Fundamentals of Cognitive Psychology

Daniel N. Bub and Michael E. J. Masson

University of Victoria

Chapter 1

General Methodological Principles

Every minute, every second of our lives, we are constantly engaged in some kind of mental activity. We often take the enormous richness and complexity of our experiences for granted; our perceptions, thoughts, memories and feelings simply appear to be *there*, apparently without much effort on our part and with little delay before they emerge fully formed into consciousness. Because of the effortless and immediate quality of many aspects of our mental world, it might be tempting to assume that the underlying mechanics of our cognitive abilities should be quite simple--it takes us hardly any time at all, for example, to identify and name a familiar object or to recognize the face of someone we know in a crowd. Surely, then, must it not be that these basic cognitive skills are straightforward for the brain to accomplish, and so also quite easy for us to understand scientifically?

Actually, our basic every-day mental abilities that operate so reliably most of the time and that we use to make our way through life--the systems that enable us to identify and name a familiar visual object, have conversations with each other, read and write, remember facts and events, plan our activities and so on--are the result of stupendously complex, exquisitely orchestrated sequences of events that we have only recently begun to analyze and describe systematically. It would be wrong to say that we have already developed a detailed understanding of these basic cognitive systems--the problems are very complex and the relevant questions that need to be answered must be tackled at a number of different levels before we can obtain really fundamental insights into the mechanisms of our own minds. However, we have made substantial progress in many domains and though some deep mysteries remain (for example, we do not have much of an idea about how consciousness arises from neural activity), cognitive psychology has emerged as an exciting and challenging scientific enterprise.

Our goal in this course is to provide you with a good (hopefully, even excellent) understanding of the modern approach that cognitive psychologists have developed to objectively analyze different mental processes and the organization of these elementary processes into complex systems.

Modular Systems

In this section, we need to discuss and understand the basic experimental tools that cognitive psychologists rely on to analyze mental systems, By "experimental tools", we do not only mean the actual physical equipment--computers, electrodes, clocks, and so on--that is usually required to measure responses from subjects taking part in experiments. We are mainly interested in conveying to you the logic we have to use before we are entitled to reach a general conclusion about a particular phenomenon that we are trying to analyze.

Before taking the plunge, let us pause for a moment to think about the complexity that confronts us, the problem or set of problems that we are trying to understand. Typically, in carrying out any successful experiment, we want to examine one particular aspect of a complicated system to understand how that part contributes to the action of the whole. This is the nature of the enterprise in all branches of science that have emerged so far: We must be sure that we can isolate one component or element of a complex whole to see how the parts interrelate. The more genuine parts we can uncover--it is no use if the parts are not the real ones--and the more we understand about the relationships between them, the deeper our understanding of the domain being studied.

To apply this way of thinking to the cognitive domain, think for a moment about what must be involved in carrying out even an apparently elementary task like reading a single word aloud, for example the word BEAR. It takes a skilled reader little more than 1/2 second to produce the pronunciation of a four-letter word like BEAR, timed from the onset of its appearance on a visual display such as a computer monitor. (In experiments, we typically measure this time by starting a clock, accurate in milliseconds [units of 1/1000 of a second], simultaneously with the appearance of a visual word. The subject is asked to read the word aloud as quickly and as accurately as she can into a microphone connected to a voice activated relay. The relay detects the vocal response and instantly stops the clock. We repeat this procedure for many words, usually about 30 or 40, to obtain an average response time).

To read the word BEAR aloud, we need to accomplish an impressive range of cognitive steps. You need to:

- look at the spatial location of the word on the screen.
- accurately analyze the visual letters making up the word (the first letter is a B, not a P or an R, which are very similar).
- maintain the order of the letters as visual forms (the first letter is a B and the last is an R, not the reverse).
- assign the correct spoken form to the sequence -EAR in the context of the initial B (it is not the pronunciation "*eer*" as in FEAR, and HEAR, but "*air*" as in BEAR and WEAR).
- program the appropriate articulatory gestures of your tongue and throat so that you actually produce the auditory form of the word.

At the same time as we engage our articulatory abilities, we understand the meaning of the word we are reading. We could easily point to the animal corresponding to the word BEAR if we were asked to select it from a group of other animals, so that we can accurately map between our language and perceptual systems, and we can call up from memory a considerable range of facts appropriate to the actual animal symbolically referred to by the word. Bears eat salmon, climb trees, live in Canada, come in several different varieties and so on.

The episode of reading the word BEAR is also registered in another set of complex systems. If the subject is asked some time later to recall the word that he read, he will most probably be able to do so, though of course, success will depend on a number of factors, including the delay between the episode and recall.

This example illustrates a crucial point that applies to the cognitive world as much as it does to the physical world--the systems that drive mental functions interconnect in a very complex, dynamic fashion, and it is difficult, though not impossible, to develop methods that can separate out the components of one functional system from the activity of the whole.

Our cognitive abilities are the result of many different systems working in concert and to some extent independently. We are not aware of this fact as functioning, conscious individuals, but the actual evidence leaves no room for doubt. Our minds work rather like an orchestra playing a single intricate melody or series of melodies; there are many different parts to the orchestra, even though we may not be aware of the complex interplay of the different sections when we simply hear to the music.

The discovery that our cognitive abilities are the result of integrated systems that operate to some extent independently represents a big step forward. We say that cognitive mechanisms are *modular* in their organization and by this we mean that there are different systems (like the string section of an orchestra, as opposed to the brass section) with components that operate separately and independently to carry out the task as a whole, just as different musicians in particular sections of an orchestra coordinate their actions to produce an intricate melody.

Isolating a Piece of the Mind

What methodological tools have psychologists developed to uncover the individual components of integrated cognitive systems? If you try to think a little about this question, you may immediately find yourself considering the problem in terms of neurological systems. Aren't the cognitive "parts" we referred to earlier located in different brain regions? If they are, psychologists could directly attack the question of the modular organization of cognitive systems by looking for clues in the brain and its particular physical organization.

Unfortunately, the matter is not quite so straightforward that we can go directly to the brain for answers. For one, we will of course get nowhere simply by looking at the gross structure of the brain, nor very far by learning about rough, general relationships between large anatomical areas (say the bottom half of the temporal lobe) and particular global mental functions (say, the ability to recognize objects). It is worth knowing, of course, that the inferior temporal lobes have some important role to play in object recognition, but we are looking for as much detail and precision as we can muster and so as cognitive psychologists, we want much more than broad correlations between neuroanatomy and cognitive function.

There is another basic point to consider in struggling with the relationship between brain systems and mental systems: It is quite possible that more than one cognitive "part" are tangled together in a particular brain region. Cognitive parts of a complex system may often be separable in the sense that they carry out different kinds of actions, but they need not be spatially separate in the brain the way the members of an orchestra section are separately located in different seats, or the way functionally different parts of your body are physically distinct.

We will never be able to discover the natural components that govern higher cognitive function without a clear set of methodological procedures that isolate different components during the performance of an actual cognitive task. And we should not, at least to begin with, develop our basic concept of "cognitive part" or module as a physical entity. Rather, we must begin by thinking of modules in terms of the specialized *functional* role each of them plays as the system carries out a particular global operation (like reading aloud, for example). If we can get this first step more or less right, we will have some hope of eventually understanding how the actual physical action of the brain accomplishes the functional steps that we have identified and analyzed.

Task Analysis

To return to the example of reading a single word aloud, we said that the task requires a number of definite steps in going from the printed letters on the page to the spoken utterance that is the actual pronunciation of the word. Our notion of "steps" at this beginning point of the analysis remains fairly intuitive, but it requires that we develop enough insight (by repeatedly thinking the problem through) to define some of the essential operations needed to carry out the global task that is of interest to us.

We may use the term *task analysis* to describe the conceptualization of several discrete cognitive operations underlying a single task. Because such an enterprise is the foundation on which a detailed understanding of cognitive systems has to be built, it is the really hard part of a research program. Unfortunately, there is no simple recipe for learning how to carry out theoretically productive task analyses that lead to clever experiments and a deeper understanding of the cognitive system. Like all such enterprises in science, we proceed at first with a simple but insightful conjecture, and we attempt to find experimental evidence for this idea. In the process, our initial understanding becomes more elaborate and refined, leading to further conceptual distinctions and more experimental evidence, and this process of conjecture and discovery continues without end as we pull ourselves up by our bootstraps!

We will discuss many examples of task analyses, in which different modular components that make up a more complex integrated system have been identified and some of their characteristics defined. As we proceed, you will develop a better understanding of what this involves; for now, let's return to the example with which we began this section: Reading aloud a single printed word, say the word BEAR.

The printed sequence B...E...A...R physically consists of sets of lines and curves on the page, divided by spaces that are used to define the location of individual visual objects of a certain kind (i.e., letters). If you were shown the string BFWR instead of BEAR, you would neither be able to derive a single word as a pronunciation from the letters nor any meaning, but you would of course still perceive the identities of the letters and the names you learned for each of them ("*bee*", "*eff*" and so on).

So the first major perceptual task for the reading system is to identify the letters in the word from the lines on the page, and this step must begin before other higher stages of processing for the sound and meaning of the word can occur.

We can say that the systems that convert print into sound and meaning (i.e., the systems that normally allow a printed word to be read aloud and understood) need input to begin their activity from perceptual modules that rapidly extract the identity of each letter in its appropriate location on the page. This system is very complicated and would be organized into many different further subsystems; for example, filtering systems that prevent letters from different locations interfering with each other, systems that integrate parts of each letter into a single object (e.g., the curved part of the letter P and the straight edge must be combined to form a single familiar object), systems that orient to the correct spatial location, and so on. We will lump all of these together for the moment under the heading "Letter Analysis". Note that by "Letter Analysis" we do not imply that each letter in the word is consciously attended and named. That kind of process would yield disastrously slow reading times and in any case, would not give a pronunciation for the word. (You cannot get from letter names like "*bee*" "*eeh*" "*aih*" "*are*" directly to the correct pronunciation of BEAR). By "Letter Analysis" we simply mean a complex system of processing components--quite distinct from other systems that derive sound and meaning from the written word--that are responsible for rapidly activating the particular visual form of a letter in each location on the page. The task requires that shapes that are similar, like R and P or C and G, are not confused (we do not usually mistake the word POPE and ROPE, even though physically, the sequences differ by only one small angled line in the first position) and that the activation proceeds rapidly for all letter positions in the string (we would all be poor readers if letter analysis always deteriorated significantly in longer words).

From the system "Letter Analysis", how do we proceed? We need to define, at least in rough outline, a plausible sequence of processing events that must take place for a string of activated letters to produce the sound of a word and the meaning of a concept that it denotes. Let's try the following as a working assumption: Suppose that the letters contact a system that matches each spelling segment in the word to an individual sound unit on the basis of a general rule. The letter B for example is usually pronounced "*buh*" in a word, EA as a pair is typically pronounced "*ee*" and R is always "*ruh*". These sounds are blended together, we may suppose, to produce the complete pronunciation of the word, which is then used to look up the meaning, just like a spoken word received from an auditory input.

You can see immediately that this idea won't work! In English, and in many other orthographic systems, spelling segments like EA (these pairs are called digraphs, because we an

Figure 1.1. Schematic diagram of the systems involved in pronouncing visually presented words.

assign a single pronunciation to them) do not correspond to a single unambiguous pronunciation. It depends on the context of the surrounding letters! For some strings, we could imagine a general rule, applying to many different sequences, that takes this context into account (for example, A before L and R has a different pronunciation than A before other consonants; compare PARCEL with PASTEL). In a case like BEAR, though, and for numerous other words as well, there is actually no way you can derive the correct pronunciation simply by associating a general rule to the segments of the word, even if you try and use context to make the rule as specific as possible. EAR is usually pronounced "*eer*" as in FEAR, HEAR, GEAR, DEAR, NEAR, REAR, and so on. But BEAR, PEAR and WEAR have a different pronunciation, and so we cannot produce any of them correctly without actually mapping the entire sequence of visual letters to the corresponding spoken form.

Let's summarize the argument we are making: To read a single word, we need to rapidly extract letters in their correct order from discrete locations on the page. These visual forms somehow must together make contact with the language system, and we considered the possibility that they do so by means of a general processing mechanism that assigns a spoken value to different spelling segments in the word and then blends them together to produce an integrated pronunciation. We can think of such a mechanism as being quite sophisticated--it can take varying contexts into account to modify the pronunciation it assigns a vowel or consonant, say--but for many languages, this processing system cannot be sufficient. There are hundreds of words that can be pronounced only if the entire sequence of letters is mapped to a unique pronunciation that is specific to the sequence itself and no other. To see this point clearly, consider the word PINT contrasted with HINT. To read PINT aloud requires that we retrieve a specific pronunciation for the sequence P...I...N...T. If we simply matched INT to a general pronunciation we would produce a short vowel for I, as in MINT, HINT, FLINT, and so on. The only time the vowel in the sequence INT is lengthened is when P stands at the beginning of the word, so there must be some kind of map from letters to pronunciation that includes knowledge of specific orthographic sequences forming entire words.

Our analysis of reading single words, then, indicates that there is some system onto which letters are mapped that includes the spelled form of the entire word. We could therefore represent at least part of the flow of information from letters to pronunciation as shown in Figure 1.1.

This simple diagram is used to depict the flow of information between perceptual systems dealing specifically with letters strings (Letter Analysis) and another higher-level system (Visual Word Form Synthesis) that provides a map to pronunciation based on the sequence of letters as a familiar word. The letter string B...E...A...R must be extracted from the marks on a page, and the sequence of letters must contact a stored description of the entire word as a spelling pattern before the correct pronunciation is activated.

We should think of the diagram in Figure 1.1 as only the crudest, most preliminary conceptual approach to the question of how visual word identification is carried out by skilled readers, unaccompanied by any empirical evidence that would confirm or elaborate our understanding. Furthermore, we have said nothing about a number of crucial questions; for example, how are unfamiliar but pronounceable sequences like RINT treated as opposed to familiar words? If

PINT is stored as a specific mapping from print to pronunciation, what about MINT, a familiar word but one with a pronunciation that can be derived by simply knowing the usual form of INT, as in LINT, TINT, FLINT, HINT, and so on? How is meaning contacted and what role does it play in pronouncing a word? How are written words treated in sentences as opposed to words in isolation? What is the relationship between auditory and written language? These and other relevant questions have fully occupied many researchers in cognitive psychology over the last twenty years.

We will cover them in detail as we proceed; for now, we have used the present example simply to illustrate the conceptual approach that you must develop so that you can extrapolate from a global task--one that may seem almost trivial at first glance (e.g., reading single words aloud)--to the enormous complexity of the underlying cognitive systems that actually orchestrate our performance. This kind of thinking requires that we look beyond the limitations imposed by our own everyday intuitions and experience, and is the basis for effective task analysis.

The Method of Specific Effects

Suppose we distinguish between two distinct systems that together participate in a global function. How might we find *proof*, other than by force of logical argument, that our distinction is in fact correct? We are now beyond the stage of pure conceptual analysis, and we are ready to engage in an actual experiment that would provide relevant evidence for our initial theoretical claim.

In this section, we will introduce you to a small experimental demonstration, designed to illustrate an important methodological tool used all the time by cognitive psychologists, notably the *Method of Specific Effects*. The term sounds formidable but the idea in principle is not really difficult: If there are two quite different systems that together participate in a global function, then we might be able to distinguish them empirically by showing that each system reacts specifically to a different variable or set of variables. The variables are like different measurement instruments or chemical agents that have a specific reaction to a particular cognitive system; that is why this methodological approach is called the Method of *Specific* Effects. To return to our original analogy of an orchestra with different sections all playing together, the Method of Specific Effects would work like a filter, allowing us to hear the music only of the string section, say, while the rest of the orchestra, the brass, wind, and percussion sections are filtered out.

Here is an example that should give you a clear idea of this methodological technique. In memorizing a list of words (say a shopping list), one activity you may carry out to help you remember the items is to rehearse the list by quietly repeating the contents to yourself, either out loud or subvocally (i.e., internally), without overt articulation. Of course, you will attend to the list in other ways as well, by thinking about each word in terms of the meaning and elaborating on this in such a way that you can hope to retain each item for the duration of the trip to the supermarket.

Let us make the following distinction: There are *at least two* memory systems *working together* that may be called upon when memorizing a shopping list for a limited period of time. System A works by rehearsing the list almost like a tape recorder, maintaining the sequence of words in their order of occurrence by relying entirely on their auditory form and maintaining this form in memory through a process of subvocal rehearsal.

System B functions by attending to the particular meaning of each word, not as if the word were a completely new concept, of course, because the items on the list are presumably all familiar, but the meaning in relationship to the particular context of the list.

So, for example, suppose the list was made up of the words MILK, BREAD, ONIONS, MUSHROOMS, SUGAR, SALAMI, TOMATOES, PASTA, FLOUR, RAISINS, CUCUMBER. System A would simply register the items as a sequence of auditory forms and would maintain then by rehearsing "milk, bread, onions, mushrooms, sugar...". System B would register the *conceptual* relationships between the different words, perhaps by organizing the list into sections: Items for making spaghetti (pasta, onions, mushrooms), salad (tomatoes, cucumber), breakfast (milk, bread, sugar), sandwiches (salami), and snacks (raisins).

We are not saying that this kind of organization is inevitable given the list, nor that this would be the only plan that System B could use to maintain each item. For now, we merely need to emphasize the following distinction: System A relies on *sound* and registers items as well as their order of occurrence. System B relies on some aspect of *meaning* so that conceptual organization rather than auditory form is crucial to its operation.

Effects on System A But Not System B

How can we separate out the two memory systems A and B? We have distinguished them by the *kind of information* on which they operate--System A operates on the sound of the word, B operates on the meaning. Now we can make another reasonable assumption: Any memory system works by preserving the distinctiveness of the items it is storing. That is, the system is designed to maintain the integrity of the information it stores, so that it does not confuse an item with potentially related other items. It is no good, for example, if I included salami in the shopping list and you bring home sausages or pastrami instead because you forgot the exact description of the item for making sandwiches. A particular memory system, then, to function correctly, should maintain the distinctiveness between the items it stores, keeping their description intact and unaffected by other potentially confusable items within the set.

If we think about memory System A, we note immediately that its purpose is to maintain the distinctiveness between items *on the basis of how they sound*. If we wanted to make the job harder for System A, what experimental manipulation might we use, given that the system is based on auditory forms?

The answer is that items that sound alike (with quite similar auditory forms) might be harder for System A to keep distinct than items that are not confusable in this way. Suppose, for example, I asked you to remember (in their exact order) the words MAN, MAD, CAP, CAN, MAP. If you rely on System A, it will attempt to preserve, by internal rehearsal, the distinct sound patterns of the words, and if the system is functioning near its limit (let us assume that it does not have an unlimited capacity to hold any number of sound units), the similarity of the information--the words overlap in their sound segments--it is attempting to maintain should cause errors.

We can check to see whether this *specific effect* is obtained by comparing the performance of a group of volunteer subjects on this type of sequence (let's call these acoustically confusable sequences, *Type A*) with other sequences that do not include this variable. For these other sequences, we should use sequences of the same length (five monosyllabic words per sequence) that are not acoustically confusable, against which to compare the specific effect of acoustic confusability. We will call this type of sequence *Type C* (for control set) and they would consist of words like PEN, RIG, DAY, BAR, SUP, instead of MAN, MAD, CAP, CAN, MAP.

Notice a crucial point: We want to know the *specific effect* of a variable like acoustic confusability on the accuracy of System A. To measure this effect on recall of short lists of words (the effect could be zero if our thinking is wrong!) we need to compare it against another set of control lists that is (ideally) equal in every respect to the experimental lists other than the specific variable that is of interest. It would be wrong to use short words in Type A and long words in Type C, for example, or unfamiliar words in Type C and familiar words in Type A because any differences obtained cannot be referred specifically to the effect of interest. We want sets of words (A versus C) that yield a measurable difference that we can unambiguously interpret as being due to the specific effect of a particular manipulation, in this case a manipulation that renders the items confusable on the basis of their sound.

There is another variable that we should include in this study. We need an additional set of 5-word lists (call this set Type B), with items confusable in another respect than acoustic similarity. Again, we are interested in demonstrating that System A is using the sound of words to maintain them in memory, and not their meaning. So we predict that lists containing words with similar meanings should not affect the operation of System A, even though that system would be affected by lists of words that sound similar. We need another comparison then, using lists of 5 words each and items in each list that are potentially confusable in terms of what they mean. For example, BIG, HUGE, BROAD, LONG, TALL. This list would be an example of a Type B list, and we want to show that the accuracy of ordered recall (remember the task is to recall the words in their exact order) of this type of list is no worse than the accuracy for a list of control words.

What kind of control words? It would be tempting to simply use performance on Type C words (so we compare performance on B versus C), but this would not be such a good idea. The reason is that we have carefully selected the words in lists of Type C to match in every respect but one (acoustic similarity!) to Type A words. Now we have chosen additional sets of Type B words and they will not be as closely matched to Type C lists (e.g., BROAD in Type B lists has two consonants at the beginning while no words in Type C lists have two initial consonants; B and C words are not precisely matched in terms of familiarity--there are published tables that cognitive psychologists use to obtain numerical values on word frequency counts and other variables known to affect performance--and so on). So we need a second set of control lists, Type D, against which to compare performance on Type B lists. This comparison will allow us to establish the (hopefully zero!) effect of the variable included in Type B lists.

We can summarize the experiment looking for an effect of auditory but not conceptual similarity on ordered list recall as follows. There are four kinds of list, each list containing five words:

- Type A (e.g., MAN, MAD, CAP, CAN, MAP) is confusable in sound but not meaning.
- Type C (e.g., PEN, RIG, DAY, BAR, SUP) is a control set that is confusable neither in sound nor meaning, and chosen for specific comparison with Type A to measure the effect of acoustic confusability on recall. We are actually interested in the average difference between accuracy of recall for Type A and Type C words.
- Type B (e.g., BIG, HUGE, BROAD, LONG, TALL) is confusable in meaning but not sound. We can call this type of set *semantically confusable* words.
- Type D (e.g., OLD, LATE, THIN, WET, HOT) is a control set that is confusable neither in sound nor meaning, and chosen for specific comparison with Type B to measure the effect of semantic confusability on recall. We are interested in the average difference between accuracy of recall for Type B and Type D words.

This experiment was in fact carried out by Baddeley (1966) and produced the results shown in Figure 1.2. Recall (in the correct order) of List A sequences is much worse than recall of List C sequences (Acoustic versus Control), whereas recall of List B is not measurably different than recall of List D sequences (Meaning versus Control). Notice that had we not included a set of control words specially matched to List B in difficulty (List D), and instead compared List B against List C, we might have reached the wrong conclusion, because recall looks somewhat

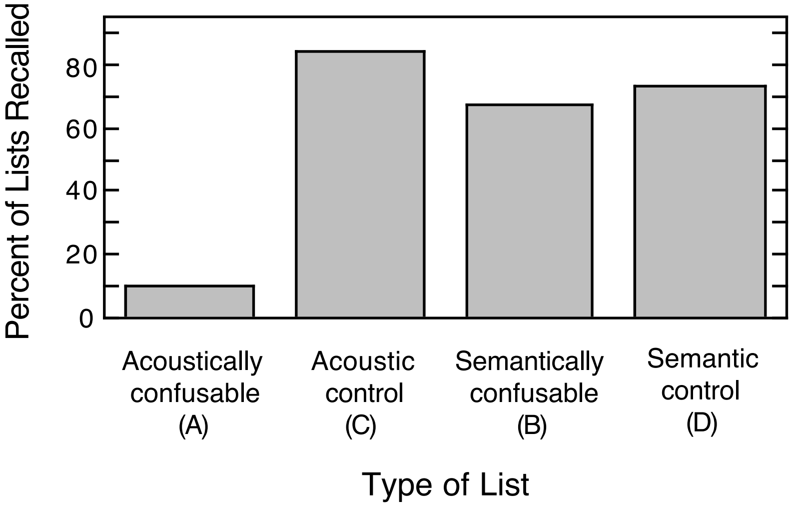

Figure 1.2. Percentage of 5-word lists correctly recalled as a function of list type. Data are from a study by Baddeley (1966a).

worse on B than C. But this difference has only to do with the fact that words in these two lists were not appropriately matched for incidental variables like familiarity. When we examine the effect of confusable meanings on recall by comparing performance with a more precisely matched control list, we see no real impact of this variable. By contrast, there is a big effect of acoustic confusability on recall (a difference of around 70% accuracy for A relative to C).

Effects on System B But Not A

This specific effect of acoustic confusability but not semantic confusability provides some evidence that lends support to our initial distinction. There is a memory system (A) that appears to be relying on the sound of words to retain them, and if the items in the sequence are hard to keep distinct because their sound constituents overlap, the system becomes more error prone. System A cares nothing about the meaning of words apparently, because making the words more confusable along this dimension has virtually no impact on recall.

If we are correct in our characterization of two distinct memory systems, A and B, we have another prediction that we should check to obtain additional support for our theory. System B relies on *meaning* for establishing the memory of words in a list, so this functional system should be affected by *semantic* rather than acoustic confusability. We are predicting that System B should be more error-prone for a list like big, huge, broad, long, tall relative to a control set of words, because the members of this list are not very distinctive given the kind of information that System B relies on for memory codes. In addition, we do not expect that System B will have more trouble with sequences like man, mad, cap, can, map relative to a list of comparison items, provided the meaning rather than the sound of each word is emphasized in setting up the memory records in this system.

We now face an interesting challenge in testing our prediction for System B. The task we set up originally was appropriate for testing the effect of acoustic confusability on System A (ordered recall of a list of five words), and was carefully chosen to target System A but not B. The assumption behind the task that we should now make explicit went roughly as follows: We want to test the specific effect of a variable (acoustic confusability) on System A, a system that we think uses the sound of words to maintain them as memory records over time, so we will devise a recall task that encourages the action of this system. Remembering a short list of five items for a brief duration is much the same as remembering the ordered sequence of digits in a telephone number, and our initial conjecture is that it is exactly this kind of task that would invoke the action of memory System A.

But we are finished looking at the effect of acoustic confusability on System A, and we want to examine the effect of semantic confusability on System B. How should we proceed? Obviously, we must find a task that actually calls upon System B and that cannot be accomplished adequately by System A. We used short five-item sequences before to test System A, on the assumption that the system is particularly useful for maintaining a limited quantity of auditory words for a short period of time. To encourage the action of System B we will try longer sequences (ten words in length). Such lists are not so easy to recall, and if we do a preliminary test, we would find that initial performance is quite poor. But there is no reason to restrict ourselves to a single attempt; we can look at repeated learning trials to obtain a sensitive measure of the effect of semantic confusability. Indeed, if you were asked to remember ten items to bring home from the supermarket (instead of five), and we reeled them off to you at a rate of one item every two or three seconds, you would definitely ask to hear the list a number of times to be sure that you had them correctly memorized!

So we will use longer lists and repeated learning attempts to invoke the action of System B. But also, we need to ensure that System A is somehow "switched off" when we assess performance--in the sense that we do not want to have it actively contributing to recall--because we are interested in testing the claim that semantic (but not acoustic) confusability has a specific effect on System B. If System A were allowed to partly contribute to recall, we would obtain mixed results (an effect of both variables), leading to the wrong conclusion.

To prevent the influence of System A on recall in order to see the pure activity of System B, we should organize events so that the contents of System A are "purged" before we examine the output of System B. This can be accomplished in the following way:

- Step 1: Present each word of the ten-item list sequentially at a fixed rate. Both Memory Systems A and B will be automatically engaged in registering and maintaining the items for recall.
- Step 2: We need an experimental manipulation that will prevent System A from contributing to recall. Therefore, before we ask for a response from our volunteer subjects we ask them to carry out a second task, designed specifically to engage System A. Whatever part of the ten-word sequence has been maintained by System A will be replaced by the items of our secondary task, leaving us only with the output of System B to measure when we ask for recall of the ten-word sequence. Thus, immediately after presenting all ten words of the sequence, but before asking for recall, we present a short sequence of eight digits to the subject, and require that the sequence be reproduced in the order of occurrence. Directly after this task has been fulfilled, we ask for recall of the list of words and record accuracy. Our assumption is that recalling a short sequence of digits will occupy System A; any words from the list that are being rehearsed and maintained in this system will be replaced by the digits. System B, however, will not be much engaged in digit recall (we assume System B relies on the conceptual relationships between words, and so will not be significantly relied on for registering an arbitrary sequence of digits), and its activity will therefore be clearly revealed after the subject reproduces the sequence of digits.

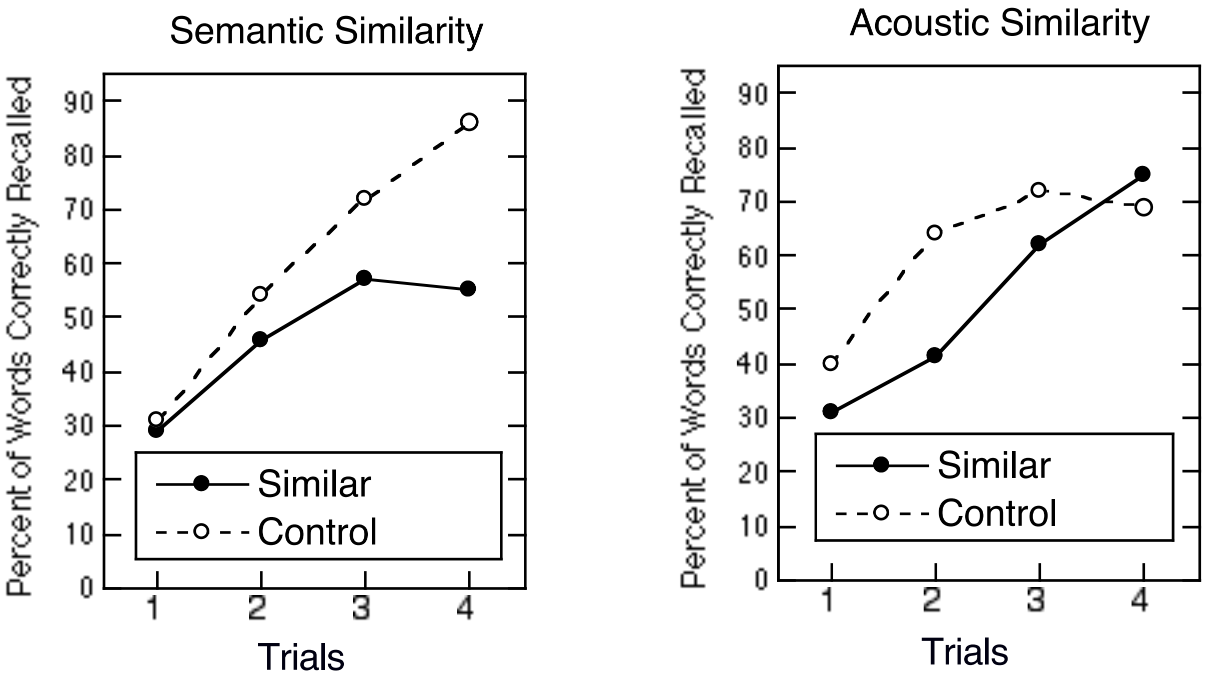

Figure 1.3. Learning as a function of acoustic or semantic similarity. Data are based on percent of words correctly recalled from a 10-item list and are from a study by Baddeley (1966b).

- Step 3: Repeat Steps 1 and 2 a number of times (say four times) to measure list learning, using the same words as before but a different sequence of digits for the secondary task (we simply are using these digits to purge the contents of System A and therefore we do not wish to use the same sequence each time).

An experiment based on this logic was first carried out by Baddeley (1966) using four lists of ten words each, such as the following:

List 1: MAN, CAB, CAN, CAD, CAP, MAD, MAX, MAT, CAT, MAP.
List 2: PIT, FEW, COW, PEN, SUP, BAR, DAY, HOT, RIG, BUN.
List 3: GREAT, LARGE, BIG, HUGE, BROAD, LONG, TALL, FAT, WIDE, HIGH.
List 4: GOOD, HUGE, HOT, SAFE, THIN, DEEP, STRONG, FOUL, OLD, LATE.

By now you should clearly understand which lists are being compared to assess the effects of semantic and acoustic confusability and the prediction that is being tested. We want to establish that list learning over repeated attempts is much harder for List 3 than List 4, using this particular experimental procedure, whereas learning of List 1 is not harder than List 2. The results of this experiment are indicated in Figure 1.3. Notice how performance changes for each list over repeated learning attempts. Is it harder to learn a semantically similar list of words than a matched control set? How about an acoustically similar set?

Double Dissociation Methodology

The method of specific effects relies on the differential impact of two or more variables on performance in two separate tasks, providing evidence for a theoretically important distinction between two different but functionally related cognitive systems. In general, Task A depends on System A and we look for an effect of variable 1 but not variable 2. Task B is geared to System B and we seek an effect of variable 2 but not variable 1. This kind of enterprise is complicated, and there are many possible ways in which the experiments can go wrong. We may not be able to prevent or find a way of separating out the contribution of System A during a test of System B, for example; or we may be unable to define a pair of variables specifically targeting the operation of one as opposed to the other system.

We will discuss many examples of highly ingenious, successful applications of the methodology outlined in the previous section. However, we would also like to introduce you to another very powerful and perhaps more direct methodological procedure that has been widely used in analyzing the performance of neurological cases: The *Method of Double Dissociation*.

The idea behind this method is quite easy to understand. Suppose again that there are two cognitive systems, A and B, that together function in carrying out a global task. Let's stay with our original example of remembering a shopping list. We have already described experimental evidence, obtained from neurologically intact volunteer subjects, supporting the claim that memory Systems A and B operate quite differently, in that they are affected by different kinds of similarity between words.

Now if these two systems are actually separate components of memory, in that they function independently, it should be possible to observe that neurological damage can affect one system without limiting the action of the other system. We should be very clear at this point what we mean by "separate components". We mean only that some permanent or temporary alteration has taken place in the brain (either through physical injury, or disease, or by some other physical action) such that cognitive System A has been disrupted in some way, whereas System B has remained intact. If the components are truly separable, then we might expect to see the reverse phenomenon as well: Neurological damage can affect System B while System A is left unaffected.

Note that we have not yet said anything about the actual physical organization of these systems in the brain, nor need we at this point. Among the range of possibilities, our two systems:

- may be located in two completely separate anatomical regions of the brain;
- they may be scrunched together in the same region but have different cellular interactions;
- they may operate through the action of the same set of cells "tuned" differently by different biochemical agents.

We need not know the answer to this question to proceed as cognitive experimentalists. In the example of memory systems we discussed, we have used two tasks designed to invoke separately the operation of System A and B. Recalling a short sequence of five words in the order presented--Task A--was designed to selectively call on System A more than System B. Learning a list of ten words using repeated trials--Task B--was designed to target System B without much influence of System A (but remember that we had to work a little to keep System A out of the picture).

Now suppose we are presented with an individual who has suffered damage to System A but not System B, what prediction would we make? We would expect very poor performance on Task A, relative to a neurologically intact control group, but normal performance on Task B. And if we observed an individual with the reverse deficit, we would anticipate seeing the opposite pattern of results: This case would be perfectly normal on Task A but very seriously impaired on Task B.

This outcome is the double dissociation we are interested in, and its occurrence provides additional evidence for the independence of the two systems that are the focus of our investigation. So we have two kinds of evidence that support our claim about two different types of memory systems: Evidence using specific effects of variables on the performance of normal volunteer subjects and evidence for a double dissociation between tasks from neurological cases.

They are challenging as research domains in different ways: To isolate a particular system in normal subjects requires great skill in devising experimental conditions that prevent or separate out the influence of additional systems on performance (refer to the previous section for an example). In neurological cases, the injury has already accomplished this step! However, a tremendous amount of background testing is required to establish this fact before we are in a position to draw a firm conclusion. And of course, we cannot know in advance what kind of alteration a brain lesion has produced so we need to go through a rigorous series of carefully planned tests before we can make any claims based on double dissociation logic.

An Example of Double Dissociation Methodology From Neurological Cases

Damage to System A But Not B

Warrington and Shallice (1969) documented a case identified by the initials K.F. (the actual name of the person is never used in published experimental reports to protect their anonymity) who had sustained a head injury as a result of a motorcycle accident at the age of 17. The accident caused a skull fracture on the left side requiring surgical intervention to relieve bleeding and swelling of the brain. The major region affected was the left parietal lobe. The research of interest to us was carried out with K.F. when he was aged 28.

In any such investigation, there are three kinds of observations that are usually co-ordinated. Brain injury (whether through head trauma or other causes like neurological or vascular disease) almost never causes isolated damage to one cognitive module; there are always several different deficits in any individual case.

- Many of these are causally unrelated to each other--for example, suppose K.F. had lost his sense of smell after the accident. We can reasonably conclude that this impairment can have no bearing whatsoever on his memory for words, and we need not pay any further attention to this sensory disorder.
- Other forms of disturbance might be indirectly relevant to the crucial experiments and need to be taken into account when carrying out the study or interpreting the results. For example, what if K.F. no longer could distinguish auditory speech sounds (like the difference between "*ba*" and "*pa*") as accurately as before? If we were interested, say, in examining the effect of acoustic confusability on K.F.'s memory, such a disorder would seriously interfere with our measurements, because K.F. might confuse auditory words like "bat" and "pat" even without having to memorize them. If we are to proceed validly, given this type of background observation, we need to demonstrate that this additional deficit is not the primary cause of the crucial experimental results.
- Finally, there are the key experimental results themselves that provide the necessary evidence we are seeking, and these are presented against the background of other observations (particularly those in the immediately preceding point that may complicate interpretation) to substantiate or qualify our claims.

Background testing on K.F. revealed that his ability to understand spoken language was well preserved. However, he was not so good at expressing himself; he spoke haltingly and with some word-finding difficulty. (This preliminary observation, a definite problem in producing words and sentences, obviously needs to be carefully considered and taken into account when interpreting the results of memory tests.) K.F. read slowly but accurately, though spelling and writing were very impaired. This latter disturbance would probably not have anything to do with performance on verbal memory tasks, and so need not further complicate our thinking.

The most striking feature of K.F.'s performance, and the one that is directly relevant to the theoretical claim regarding different memory systems, was the serious difficulty he had repeating

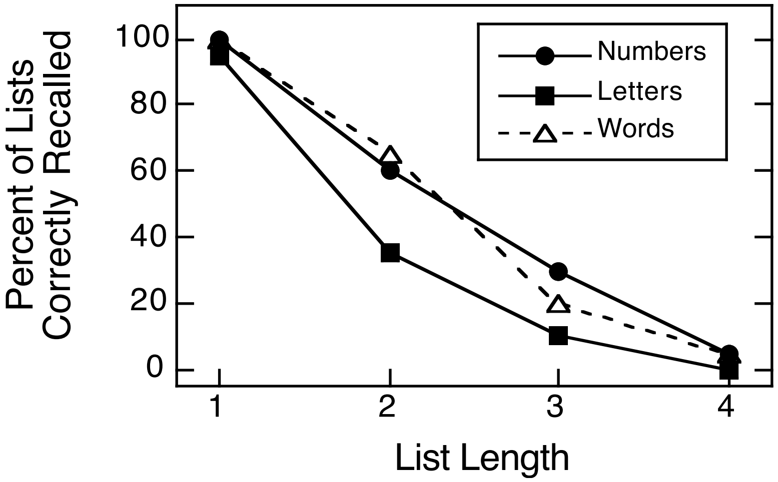

Figure 1.4. Performance by neurological patient K.F. on a memory task involving ordered recall of a list of numbers, letters, or words. Data are from Warrington and Shallice (1969).

a short list of verbal items. Warrington and Shallice documented the extent of problem: If presented with a *single* number, letter, or word, and asked to repeat the item, K.F.'s performance was flawless. However, his ability declined very markedly if he was asked to repeat two or more items in their order of presentation. His performance on single items, pairs, triplets, and quadruplets is shown in Figure 1.4.

Now, the claim to be evaluated is that K.F. failed to repeat correctly even a short sequence of items because for him, System A has been so badly damaged as a result of his motorcycle accident that the capacity of the system is abnormally limited. By contrast, the deficit in System A does not entail any corresponding deficit in System B, since we assume functional independence between them. If K.F. has no damage to System B, then any task that requires the involvement of System B but not System A should be carried out quite normally. So the dissociation of interest would be: (1) Performance on Task A (specifically tapping System A) is very impaired relative to a normal control group; (2) Performance on Task B (specifically tapping System B) is quite normal. We also need to obtain some ancillary results: We need to prove that impairment on Task A is not due to another cause that has led us to produce a mistaken theoretical claim. Given that K.F. has other kinds of language impairment, failure on Task A could occur for reasons that have nothing to do with our claim that System A exists and can be specifically damaged. We need to produce convincing evidence using carefully planned tests that disprove this alternative possibility.

The *full* experimental proof of the claim that System A can be independently damaged, leaving System B intact, requires quite a complicated series of steps, as you can see. That is why cognitive research on neuropsychological cases is very time-consuming and requires a highly specialized approach. We can provide only a brief description of the work done with K.F. He represents one of now many cases that have been documented, all providing strong support for a memory system maintaining a temporary record of *auditory* items that can be damaged independently of additional systems that provide a more durable record of items as experienced events.

We can summarize the experimental analysis of K.F. as follows:

- He is seriously impaired in ordered recall of even a very short list of digits, numbers or letters *(Task A is very impaired)*.

- By contrast, he was found to be completely normal, and even somewhat above average in his ability to engage in learning a list of ten words over repeated trials. He needed only seven learning attempts to recall a list of ten different words perfectly without regard to order of presentation, while normal control subjects needed an average of 9 attempts. Astonishingly, after an interval of two months, K.F. was able to recall seven of the ten words without relearning. (*Task B is normal or even superior!*)
- His difficulty is *not* due to a disturbance in auditory perception. For example, he easily detected a target item, such as the number 3, in an auditory sequence of numbers presented at a rate of one item per second. (*Impairment on Task A is not merely the result of a subtle difficulty in auditory perception.*)
- His difficulty was also *not* due to his documented failure to produce words and sentences in discourse. Crucially, K.F. was just as impaired in reproducing a short sequence of digits when the measure of performance did not require production of speech. For example, if he was given the numbers from 1 to 9 on cards and asked to reproduce a spoken sequence of digits by pointing to each item on the corresponding card, his recall accuracy was no better than if he attempted to reproduce the sequence by repeating each digit aloud. (*The failure on Task A cannot be attributed to K.F.'s disturbance in speech production*).

The failure on Task A and normal performance on Task B (along with ancillary evidence that impairment on Task A cannot be attributed to disturbances outside the system of interest) represents one part of the double dissociation that we are after, and can be graphically displayed as shown in Figure 1.5.

Damage to System B But Not A

Now for the opposite dissociation! We are expecting that neurological damage can seriously impair the ability to engage in sustained learning of a moderately long list of words (System B), yet leave completely unaffected the ability to register a shorter sequence of words for immediate

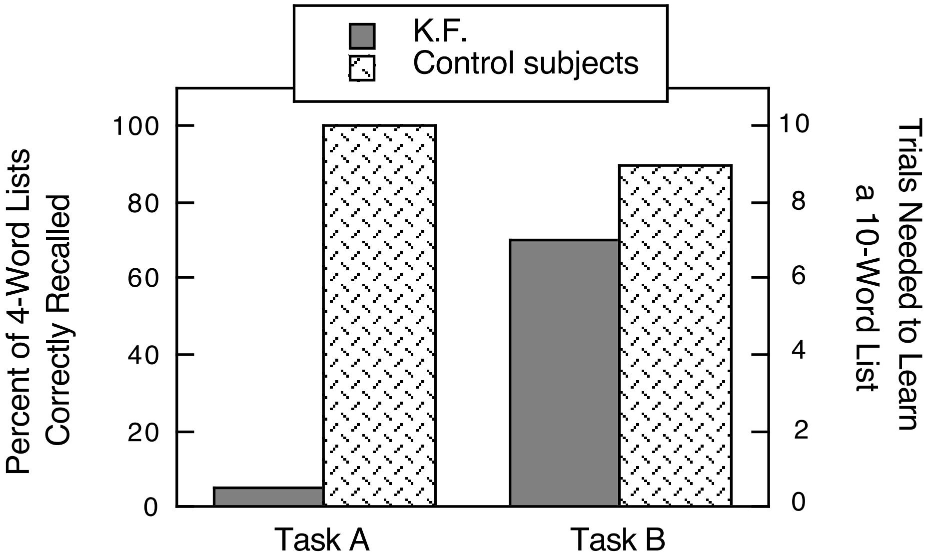

Figure 1.5. Comparison of performance by neurological patient K.F. and normal control subjects on Task A (recall of 4-word lists) and Task B (trials needed to learn a 10-word list). Data are from Warrington and Shallice (1969).

recollection (System A). If you think about what this kind of dissociation would look like in an everyday context, we are talking about the possibility of an individual being able to easily repeat back a seven digit telephone number, yet if asked to memorize a shopping list of, say, ten items, for the duration of the shopping trip she would have serious difficulty, even if he was given repeated chances to learn the list items. And of course, as in the previous example, we would only be convinced that this outcome represents a valid dissociation if the case or cases we are testing do not have other impairments that may indirectly interfere with memorization ability (for example, cases with neurological damage that has disrupted alertness, conceptual ability, concentration, and so on).

There is now a great deal of evidence supporting this kind of dissociation. Here is just one example: Drachman and Arbit (1966) documented five patients, each with damage to the hippocampus, a complex structure deep within the temporal lobes. The cause of the brain lesions varied from case to case and included herpes simplex encephalitis, a viral disease known to affect the temporal cortex (2 cases); a brain hemorrhage (1 case); and surgery for relief of epilepsy (2 cases). Background testing indicated that all cases forming the cohort had normal intelligence (average Full Scale IQ was 119, no different from that of the normal control group), no language problems, confusion, or other signs of intellectual impairment.

Testing for System A. Each case was given auditory sequences of five digits to repeat, and the length of each sequence was increased by one additional item if performance was found to be accurate. This incremental procedure was applied until the sequence became just long enough to produce recall errors. The previous length was then used as a measure of the *maximum* number of digits that could be accurately recalled. Typically, the length of such a *digit* sequence ranges between 5 and 9 for normal subjects (it varies somewhat for other kinds of verbal material). None of the brain damaged group obtained less than the normal value for maximum sequence length on this task.

Testing for System B. The subjects were given longer lists of digits to recall, but this time each sequence was given with repeated training trials. After each trial, the subject attempted to recall the sequence and if an error occurred, the sequence was once again presented until recall was accurate. If the subject failed to memorize a sequence after *25 repeated exposures*, testing was halted. In this way, normal control subjects were able to accurately memorize sequences of *twenty* digits without error. However, none of the patients could recall sequences longer than *twelve* digits even when given 25 presentations of the list. In one case (H.M.), correct recall was limited to a sequence of 6 digits, the same number that corresponded to his maximum span using the test procedure described in the previous section. This means literally that H.M. could repeat a sequence of six digits without error. Presented with a sequence of seven digits he will now produce some mistakes. If the same sequence of seven digits is presented *for 24 additional learning attempts*, H.M. will still not manage to reproduce all seven digits correctly!

We can graph the performance of H.M. (or any of the other five cases reported in the paper) on the two kinds of task relative to the normal control group of subjects (see Figure 1.6). H.M. is quite normal when recall requires only reproduction of an auditory sequence that does not exceed the capacity of System A. If required to memorize a longer sequence necessitating the additional contribution of System B, however, H.M. shows an enormous deficiency.

Plotting the Double Dissociation

Finally, we can plot a set of results demonstrating the full double dissociation that proves the functional distinction between System A and B, using the performance of both H.M. and K.F. Notice, though, that we have not actually used exactly the same tasks for the two cases.

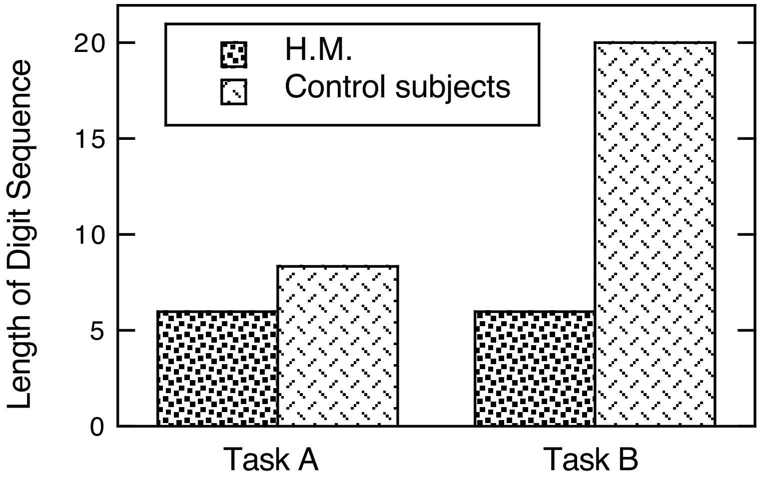

Figure 1.6. Comparison of performance by neurological patient H.M. and normal control subjects on Task A (longest digit sequence that can be recalled perfectly after one presentation) and Task B (longest digit sequence that can be recalled perfectly after 25 presentations). Data are from Drachman and Arbit (1966).

Learning a list of 10 words after repeated trials (K.F.) is not quite the same as learning a list of digits (H.M.). But we can safely assume from the evidence that H.M. would be seriously impaired in his ability to accurately learn a list of 10 words, and that K.F. would succeed, if allowed repeated attempts, to memorize a 10-item sequence of digits. Let us plot the *expected performance* of K.F. and H.M. on a task that requires ordered recall of a list of six digits (Task A), as well as their anticipated scores on a test that requires learning a list of 10 words with repeated trials (Task B). We also plot the expected values of normal performance on the same tasks (see Figure 1.7).

K.F. is seriously impaired on Task A (specifically testing for System A) but quite normal on Task B (targeting System B). H.M. is perfectly normal on Task A but his performance on Task B

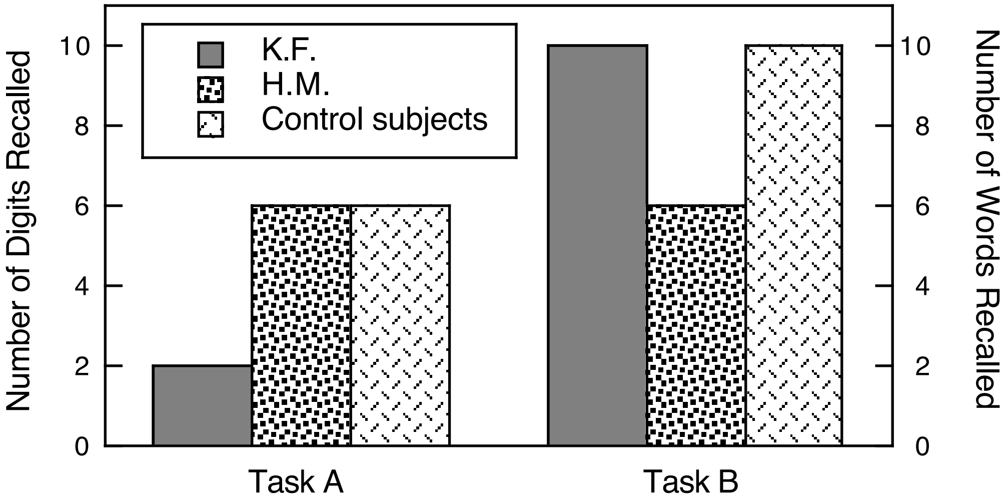

Figure 1.7. Comparison of hypothetical performance by neurological patients K.F. and M.H. and control subjects on Task A (recall of a six-digit sequence after one presentation) and Task B (recall of a 10-word list after multiple presentations). The data are reasonable estimates of what would be

expected based on data reported by Drachman and Arbit (1966) and Warrington and Shallice (1969).

is very impaired. In fact, we assume that whatever accuracy on this task has been obtained by H.M. is probably based entirely on the availability of an intact System A that, given the experimental procedure, has been allowed to contribute its memory records to performance on Task B.

Synopsis

To develop an understanding of nature, science proceeds always by discovering *relationships* between observed phenomena. Such understanding requires that we succeed in decomposing what appears on the surface to be an undivided entity into genuine parts. We try in essence, to "carve nature at the joints". White light, for example, is not indivisible; it is composed of purer colors that form the visible spectrum. What is the underlying relationship between these different colors? They form part of a much larger range of natural energies called the electromagnetic spectrum. Are there other deeper principles that will further guide our understanding of this set of related phenomena? Yes, certainly there are, and discovering them has led to major insights into the nature of matter and energy that has forever changed our view of the physical world.

The attempt to develop a scientifically rigorous analysis of cognition as another aspect of the natural world proceeds along similar lines. We now understand that mental functions appearing on the surface to be simple and undivided, are very complex and fractionated into parts. This principle, the principle of modularity, forms the background against which our methodological approach is developed.

How do we proceed to carve the mind at its joints? How do the different cognitive systems interact to produce a fully functioning, conscious entity? How does the physical action of the brain produce mental activity? These are the three big questions that confront us. We begin modestly but with the definite intention to dive deeply! Thinking carefully about basic cognitive abilities, we attempt to define the necessary functional steps into which relevant tasks may be decomposed. We cannot hope, of course, to arrive immediately in this way at a very abstract, mathematical understanding of cognitive elements, reaching the kind of depth physicists have gained in analyzing matter and energy. Our initial cognitive "parts" will still be describable in everyday language (say, the modular system for extracting the visual form of words from letters as input), and accounts of their functioning, though possibly mathematical, will stand in some direct relationship to this initial elementary conceptualization. We assume, however, that if we proceed rigorously but insightfully in this way, we will be isolating functionally real components that we can characterize in deeper and deeper ways, just as physicists did when they began with the initial insight that white light is decomposable into the spectrum of violet, blue, green, yellow, orange, and red colors (everyday color terms that are derived from everyday experience!) and then relatively quickly began to develop more abstract principles that linked these visible phenomena to other kinds of energies in the universe that went beyond their immediate experience.

In this chapter, we introduced the ideas behind two separate but related methodologies, the Method of Specific Effects, and the Method of Double Dissociations. Please note that we are not interested in having you simply memorize these terms and their definitions. Such rote memorization will be of no use to you when you think about different experimental results. *We want you to understand clearly and intuitively the logic behind the two methods* . In the Method of Specific Effects, we wish to test the assumption that there are two separate systems that together may contribute towards a set of tasks. So we think hard and develop two tasks that will selectively target each system--not selectively to the extent that each task is completely restricted to one system; matters are usually not that easy. We can proceed if Task A calls on the action of System A much more than System B, and the reverse for Task B.

We then attempt to identify a variable that can be manipulated in Task A and to which, *on theoretical grounds*, System A is differentially sensitive; that is, the variable of interest affects performance on Task A but has a negligible effect on Task B. And a *second* relevant variable manipulated in Task B influences performance on that task but not on Task A. Notice again that the choice of variable is linked to the nature of the cognitive system we are trying to isolate--acoustic confusability, in the example we used, was manipulated because we claimed that System A relies in part on auditory records to maintain information in memory.

Just as we use the Method of Specific Effects to seek differential effects of variables on task performance, *Double Dissociation Methodology* is used to establish selective impairment of relevant *tasks* that have been defined according to the nature of the functional systems that are being investigated. Task A is designed to engage System A while Task B is targeted for System B. Again, we are unlikely, given reality, to be able to develop totally pure tasks that have precise specificity with respect to the system of interest, but we can make do with tasks that place much greater emphasis for correct performance on the activity of one system than the other. If the two cognitive systems are distinct, then some kind of brain injury might decouple them. If this is in fact true, then we can find one type of neurological case who is very impaired on Task A but completely normal on Task B, while another set of cases would show the reverse dissociation; quite normal on Task A but very impaired on Task B. The pattern of the two kinds of neurological cases presented relative to normal performance is the relevant double dissociation.

We should add a number of final comments on double dissociations. First, the two dissociations considered together are very much more convincing than a single dissociation because their combined existence rules out the possibility that a single dissociation is simply due to the fact that the tasks selected vary in difficulty rather than in a more interesting way. Repeating a short sequence of digits (say, a list of seven digits) is obviously much easier than memorizing a sequence of fourteen digits. If we observe that certain patients have difficulty learning a longer sequence of digits but can easily repeat back a shorter auditory sequence, we cannot argue with much confidence that the dissociation between the tasks necessarily implies distinct memory systems. We can make a strong inference, however, if we observe that other neurological cases clearly show the reverse dissociation--the task thought to be intrinsically easier is in fact the one that these cases perform abnormally, while the much harder task now yields normal performance. Clearly, then, the double dissociation is inconsistent with the simple idea that the tasks merely vary in difficulty.

Notice also that the extent of the dissociation is determined by the degree to which the two systems are functionally independent. Complete independence implies that one task can be seriously impaired by damage without any affect whatsoever on the other task. This pattern *can* occur, but it is also true that we find dissociable systems that are only partially separable: Task A is very impaired while Task B is only slightly disturbed relative to normal ability and the reverse. This outcome forces us to consider the nature of the interaction between systems--they are clearly not fully independent--and would demand further theoretical and experimental analysis.

In all subsequent chapters describing particular cognitive abilities, we will make use of the basic conceptual tools reviewed in this chapter, and introduce you to new ones as we proceed. We will be looking at global tasks in terms of distinct functional steps, and we will use dissociation methodology and specific effects to fractionate complex cognitive systems into more basic components. It gets complicated, because nature is subtle and the mind presents a vastly intricate phenomenon (or set of phenomena), without doubt the most complicated and mysterious part of the natural world that we can experience. Our approach is integrated though multidisciplinary; we combine evidence throughout from both normal and neurologically damaged populations and, where appropriate, we will consult what can be learned by studying the physical action of the brain itself.