3 Selecting the broad design of your study

- A key decision in your design is likely to be whether to perform an experimental manipulation or simply record natural variation. Both techniques have their advantages and disadvantages; and a combination of the two is often effective (Section 3.1).
- You may then have to address whether to study your subjects in their natural environment or in the more controlled conditions of the laboratory (Section 3.2) or whether to carry out experiments *in vitro* or *in vivo* (Section 3.3).
- All these decisions involve an element of compromise, and whilst there are good and bad scientific studies (and all the shades in between), there are no perfect ones (Section 3.4).

3.1 Experimental manipulation versus natural variation

Once you have chosen your research question, you then face the problem of how you are going to test your specific hypotheses. This is the crux of experimental design. One of the major decisions you will have to make is whether your study will be **manipulative** or **correlational**. A manipulative study, as the name suggests, is where the investigator actually does something to the study system and then measures the effects these manipulations have on the things that they are interested in. In contrast, a correlational study makes use of naturally occurring variation, rather than artificially creating variation, to look for the effect of one factor on another. A correlational study may also be called a *mensurative experiment* or an **observational** study.

In a **manipulative** study the experimenter changes something about the experimental system then studies the effect of this change, whereas **observational** studies do not alter the experimental system.

3.1.1 An example hypothesis that could be tackled by either manipulation or correlation

Imagine that we had a hypothesis:

> Long tail streamers seen in many species of bird have evolved to make males more attractive to females.

From this we could make the straightforward prediction that males with long tails should get more matings than males with short tails, but how would we test this?

Correlational approach

One way to test the prediction would be to find ourselves a study site and catch a number of males. For each male that we catch, we measure the length of their tail streamers, add leg bands to the birds to allow us to distinguish individuals, and then let them go again. We could then watch the birds for the rest of the season and see how many females mate with each male. If, after doing the appropriate statistical analysis, we found that the males with longer tails obtained more matings, this would support our hypothesis. A study like this is a correlational study—we have not actually manipulated the factor we are interested in ourselves, but made use of the naturally occurring variation in tail length to look for a relationship between tail length and number of mates. It is worth mentioning that some people get confused by the term correlational study, assuming that the name implies that the statistical test of the same name must be used to analyse the data collected. It does not.

Manipulative approach

An alternative approach would be to actually manipulate the length of the tail. So again, we would catch the male birds, but instead of just measuring them and letting them go, we would manipulate their tail length. For example we might assign the birds into three groups. Birds in group 1 have the ends of their tail streamers cut off and stuck back on again so that their streamer length is unchanged; these would form the control group. Birds in group 2 would have the ends of their tail streamers cut off, reducing their length. Birds in group 3 would have their tails increased in length by first cutting off the end of their streamers then sticking them back on, along with the bits of streamers that were removed from the birds in group 2. We then have three groups all of which have experienced similar procedures, but one resulted in no change in streamer length, the next involves shortening of the streamers and the last involves elongating them (see Figure 3.1). We would then add the leg bands, let the birds go, and monitor the numbers of matings. If the birds in the group with the extended tails got more matings than the birds in the other groups, this would support our hypothesis. If the birds that had had their streamers reduced also got fewer matings than the controls with unchanged length, this would also add further support for our hypothesis.

In this example, both the manipulative and correlational techniques seem effective; next we discuss the factors that must be considered to decide which would be most effective.

Both manipulative and correlative studies can be effective, and the best approach will depend on the specifics of your situation.

3.1.2 Arguments for doing a correlational study

Correlational studies have several advantages. They are often easier to carry out than manipulative studies. Even from the number of words that we've just used to describe

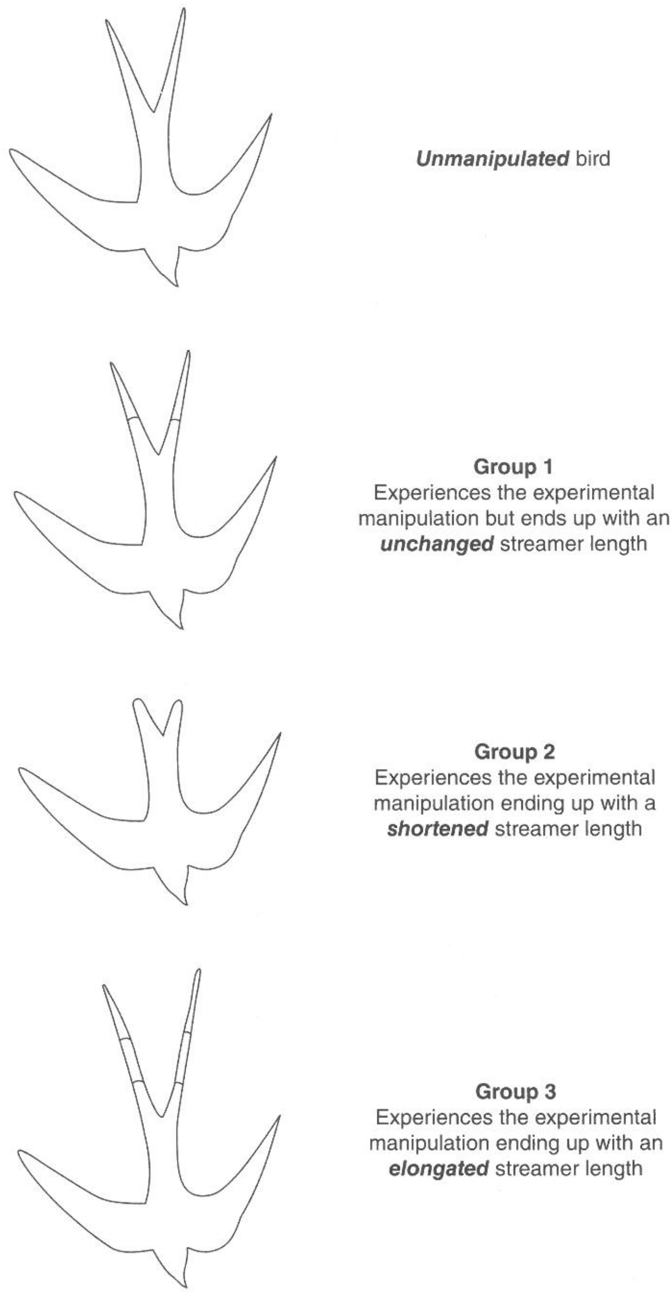

Figure 3.1 For the experiment exploring the relationship between streamer length and mating success in a bird species discussed in Section 3.1.1, we argue that three experimental groups are required. Each group experiences manipulation of its streamers, but this manipulation has a different effect on streamer length in the three cases: in Group 1 the streamers are unchanged in length after manipulation, in Group 2 they are shortened, and in Group 3 they are increased in length.

these two different ways of testing our hypothesis about tail streamers, it is clear that the correlational study will often involve less work. This may not just be an advantage through saved time and effort, it may also mean that you have to handle or confine organisms for much less time, if at all. If we are dealing with organisms that are likely to be stressed or damaged by handling, or samples that can be contaminated, this is obviously a good thing.

A major worry of doing manipulative studies is that the manipulation that you have carried out will have unintended effects. Biological organisms are integrated units and any change in one part may have profound effects on other functions. If we cut off part of a male's tail, this might affect his ability to fly as well as his attractiveness, and any results we see as a consequence might be due to changes in his flight ability, and not due to his tail length directly. Even in fields where modern techniques of genetic engineering allow single genes to be modified or knocked out, it is impossible to be sure that our manipulation doesn't alter things other than the characters we are interested in. If we design our experiments carefully, with adequate and appropriate controls, we should be able to detect such spurious effects if they occur, but we should always be cautious. In the current study, we could imagine how all our manipulations might impair flight performance and so foraging ability, thus causing our study individuals to be in poor condition. The overall lower condition of birds in our sample would mean that our ability to generalize our conclusions to birds with a range of body conditions is weakened. Further, the poor condition of all our birds might reduce their attractiveness to females, making any difference between groups more difficult to detect (a floor effect: see Section 11.6.5). Such problems will not arise in a correlational study.

A final benefit of correlational studies is that we can be sure that we are dealing with biologically relevant variation, because we haven't altered it. Suppose that we extend or reduce tail streamers by 20 cm, but in nature, tail streamers never vary by more than 2 cm across the whole population. Since we have modified birds such that they have traits that are far outside the naturally occurring range, it is doubtful that our experiment can tell us anything biologically relevant about the system. Again, this need not be a fatal problem of manipulative studies. As long as manipulations are carefully planned and based on adequate biological knowledge and pilot data of the system, this problem can be avoided. That said, we urge you to think carefully about the biological relevance of any manipulation that you plan before you carry it out.

Correlational studies are generally easier to perform, and have less chance than manipulative studies of going badly wrong.

3.1.3 Arguments for doing a manipulative study

Given all the issues raised in the preceding section, you might now be wondering why anyone ever bothers to do a manipulative study at all. Despite the advantages offered

A **third variable** (also called a *confounding factor* or *confounding variable*) is a variable (*C*) that separately affects the two variables that we are interested in (*A* and *B*), and can cause us to mistakenly conclude that there is a direct link between *A* and *B* when there is no such link.

by correlational studies they suffer from two problems: **third variables** and *reverse causation*. As problems go, these can be big ones.

Third variables

We can sometimes mistakenly deduce a link between factor *A* and factor *B* when there is no direct link between them. This can occur if another factor *C* independently affects both *A* and *B*. *C* is the third variable that can cause us to see a relationship between *A* and *B* despite there being no mechanism providing a direct link between them.

As an example, imagine that we survey patients in a general practitioner's (GP's) waiting room and find that those that travelled to the GP by bus had more severe symptoms than those who travelled by car. We would be rash to conclude from this that travelling by bus is bad for your health. The cause of the correlation is likely to reside in a third variable: for example, socioeconomic group. It may be that there is no direct link between bus travel and poor health, but those from lower socioeconomic groups are likely to be both in poorer health and (separately) more likely to use buses than the more affluent.

Let's go back to the correlational study earlier where we found a relationship between tail streamer length and the number of matings that a male obtained. Does this show that the length of a male's tail affects the number of matings that he gets? What if females actually base their choice on the territory quality of a male, not on his tail length at all, but males on good territories are able to grow longer tails (maybe they can get more food on the better territories). We might think that we have observed a causal relationship between the number of matings that a male gets and his tail length, but what are actually occurring are separate relationships between the quality of territory and both the number of matings that the male gets and his tail length. Territory quality is a third variable that affects both male tail length and the number of mates that the male gets. Because it affects both, it leads us to see a relationship between the number of matings that a male gets and the length of his tail, even though females do not consider tail length when evaluating a male at all. In almost any correlational study there will be potential third variables that we have not measured and that could be producing the relationship that we observe. It is important that you understand the concept of third variables clearly, so let's look at some further examples.

Ronald Fisher, a famous (and sometimes eccentric) evolutionary biologist, statistician, and pipe-smoker, is reputed to have used third variables to discount the observed relationship between smoking and respiratory diseases. Smoking, he argued, does not cause diseases; it is just that the types of people that smoke also happen to be the types of people that get diseases for other reasons. Maybe these are diseases caused by stress, and stressed people are also more likely to smoke.

More women graduates never marry than would be expected for the population as a whole. This does not mean that going to university makes a woman less likely to marry as such (or that no one would want to marry the sort of male you meet at university). It perhaps means that personality traits or social circumstances associated with a slightly increased chance of going to university are also associated with a slightly decreased chance of marrying.

There is a correlation between the amount of ice cream sold in England in a given week and the number of drowning accidents. This is unlikely to be a direct effect: that, say, heavy consumption of ice cream leads to muscle cramp or loss of consciousness among swimmers. More likely a third variable is at work: when the weather is warm then more ice creams are sold but also (and separately) inexperienced sailors hire boats and people who are not strong swimmers dive into rivers and lakes.

In short, third variables mean that it is difficult to be confident that the pattern we have observed in an unmanipulated system is really due to the factors that we have measured and not due to correlation with some other unmeasured variable. The only way to be certain of removing problems with third variables is to carry out experimental manipulations.

Q 3.1 In a survey of road-killed badgers it was found that those with higher levels of intestinal parasites had lower bodyweights: can we safely conclude that intestinal parasites cause weight loss or is there a plausible third variable effect that could explain this observation?

Reverse causation

The second problem of correlational studies is **reverse causation**. This can occur when we see a relationship between factors *A* and *B*. It means mistakenly assuming that factor *A* influences factor *B*, when in fact it is change in *B* that drives change in *A*.

Reverse causation is mistakenly concluding that variable *A* influences variable *B* when actually it is *B* that influences *A*.

For example, imagine a survey shows that those who consider themselves to regularly use recreational drugs also consider themselves to have financial worries. It might be tempting to conclude that a drug habit is likely to cause financial problems. The reverse causation explanation is that people who have financial problems are more likely than average to turn to drugs (perhaps as a way to temporarily escape their financial worries). In this case, we'd consider the first explanation to be the more likely; but the reverse causation explanation is at least plausible. Indeed, both mechanisms could be operating simultaneously.

Let's consider another example of reverse causation. There is a correlation between the number of storks nesting on the chimneys of a Dutch farmhouse and the number of children in the family living in the house. This sounds bizarre until you think that larger families tend to live in larger houses with more chimneys available as nest sites for the storks. Large families lead to more opportunities for nesting storks; storks don't lead to large families!

Reverse causation is not a universal problem of correlational studies. Sometimes reverse causation can be discounted as a plausible explanation. In our correlational study of male tail streamer length and mating success described earlier, it would be extremely difficult to imagine how the number of matings a male gets later in a season could affect his tail length when we catch him at the beginning of the season. However, imagine that we had instead caught and measured the males at the end of the season. In that case it might be quite plausible that the number of matings a male gets affects his hormone levels. The change in hormone levels might then affect the way that the male's tail develops during the season in such a way that his tail length comes to depend on the number of matings that he gets. In that case we would observe the relationship between tail length and matings that we expect, but it would be nothing to do with the reason that we believe (females preferring long tails). Such a pathway might seem unlikely to you and you may know of no example of such a thing happening. However, you can be sure that the Devil's Advocate will find such arguments highly compelling unless you can provide good evidence to the contrary. Experimental manipulation gets around the problems of reverse causation, because we manipulate the experimental variable.

These two problems of non-manipulative studies are captured in the warning, 'correlation does not imply causation' and are summarized in Figure 3.2. Many of the hypotheses that we will find ourselves testing as life scientists will be of the general form 'some factor *A* is affected by some factor *B*' and our task will be to find out if this is indeed true. If we carry out a correlational study and find a relationship between *A* and *B*, this provides some support for our hypothesis. However, the support is not in itself conclusive. Maybe the reality is the *A* affects *B* through reverse causation or that some other factor (*C*) affects both *A* and *B*, even though *A* and *B* have no direct effect on each other. Such problems mean that at best our correlative study can provide data that are *consistent* with our hypothesis. If we wish to provide unequivocal evidence that *A* affects *B*, then we must carry out a manipulative study. Thus, we would encourage you to think carefully before embarking on a solely correlational study.

Q 3.2 Would you opt for correlation or manipulation if you wanted to explore the following:

(a) Whether having a diet high in processed foods increased a person's propensity for depression.

(b) Whether a diet high in saturated fats increases the risk of a heart attack.

Third variable (and to a lesser extent) reverse causation effects are big drawbacks of correlational studies that are likely to make a manipulative study more attractive.

3.1.4 Situations where manipulation is impossible

In the last section we were pretty harsh about correlational studies. Yet many correlational studies are carried out every day, and the scientific journals are full of examples. There are a number of situations in which correlational studies can provide very valuable information.

Sometimes it is simply not possible to manipulate. This may be for practical or ethical reasons. You can imagine the (quite reasonable) outcry if, in an attempt to determine the risks of passive smoking to children, scientists placed a number of babies in incubators into which cigarette smoke was pumped for eight hours a day. Such problems are common in studies relating to human health and disease (epidemiology) and, as a consequence, correlational studies fulfil a particularly important role in this field (we discuss aspects of their use in this field in Box 3.1).

It may also not be technically feasible to carry out the manipulation that we require in order to test our particular hypothesis. Modifying streamer length was a difficult enough manipulation; experimentally modifying beak length or eye colour in a way that does not adversely affect the normal functioning of subject birds would be nearly impossible.

A second valuable role for correlational studies is as a first step in a more detailed study. Imagine that you want to know what sorts of factors affect the diversity of plants in a given area. One possible approach would be to make up a list of everything that you think might be important—all the soil chemicals and climactic factors—and then design a programme of experiments to systematically examine these separately and then in combination. Such a study would be fine if you had unlimited research funds (not to mention unlimited enthusiasm and research assistants). However, a more efficient approach might be to begin with a large correlational study to see which factors seem to

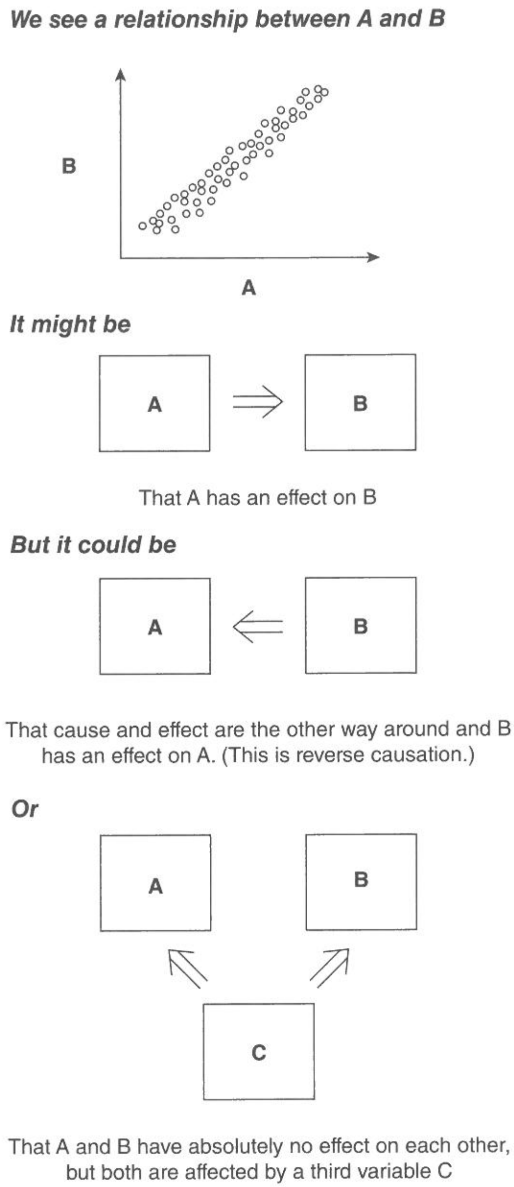

Figure 3.2 When we find a relationship between two variables (*A* and *B*) then we must be careful in how we interpret the mechanism underlying the observed relationship, since a number of (non-exclusive) possibilities exist. If we want to argue that the likely explanation is that the value of *A* influences the value of *B*, then we need to demonstrate that this is a more plausible mechanism than two alternatives: reverse causation and third variable effects. In our case, the reverse causation mechanism is that variable *B* strongly influences *A* (rather than vice versa); the third variable explanation is that actually there is no direct mechanism linking *A* and *B*, but both *A* and *B* are strongly linked to a third variable (*C*).

BOX 3.1 The role of correlative studies in human epidemiology

Correlation studies are particularly important in epidemiology: the study of the factors relating to health and illness in a population, where it is generally neither practical nor ethical to carry out manipulations. Ethically, manipulations generally have to be changes that are expected to have a neutral or positive impact on the health and welfare of the subjects involved. Thus the most common use of manipulative study in the medical sciences is in clinical trials of new therapies. Such studies generally take a great deal of organization to set up because it can be very easy for conflict to develop between interventions that are perceived to be best for an individual patient and the needs of the trial. If during the trial, having been randomized to a new treatment, a patient does not seem to be responding as well to treatment as the doctor would expect, then there is an understandable tendency for the doctor to want to switch that patient to the established treatment. Conversely, if over the course of a trial it becomes clearer that a novel treatment is performing much better or worse than the established treatment, then doctors involved in the study might (again reasonably) want to call the trial to a halt and treat all their patients in what appears to them to be the most efficacious manner. These problems can be resolved to some extent by blind procedures (see Section 11.6.3), by briefing participants clearly about the value of the trial, and by having protocols in place to stop the trial earlier than planned if interim analyses of partial results provide a clear conclusion. Informed consent is a normal requirement for patients to take part in a clinical trial, and this can be time-consuming to achieve and needs to be done very carefully to avoid bias arising from self-selection of subjects. Getting patient agreement can be particularly challenging where placebos are involved. One large-scale trial of a potential AIDS treatment was greatly damaged by informal groups of patients enrolled in the trial pooling their drugs such that even those assigned to the placebo would get some of the potential benefit from the new drug. For these reasons correlational studies are particularly valuable in the medical sciences.

be most important. Once potentially influential factors had been selected, manipulative studies could be used in a more targeted way to confirm and refine these findings.

So ultimately there is nothing wrong with correlational studies—they fulfil an important role in the life sciences. Often a correlational study followed by carefully targeted manipulative studies will provide more compelling arguments than either would have provided alone. Correlational studies can have weaknesses, and the conclusions that we can draw will ultimately be limited by these weaknesses. However, as long as we are aware of these weaknesses, and do not overstate our results, correlational studies can be very useful.

Correlational studies can be a useful and practical way to address biological questions, but their limitations must always be borne in mind.

3.2 Deciding whether to work in the field or the laboratory

Another decision that you will often be faced with in many life science studies is whether it will be laboratory-based or field-based. Here the answer will depend on the question you are asking, and the biology of the system concerned. There are advantages and disadvantages to both approaches. Suppose that we are interested in knowing whether provisioning a larger clutch of young reduces a female zebra finch's survival. We decide that we will manipulate clutch size, by removing or adding eggs to zebra finch nests, and then monitoring the survival of the mother after the chicks have fledged.

We could potentially carry out such an experiment in either the lab or the field. How should we choose? Let's begin with the lab. Maybe the most obvious question to ask is whether your study organism will be comfortable in the lab. In this case, we are unlikely to have a problem, as zebra finches will breed readily in captivity; but if we had been looking at the same question in a bird that is more challenging to keep in captivity (like an albatross), we might have had problems. The suitability of an organism for lab studies is hugely variable, and must be given careful thought. If an animal is not well disposed to captivity, then there are obvious welfare implications as well as the risk that your results will have limited relevance to the situation in nature.

Now, assuming that your organism will be happy in the lab, there are several advantages of a lab study. In general it will be far easier to control conditions in a lab setting, allowing you to focus on the factors of interest without lots of variation due to other uncontrolled factors. Things like temperature, daylight, and food supply can all have profound effects on organisms, and variation due to these factors might mask the effects we are interested in. We can also ensure that all of our animals are well fed or our plants well watered, removing between-individual variation that could be caused by these factors in a natural setting. Observation will also generally be much easier in the lab. While the thought of watching zebra finches in the sunny Australian outback may sound idyllic, the reality of spending weeks trying to find your study birds is far less attractive. It will nearly always be easier to make detailed measurements on most organisms in the lab.

On the other hand, the controlled nature of the lab environment is also its major drawback. Laboratory individuals will not experience many of the stresses of everyday life in the field, and that can make it difficult to extrapolate from lab results. Suppose that we find absolutely no effect of our laboratory manipulations on the lifespan of female zebra finches. What can we conclude? We can conclude that the manipulation had no measurable effect *under the particular laboratory conditions that we used.* This is very different from saying that it would have had no effect in the wild, which is presumably what we are really interested in. It is quite conceivable that our well-fed laboratory birds in their temperature-controlled rooms, free from parasites, can easily cope with extra chicks, but that in the harsher environment of the field they would have suffered a large cost. Of course, if we found no effect in the field, this result would only apply to the specific environmental conditions that occurred during our study; but those conditions are still likely to be more representative than the conditions in a lab. Thus, it is usually safer to generalize from a field study than a lab study. Generalization is a subject that is at the heart of statistical methodology, so we explore it a little further in Statistics Box 3.1.

Sometimes, our research question means that a lab study is impractical. If we are interested in differences between the sexes in effort expended in feeding the young in the nest using zebra finches, then it would be very difficult to create foraging conditions in an aviary where the conditions were close enough to those naturally experienced by wild birds. In the wild parents will bring back a great diversity of food types gathered from a wide variety of microhabitats sometimes hundreds of metres distant. This would be impossible to faithfully recreate in the lab. The danger is that any aviary experiments that you conducted on this would be discounted by Devil's Advocates as being entirely artefactual, due to your asking birds to operate in a foraging situation far removed from that which they have been evolutionarily adapted to cope with. However, if your research question is about how egg laying affects the distribution of reserves of calcium in different parts of females' bodies, then it would be easier to argue that this is less likely to be influenced by the environmental conditions, and hence a laboratory experiment might be reasonable. So, as ever, *the most appropriate approach depends on your research question.*

STATISTICS BOX 3.1 **Generalizing from a study**

An important issue in the interpretation of a study is how widely applicable the results of the study are likely to be. That is, how safely can you generalize from the particular set of subjects used in your study to the wider world? Imagine that we measured representative samples of UK adult males and females and found that males in our sample were on average 5 cm taller. Neither we nor anyone else are particularly interested in our specific individuals, rather we are interested in what we can conclude more widely from study of the sample. This becomes easy if we think about the population from which our sample was drawn. Our aim was to create a representative sample of UK adults. If we have done this well, then we should feel confident about generalizing our results to this wider population. Can we generalize even wider than this: say to European adults or human adults in general? We would urge a great deal of caution here. If your interest was in European adults, then you should have designed your study in the first place to obtain a representative sample of European rather than only UK adults. However, providing you add an appropriate amount of caution to your interpretation then it may be appropriate to use your knowledge of biology to explore how your results can be extrapolated more widely than your original target population. In this specific case, the specific difference of 5 cm would probably have little relevance beyond your specific target population of UK adults, since other countries will differ significantly in factors (e.g. racial mix, diet) that are highly likely to affect height.

Our advice would be to aim to work in the field—generally giving results that are easier to generalize from—unless it is impracticable to do so.

3.3 *In vivo* versus *in vitro* studies

In many ways, the question of lab or field has analogies in the biomedical sciences with whether to carry out studies *in vivo* or *in vitro*. If we want to know whether an antimalarial drug alters the reproductive strategy of a malaria parasite, do we measure this using parasites in Petri dishes or within organisms? *In vitro* will generally be easier to do (although this is certainly not always the case), easier to control, and easier to measure. But do the results have any bearing on what would happen in the natural system? The most effective approach will depend on the details of your study and there are advantages and disadvantages to each. Indeed the best study would probably contain evidence from both approaches.

Issues of generalization of results will lead you towards *in vivo* experiments, whereas issues of practicality will lead you to *in vitro*.

3.4 There is no perfect study

Hopefully by now you will have got the impression that there is no perfect design that applies to all experiments. Instead, the best way to carry out one study will be very different from the best way to carry out another, and choosing the best experimental approach to test your chosen hypothesis will require an appreciation of both the biology of the system and the advantages and disadvantages to different types of studies. This is why *biological insight is a vital part of experimental design*. Let's illustrate these points by considering another example: the relationship between smoking and cancers.

In a sense, all the data that we collect tells us something, but whether this something is useful and interesting can vary dramatically between data sets. Some data will be consistent with a given hypothesis, but will also be consistent with many other hypotheses too. This is typical of purely correlational studies, where it is difficult to discount the effects of reverse causation or third variables. A positive relationship between lung cancer and smoking definitely provides support for the idea that smoking increases the risk of lung cancer, but it is also consistent with many other hypotheses. Maybe it is due to stress levels that just happen to correlate with both smoking and cancer. Or maybe stress is an important factor, but there is also a direct link between smoking and cancer. In order to draw firm conclusions, we need something more. Our confidence might be improved by measuring some of the most likely third variables—like stress or socio-economic group—to allow us to discount or control for their effects. This would reduce the possibility that an observed relationship was due to some other factor, but would not remove it entirely (since there may still be some confounding factor that we've failed to account for).

If we were able to do an experiment where people were kept in a lab and were made to smoke or not smoke, any relationship between cancer and smoking emerging from such a study would be far more convincing evidence that smoking caused cancer. If this could be repeated on people outside the lab, the evidence that smoking caused cancer in a real world setting would become compelling. However, such experiments are ethically intolerable. Even if we can't do these experiments we can do other things to increase our confidence. Maybe we can demonstrate a mechanism. If we could show in a Petri dish that the chemicals in cigarette smoke could cause cells to develop some pathology, this would increase our confidence that the correlational evidence supported the hypothesis that smoking increases the risk of cancer. Similarly, experiments on animals might increase our confidence. However, such experiments would entail a whole range of ethical questions, and the generality of the results to humans could be questioned.

Good experimental design is all about maximizing the amount of information that we can get, given the resources that we have available. Sometimes the best that we can do will be to produce data that provide weak evidence for our hypothesis. If that is the limit of our system, then we have to live with this limitation. However, if what we can conclude has been limited not by how the natural world is but by our poor design, then we have wasted our time and probably someone's money too. More importantly, if our experiment has involved animals these will have suffered for nothing.

Hopefully, if you think carefully about the points in this chapter before carrying out your study, you should avoid many of the pitfalls. If you want to test your knowledge of the concepts introduced in this chapter a little more, then we offer more self-test questions in the supplementary information. Otherwise, let's proceed to the next chapter, where we explore how we meet one of the central challenges in experimental design: dealing with the variation between individuals that is widespread in biology.

There are always compromises involved in designing an experiment, but you must strive to get the best compromise you can.

Summary

- Correlational studies have the attraction of simplicity but suffer from problems involving third variable effects and reverse causation.
- Manipulative studies avoid the problems of correlational studies but can be more complex, and sometimes impossible or unethical.
- Be careful in manipulative studies that your manipulation is biologically realistic and does not affect factors other than the ones that you intend.
- Often a combination of a correlational study followed by manipulation is very effective.

- The decision whether to do animal experiments in the field or laboratory will be influenced by whether the test organism can reasonably be kept in the laboratory, whether the measurements that need to be taken can be recorded in the field, and on how reasonably laboratory results can be extrapolated to the natural world. All these vary from experiment to experiment.
- There is no perfect study, but a little care can produce a good one instead of a bad one.