing techniques) and the plethora of possible methods of analysis (both bivariate and multivariate methods of waveform analysis, periodicity analysis, event detection, pattern recognition and clustering techniques).

A simple measure such as heart rate (counted in beats per minute) seems a trivial parameter to acquire, until you ask yourself how you are going to measure the heart rate. Having found out that two electrodes placed, say, on each wrist will enable the acquisition of the information, your next problem is to work out how you are going to extract the heart rate parameter itself: that is, how you record the electrical signals. Assume next that you are provided with a computer-based recording system set up to output a number every 10 seconds or so which indicates beats per minute. Looking at the number, you see the heart rate is alternating between 50 and 70 beats per minute. Is this acceptable? The individual being assessed is sitting quietly. Your local expert happens by and notices that the 50 Hz hardware notch filter is off. In addition, checking the earth electrode shows that very poor electrical contact is being made between this and the individual. By improving this contact and switching the notch filter in-line, the heart rate stabilizes around 70 beats per minute. To understand what has happened requires knowledge of the expected heart rate, the properties of metallic electrodes, earthing problems, the operation of a notch filter, and the appreciation of how a heart rate monitor works. This is all *before* you begin to manipulate a single psychological variable. Note also that here you were dealing with a relatively large biological signal. Imagine attempting to measure high-frequency EEG of maybe 5 μV in amplitude with amplifiers that have background, self-generated electronic noise of about 1 μV, and where mains noise can be as large as 10–20 μV. The knowledge required to ensure that the signal you are seeing is actually biologically generated and not some property of the hardware in use, or of bad measurement technique, is quite considerable.

Unlike much purely psychological research, it is possible to generate quantitative physiological data that are literally pure error. This is a problem in some topographic EEG systems that provide maps of brain electrical activity computed from many electrodes placed upon the scalp. Most systems have automated filtering such that only frequencies between 0 and 40 Hz are displayed. However, if an electrode becomes detached from the scalp or its connecting wire breaks (inside the insulating plastic), this electrode will pick up large amounts of background mains noise (and any other stray frequencies present in the environment). Depending upon the efficiency of the filters, this electrode position will be seen as producing either very low-amplitude signals across the signal spectrum or high-frequency beta of moderate amplitude (where beta activity was defined as being from 20 Hz upwards). In this latter case, the filter does not remove *all* 50 Hz activity and, owing to spectral smearing (given a low sampling speed and short segment of EEG), this gets mapped as high-frequency activity in your EEG records. Experienced EEG technicians and researchers can invariably

detect this. For a novice researcher, it poses a serious problem. Once again, only knowledge of the measurement process and the characteristics of the hardware can guard against this incorrect interpretative process.

8.3.3 Designing the experiment and choosing parameters to measure

If you set up an experiment protocol, and have acquired some psychophysiological data, your next problem is deciding what parameters to extract from these data. This stage of the measurement process *must* be decided on the basis of a priori measurement and psychological hypotheses. Data dredging (extracting every conceivable parameter and attempting to relate them to the psychological parameters) in the hope of finding something is virtually impossible to implement in this area. So many parameters can be computed that attempting to sift through your data in this manner is a recipe for disaster. You will run out of time, computing facilities and energy! Modern laboratories routinely keep all physiological data on some form of archive medium (e.g. magnetic, CD-ROM or DVD). However, only certain hypothesis-specific parameters are extracted from this archive for use in the examination of psychological relationships. Should other hypotheses evolve over time, the archive data can then be reanalysed (where relevant) in order to permit the extraction of the new parameters.

One major problem you may face is that the system you are using to acquire psychophysiological data may permit only certain forms of analysis or, more rarely, provide no parameters at all. That is, you may have access to a computer-based skin conductance recording system, which will acquire and store the continuous conductance levels. However, if you do not have a program that analyses this output in terms of response latency and amplitude, then the data are practically useless. Your only options are to write all the incoming data to a chart recorder and carry out all such measures by hand, or (more usually) obtain or write a computer program yourself that implements the procedures necessary to extract these parameters. This highlights another global feature of psychophysiological data acquisition: the collection of data can take a few minutes, but the volume of data generated can tax the computer system whilst the analysis of one participant's data by hand can take days! This is particularly true for methods that measure brain activity such as electroencephalography, magnetoencephalography and fMRI where several gigabytes of data may be simultaneously recorded from a large number of locations in just a few hours. Even the latest analysis packages running on high-specification computers can take hours to complete each stage of the necessary analysis.

Of course, returning to the heart rate example above, it may be that only five such measures are made throughout an experiment, where (say) the only focus of interest is the effect of difficulty of task problem on heart rate. The drawback to such simple experiments is that the explanatory power of any results is limited by the paucity of variables analysed! As Fried and Grimaldi (1993) also point out in

their discussion of pulmonary (respiration) research, using observable movements of the chest or abdomen (pneumography) alone as indicators of respiration activity is not to be recommended, as $PETCO_2$ activity demonstrates that such movement can be quite unrelated to actual airflow into and out of the lungs. Thus, to use respiration rate or depth as an indicator of increasing or decreasing airflow is liable to be prone to error. In the same way, the use of heart rate alone is not of much practical use except as a simple descriptor of one particular feature of cardiac activity.

8.4 CONCLUSION

Psychophysiological methods offer insights into a wide range of human behaviours and experiences. In this chapter we have attempted to convey the breadth of techniques available to the psychophysiological researcher. In a chapter like this it is not possible to go into much depth, but it is hoped that we have whetted the appetite of students and researchers to look further into this area of investigation. The following short section on further reading should provide the requisite detail for helping a researcher embark on effective psychophysiogical research.

8.5 FURTHER READING

Andreassi (2000) is an excellent introductory text. It is probably the best general textbook for students who are completely new to the area. Cacioppo *et al.* (2000) should be read straight after Andreassi's text. This is a comprehensive book that is intended both as a reference source for the specialist and yet to be accessible to undergraduates.

Dempster (2001) is a good introductory text on the recording and analysis of psychophysiological data using modern computer-based data acquisition systems. Since electroencephalography is one of the largest research areas in psychophysiology, it is useful to take a look at Fisch (1999). This is written at an introductory level suitable for students who have no prior knowledge of psychophysiology but is also of value to experienced EEG users. For students who wish to undertake projects involving electroencephalography, it is an essential handbook that provides much practical as well as some theoretical information. For those who wish to learn about functional magnetic resonance imaging, Jezzard, Matthews and Smith (2001) provides an excellent starting point. Aimed at postgraduate level, it covers the underlying principles of fMRI and the design and analysis of fMRI experiments. Finally, Fried and Grimaldi (1993) is an absolutely brilliant book. It contains an excellent introductory section on psychophysiological measurement and provides a masterful description of respiratory functions and processes. In addition, the provocative and challenging hypotheses in the book make this probably one of the best 'specialist' books in this area.

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