Sight Unseen

An Exploration of Conscious and Unconscious Vision

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OXFORD
UNIVERSITY PRESS

PREFACE

The story of this book began over 30 years ago in St Andrews, Scotland, where the two authors met and first began to work together. It would not have been written, however, but for the events that unfolded some 15 years later than that, when the two remarkable people we are calling Dee and Carlo first entered our lives.

The fortuitous coincidence of our first observations on the effects of Dee's brain damage at a time when several new developments were emerging in the neuroscience of visually guided movement, opened our eyes to the theoretical notions that were crystallized in our previous book together, *The Visual Brain in Action* (Oxford University Press, 1995). The present book is an attempt to bring those ideas, in an updated form, to a wider audience.

We continue to enjoy the unfailingly cooperative and good-humored help of Dee and Carlo. We are deeply grateful to Dee for sharing her visual world with us and for spending many long hours in the laboratory. We owe them both a deep debt of gratitude. They have taught us not only about the visual brain, but also how people can overcome the most devastating of problems with fortitude, and still enjoy a full and happy life. As with all of the brain-damaged patients we describe in the book, Dee's name is fictitious, retaining only her true initials.

We also acknowledge the help at both intellectual and practical levels of many of our colleagues, past and present, especially including (in alphabetic order): Salvatore Aglioti, David Carey, Jason Connolly, Jody Culham, Chris Dijkerman, Richard Dyde, Angela Haffenden, Monika Harvey, David Heeley, Yaoping Hu, Keith Humphrey, Lorna Jakobson, Tom James, Marc Jeannerod, Jonathan Marotta, Rob McIntosh, François Michel, Mark Mon-Williams, Kelly Murphy, David Perrett, Yves Rossetti and Philip Servos. We also owe a special thanks to Lynne Mitchell for taking care of all the details associated with arranging Dee's many visits to Canada.

Prologue

Vision, more than any other sense, dominates our mental life. Our visual experience is so rich and detailed that we can hardly distinguish that experience from the world itself. Even when we are just thinking about the world and not looking at it directly, we cannot help imagining what it *looks* like.

But where does that rich visual experience come from? Most of us have the strong impression that we are simply looking out at the world and registering what we see—as if we were nothing more than a rather sophisticated camera that delivers a faithful reproduction of the world on some kind of television screen inside our heads. This idea that we have an internal picture of the world is compelling, yet it turns out to be not only misleading but fundamentally wrong.

There is much more to vision than just pointing our eyes at the world and having the image projected onto an internal screen. Our brain has to make sense of the world, not simply reproduce it. In fact, the brain has to work just as hard to make sense of what's on a television screen in our living room as it does to make sense of the real world itself. So putting the television screen in the brain doesn't explain anything. (Who is looking at the screen in our heads?) But an even more fundamental problem is that our visual *experience* is not all there is to vision. It turns out that some of the most important things that vision does for us never reach consciousness at all.

One way to get a handle on how vision works is to study what happens when it goes wrong—not just when it goes wrong in the eye but when it goes wrong in the brain. Studying the visual life of people with certain kinds of brain damage has revealed just how misleading our intuitions about how vision works can be.

In some cases it is easy to get a feel for what such individuals might experience; in others, as is the case with the woman we are calling 'Dee Fletcher' in this book, it can be startlingly difficult to see the world through their eyes.

When we study how brain damage can disturb vision, we do not need to restrict ourselves to wondering how it affects *conscious visual experience*. Of course that is what the brain-damaged person will tell us about. When they talk about their visual problems, they are describing their conscious experience of the world—like the rest of us, they can describe only what they are aware of. But there are other ways of finding out what people can see. If we look at their behavior rather than simply listening to what they tell us, we may discover that they have other visual problems not apparent to their own awareness—or in other cases that they may be able to see far more than they think they can.

Trying to understand the visual problems that brain damage can cause leads directly to a more fundamental question: why do we need vision in the first place? In this book, we take the view that we need vision for two quite different but complementary reasons. On the one hand, we need vision to give us detailed knowledge of the world beyond ourselves—knowledge that allows us to recognize things from minute to minute and day to day. On the other hand, we also need vision to guide our actions in that world at the very moment they occur. These are two quite different job descriptions, and nature seems to have given us two different visual systems to carry them out. One system, the one that allows us to recognize objects and build up a database about the world, is the one we are more familiar with, the one that gives us our conscious visual experience. The other, much less studied and understood, provides the visual control we need in order to move about and interact with objects. This system does not have to be conscious, but it does have to be quick and accurate.

The idea of two visual systems in a single brain might initially seem counterintuitive or even absurd. It might even seem incredible to the layperson. Indeed, the idea has not even been seriously entertained as a hypothesis by most visual scientists until very recently. Our visual experience of the world is so compelling that it is hard to believe that some other quite independent visual system—one that operates completely outside of consciousness—is guiding our movements. It seems intuitively obvious that the

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visual image that allows us to recognize a coffee cup is the same one that guides our hand when we pick it up. But this belief is an illusion. As we will try to show in this book, the visual system that gives us our visual experience of the world is *not* the same system that guides our movements in the world.

I

A tragic accident

It was a bright morning in St. Andrews, Scotland, in May 1988 when we first heard about Dee Fletcher. We received an unexpected phone call from a colleague at the University of Aberdeen. He had recently returned from Milan where he had heard about a young Scottish woman who had suffered a tragic accident at her new home in Italy. Apparently, the accident had severely affected her ability to see. She had recently returned to Scotland to stay for a few months with her parents. Would we be interested in examining her? We said we would be happy to help out, although her case did not sound promising from a research point of view. Her case looked even less promising when copies of the results of clinical testing carried out in Italy arrived in the mail soon afterwards. Dee had clearly suffered a severe loss of visual function. Her visual problems were not restricted to a single domain such as the ability to recognize faces or to read words—the kind of selective loss that has long held a fascination for psychologists and other scientists interested in how the brain works. Nevertheless we fixed a date to see her.

A few days later, Dee Fletcher arrived at our St Andrews laboratory. Her mother, who understandably was extremely upset at what had happened to her only daughter, accompanied her. Dee, a small, smartly dressed woman in her early 30s, seemed a bit reserved at first, but soon began to share her unhappy story with us. Dee spoke with the assurance of a well-educated and confident individual, but one who was nevertheless clearly puzzled and distressed about her condition. As she and her mother described her life and how it had been so completely changed by a freak accident, we were able to piece together what had happened.

Dee was born and spent her early years in Scotland, but went on to spend a large part of her life in other countries—in the

Caribbean and in Africa where her father had held a number of academic posts. She now lived in Italy, where she had settled down with her partner Carlo, an Italian engineer whom she had met in Nigeria. Dee had completed a college degree in business studies, and this degree, coupled with her fluency in Italian (and several other languages) had enabled her to work as a freelance commercial translator in Italy. She had clearly been an active and lively person with many interests. While in Africa, she had become an accomplished horsewoman and, in the last two years, had learned to fly a private plane. She and her partner had enjoyed a full and happy life. Sadly, one fateful day in February 1988, their life changed forever.

On that day, Dee had been taking a shower in the newly renovated house that she and Carlo had bought in a small village north of Milan. The water for the shower was heated by a propane gas heater—a common practice in many homes in southern Europe even now. As it turned out, this particular heater was improperly vented and carbon monoxide slowly accumulated in the bathroom. Dee, of course, was unable to detect the fumes, which are quite odorless, and she eventually collapsed into a coma as the carbon monoxide displaced the oxygen in her blood. There is little doubt she would have died of asphyxiation had Carlo not arrived home just in time to save her. He gave her the kiss of life and rushed her to the local hospital, and she survived. Possibly she would have suffered less brain damage if she could have gained more specialized treatment at that early stage; but at least she survived.

The vast majority of people who survive carbon monoxide poisoning show little if any noticeable neurological effects. It was obvious to Carlo, however, as soon as Dee regained consciousness, that she was not among that fortunate majority, and he feared the worst. While she seemed alert and could speak and understand what was said to her, she could see nothing. The initial diagnosis of local doctors was therefore 'cortical blindness'. This is a condition caused by damage to the primary visual area at the back of the brain, depriving the individual of all visual experience. But gradually in the days following her arrival in the hospital, Dee began to regain some conscious sight. The first visual experience that she recalls having is a vivid sensation of color. Dee could see the red and green colors of the flowers in the vase

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beside her bed and the blue and white of the sky outside. She remarked to Carlo that he was wearing the same blue sweater he had worn the day before. Clearly, Dee did not have cortical blindness.

Box 1.1 Carbon monoxide poisoning

Carbon monoxide (CO) is an invisible odorless gas that is produced whenever fuels such as gasoline, oil, propane or wood are burned. Dangerous amounts of CO can accumulate when fuel-burning appliances are not properly vented. Carbon monoxide poisoning occurs because CO displaces blood-borne oxygen (by competing successfully with the oxygen molecule for sites on the hemoglobin molecule). The most common symptoms of CO poisoning are headache, dizziness, weakness, nausea, vomiting, chest pain and confusion. High levels of carbon monoxide can cause loss of consciousness and death. In fact, CO poisoning is the number one cause of unintentional poisoning deaths in the world. The main way CO kills is by depriving the brain of oxygen. In other words, CO poisoning causes anoxia.

Anoxia is a condition in which there is an absence of oxygen supply to an organ's tissues even though there is adequate blood flow to the organ. Hypoxia is a milder form of anoxia. The brain is particularly sensitive to the loss of oxygen and brain cells cannot function without oxygen for more than a few minutes.

Nevertheless, Mrs Fletcher, who had flown out to Italy to be with her daughter, was devastated when she walked into the hospital room and Dee looked at her but did not recognize who she was. Dee immediately recognized her voice, however, and Mrs Fletcher was relieved to discover as she talked to her daughter that Dee could still remember everyday things and talk about them in her usual way. She realized that while Dee's problems were serious, they seemed to be largely restricted to seeing things properly and making sense of them. For example, Dee had no trouble telling what things were when she picked them up and explored them by touch.

The following day, Dee and her mother talked together over coffee. As Mrs Fletcher passed a cup to her daughter, Dee said something rather startling. 'You know what's peculiar, Mum?' she said. 'I can see the tiny hairs on the back of your hand quite clearly!' This surprising remark led her mother to think that perhaps Dee's sight was on the road to a full recovery. But her pleasure was short-lived, when Dee added that despite seeing those fine details, she could not make out the shape of her mother's hand as a whole. In fact it soon became apparent that Dee was completely lost when it came to the shape and form of things around her. Unless an object had a distinctive color, or visual texture or grain, she had no idea what it was. Over the next few days and weeks it became painfully clear to all concerned that Dee's vision was no longer improving.

Vision without shape

As we heard this story, it became apparent to us that Dee's visual problems could not be due to a general deterioration in her visual system caused by diffuse brain damage that affected everything. For one thing, even though she could not use shape to tell one object from another, she could still use their surface detail and color. This ability to see surface properties was confirmed in formal testing that we later carried out on Dee in St Andrews. We found that she could not only name colors correctly but was also able to make fine discriminations between different shades of the same color. She could also distinguish the surface features of many objects, allowing her to identify the material they were made from (see Plate 1, top). So she might say that an object was made of red plastic or out of shiny metal—but at the same time she could only guess at its shape or function. In some cases, however, color and surface features can be highly diagnostic of what kind of object a picture represents (like the yellow color of a banana or the tiny seeds on the surface of a strawberry; see Plate 1 (bottom) for another example).

We tested Dee's ability to see fine detail (like the hairs on her mother's hand and the tiny seeds on the strawberry) by showing her patterns of lines on a computer screen (see Figure 1.1). She did as well as a visually normal person in detecting a circular patch of closely spaced fine lines on a background that had the same average brightness. Yet, remarkably, even though she could see that there was a patch of lines there, Dee was completely

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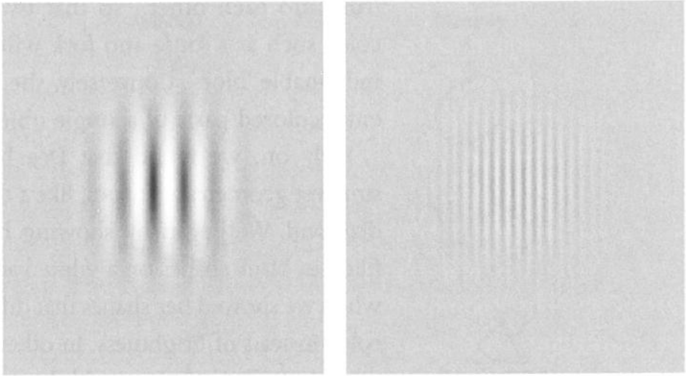

Figure 1.1
Examples of the several 'grating' patterns used to test Dee's vision for fine detail. The number of stripes per unit distance is called the spatial frequency of the pattern—the grating on the left has a low spatial frequency, the one on the right has a high spatial frequency. For each pattern, we determined the degree of contrast between dark and light stripes that was needed for Dee to see it reliably against a gray background with the same overall brightness. Dee did remarkably well in detecting these faint patterns, especially at the high spatial frequencies, but she could not reliably tell us whether the stripes were horizontal, vertical, or oblique.

unable to say whether the lines were horizontal or vertical. The fact that she could see detail just as well as a person with normal sight ruled out one obvious explanation of the problem she had in recognizing the shapes of objects. It could not be the case that her vision was simply a blur—as it would be for a short-sighted person without their eye glasses. Dee, unlike the person with myopia, could see the detail. It was the edges and outlines of objects that she couldn't make out. Her difficulty in telling even horizontal from vertical lines shows just how extreme this deficit was.

Dee has never regained a full and integrated experience of the visual world. The world she sees still lacks shape and form. So even today, more than fifteen years after the accident, Dee is unable to identify objects on the basis of their form alone. She has never, for example, been able to recognize short printed words on paper, or the faces of her friends and relatives, nor drawings or photographs of everyday objects. She has enormous difficulty in following a program on television, especially one in black and white, though she enjoys listening to audio cassettes of novels, read by an actor or the author, intended for the visually impaired.

We discovered that Dee even had problems in separating an object from its background—a basic first step for the brain in working out what an object is. Dee said that objects seemed to 'run into each other', so that two adjacent objects of a similar color such as a knife and fork will often look to her like a single indefinable 'blob'. Conversely, she will sometimes see two differently colored parts of a single object as two different objects.

Early on, we found that Dee had difficulty naming even the simplest geometrical shapes, like a triangle, a square, an oblong or a diamond. We began by showing her line drawings of shapes, or filled-in black shapes on a white background. But she was no better when we showed her shapes that differed from their backgrounds in color instead of brightness. In other words, although she could see the colors all right, she couldn't make out the edges between them. Neither could she recognize a shape made up of random dots where the dots making up the shape were textured differently from the background. Nor could she see 'shape from motion' where a patch of dots is moved against a background of stationary dots. A person with normal vision will see the shape immediately, even though it rapidly 'disappears' once the motion has stopped. Dee too saw something moving under these circumstances, and could tell us in which direction—but was quite unable to tell us what the shape was. To cut a long story short, it did not matter how a shape was defined, whether by brightness, color, texture or motion, Dee still could not recognize it (see Plate 1, middle).

Dee's difficulty in identifying objects or line drawings is not one of finding the right name for the object, nor is it one of knowing or remembering what common objects look like. Her problem is more fundamentally 'visual' than that. Dee has enormous difficulties in copying drawings of common objects or geometric shapes (see Figure 1.2). Some patients who are unable to identify pictures of objects can still slavishly copy what they see, line by line, and produce a recognizable product. But Dee cannot even pick out the constituent elements of a picture in order to copy them. Presumably unlike those patients, then, Dee's problem is not one of *interpreting* a clear visual experience—her problem is that she doesn't have that clear visual experience to start with.

Also, despite her copying problems, Dee can draw pictures of many common objects from memory. For example, when asked to 'draw an apple' or 'draw a house', she does this quite well. Her drawings are by no means perfect, but then it is almost as if she is drawing with her eyes closed, because she does not appreciate visually what she is drawing. It is not surprising that sometimes

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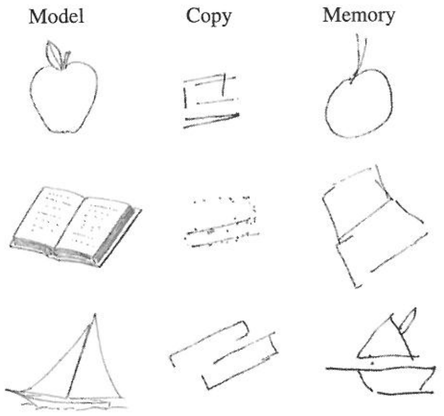

Figure 1.2

Dee was able to recognize none of the three drawings on the left. In fact as the middle column shows, she could not even make recognizable copies of the drawings. When she tried to copy the book Dee did incorporate some of the elements from the original drawing—the small dots representing text, for example—but her copy as a whole was poorly organized. After all, she had no idea what she was copying. Dee's inability to copy the drawings was not due to a failure to control her finger and hand movements as she moved the pencil on the paper, since on another occasion, when asked to draw (for example) an apple from memory, she produced reasonable renditions, as shown in the right-hand column. Dee was presumably able to do this because she still has memories of what objects like apples look like. Yet when she was later shown her own drawings from memory, she had no idea what they were. From Milner, A.D. & Goodale, M.A. (1995). Visual Brain in Action, Oxford University Press (Figure 5.2).

the parts of the drawing are misaligned, because when she lifts the pencil from the page she does not always put it back again in the right place. But the fact that she does as well as she does must mean that her problem with copying drawings is not that she has lost her ability to draw, nor is it that she has lost her general knowledge of what objects look like. Needless to say, when she is shown drawings that she has produced herself she is no better at recognizing these than any other drawings.

When Dee is 'drawing from memory' she can rely on visual experiences she had before her accident. It seems that Dee has as rich a store of visual memories and visual knowledge as anyone else—apart from the fact that these memories have not been updated with new visual information during the years since her accident. (Of course she would also still be constantly reminded of the shapes of small everyday objects through her sense of touch from handling them now and then.) This general knowledge about the appearance of objects enables her to bring visual images of familiar things into consciousness and talk and think about them.

The ability to see things 'in our mind's eye' allows us to carry out mental operations on objects when the objects are not actually present. Suppose you are asked to say whether a particular animal has a tail that is longer than its body. You will probably do this by conjuring up a visual image of the animal. Examining this image allows you to say that a mouse, for example, has a tail longer than its body, while a cow does not. Dee can do this just as well as most people, and unfailingly comes up with the right answers. She can even do things involving more complex mental operations. Take the following case: 'Think of the capital letter D; now imagine that it has been rotated flat-side down; now put it on top of the capital letter V; what does it look like?' Most people will say 'an ice-cream cone'—and so does Dee.

So Dee can imagine things that her brain damage prevents her from seeing. This must mean that manipulating images in the mind's eye does not depend on exactly the same parts of the brain that allow us to see things out there in the world. After all, if visual imagination did depend on those brain structures, then Dee should not have been able to imagine things at all—at least visually.

Not only can Dee deliberately form mental images, but she also finds herself doing so involuntarily at night when dreaming. She often reports experiencing a full visual world in her dreams, as rich in people, objects, and scenes as her dreams used to be before the accident. Waking up from dreams like this, especially in the early years, was a depressing experience for her. Remembering her dream as she gazed around the bedroom, she was cruelly reminded of the visual world she had lost.

Visual agnosia

Dee's basic problem is in recognizing shapes. In cases such as hers, where brain damage causes a disturbance in people's ability to recognize things, the disorder is known as 'agnosia'. This term was coined in the late nineteenth century by a then little-known neurologist named Sigmund Freud. He borrowed two elements from the ancient Greek (*a* = not, and *gnosis* = knowledge), in order to convey the idea that patients of this kind have a problem in making sense of what they see. Although we are focusing here on visual deficits, agnosias can be found in other senses, such as touch and hearing. Within vision itself, agnosia can be limited to particular visual categories, such as faces, places, or even words.

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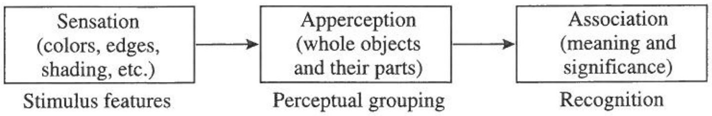

Figure 1.3

During the nineteenth century, the prevailing view was that we put together our raw sensations into percepts, and then attach associations to these to give them significance. Heinrich Lissauer believed that either of these two links could be severed to cause a brain-damaged person to lose the ability to recognize what he or she saw. If the first link was broken, then the person would have 'apperceptive agnosia', while if the second was broken he or she would have 'associative agnosia'. We retain broadly the same ideas today, though the terminology is different.

Even before Freud wrote about it, a distinction had been made by the German neurologist Heinrich Lissauer between two forms of agnosia (which at that time was called 'mind-blindness' or *Seelenblindheit*). According to Lissauer, agnosia could be caused by a disconnection either between perception and meaning, on the one hand, or between sensation and perception on the other (see Figure 1.3). The influential MIT neuroscientist Hans-Lukas Teuber characterized the first of these disorders (what is generally called 'associative' agnosia) as one that left people with 'percepts stripped of their meaning'. In other words, although their visual experience was intact, patients with associative agnosia could no longer attach meaning to that experience. To imagine what this would be like, think about what a typical Westerner experiences when faced with a Chinese ideogram. This symbol—full of meaning for a Chinese speaker—would be perfectly well perceived, but nonetheless remain a meaningless and puzzling pattern for the Westerner. A patient with associative agnosia would presumably react the same way when faced with a drawing of a common object such as a telephone or a bicycle. They would be able to copy the picture quite accurately (as we could do with an ideogram), but they would not have the slightest inkling of what it was they were drawing.

The other kind of agnosia that Lissauer described, which he conceptualized as a disconnection between sensation and perception, is generally called 'apperceptive' agnosia. In making this distinction between sensation and perception, Lissauer was using psychological concepts that were fashionable at the time. For the nineteenth-century thinker, sensation meant the raw sensory qualities like the color, motion, and brightness of objects or their parts, while perception referred to the process that put all of these elements together to create our visual experience, or 'percept', of an object, such as a table or a tree. A patient with apperceptive agnosia, then, would not perceive the world properly, though he or she might have perfectly intact sensory data. Because their brain cannot reconstruct the world from the information their eyes provide, they would be unable to copy line drawings of tables, trees, or even simple geometric shapes.

Nowadays Lissauer's rationale for the distinctions he was making is regarded as a little simplistic. He perhaps put too much emphasis on what today would be called 'bottom-up' processing, in which the percept is constructed directly from an analysis of the pattern of light falling on the eye. Today most visual scientists believe that such bottom-up processing, while certainly necessary, is far from sufficient for perception. They argue that what we see is also shaped by what we know about the world: in other words that learning, memory, and expectations play a crucial role in molding our perceptions. The contribution of these influences from the brain's knowledge-base about the world is often referred to as 'top-down' processing. The final percept is a combination of both current sensory input and stored information from past experience (see Plate 2, top).

Despite these reservations, most clinicians would agree that Lissauer's classification scheme still provides a useful rule of thumb for distinguishing between different levels of agnosia. Dee, of course, would fall into Lissauer's 'apperceptive' category. Her percepts are certainly not normal, and she certainly cannot produce recognizable copies of line drawings. So Dee's problems correspond well with Lissauer's conception of apperceptive agnosia. But since Lissauer's time, the designation 'apperceptive agnosia' has been used by different writers to refer to a range of different perceptual problems, not all of which involve such a basic disorder of shape perception. To avoid confusion, therefore, we will avoid using the phrase altogether. Instead, we will follow the neurologists Frank Benson and J. P. Greenberg of Boston University, who in 1969 coined the more suitably descriptive term 'visual form agnosia' for a famous patient of theirs whose basic problem, like Dee's, lay in perceiving visual form or shape. In fact, their patient, who was systematically studied by the American psychologist Robert Efron in a seminal paper also published in 1969, was uncannily similar to Dee Fletcher in a

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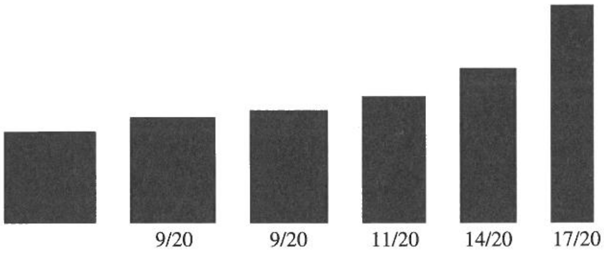

Figure 1.4
Efron's rectangles: these all have the same surface area but differ in shape. Dee was tested with several different rectangles, each in a separate test run. On each trial, she was shown a pair of shapes, either two squares, two rectangles, or one of each (with the square either on the right or the left). She was asked to say whether the two shapes were the same or different. When we used either of the two rectangles that were most similar to the square, she performed at chance level. She sometimes even made mistakes when we used the most elongated rectangle, despite taking a long time to decide. Under each rectangle is the number of correct judgments (out of 20) that Dee made in a test run with that particular rectangle.

number of ways. 'Mr. S' (as Efron referred to him) had suffered a carbon-monoxide poisoning accident while taking a shower, just like Dee did 25 years later. And like Dee, he was able to distinguish colors, but was quite unable to distinguish among geometric shapes.

Efron devised what is now a standard diagnostic test of visual form agnosia (see Figure 1.4). He wanted to measure the degree of disability a patient had in distinguishing shapes, and this meant he needed a test whose level of difficulty could be scaled, so that he could compare the degree of deficit in different patients. He hit upon the idea of creating a series of rectangular shapes that varied in length and width but not in area. These objects could be distinguished only by attending to their relative dimensions, not to their overall size. We have tested Dee using these shapes on a number of different occasions over the years. She still has great difficulty in telling pairs of these 'Efron' shapes apart, and even when she gets them right, she seems to arrive at her decision through a long and arduous process far removed from the immediacy of normal visual perception.

Summary

After three sessions of testing in our St Andrews laboratory, it was obvious to us that Dee had a profound visual form agnosia. At the same time, her memory, her ability to express herself verbally and her senses of hearing and touch were all remarkably unaffected by the asphyxia that had devastated her visual experience of the world. And even here the damage was selective, with only some aspects of visual experience being affected. Her experience of color and the surface 'texture' of objects seemed to be relatively normal. In other words, Dee's visual form agnosia appeared to be an unusually pure one. It was also obvious to us from the moment she walked into our laboratory that Dee did not suffer from any serious motor disability. That is, she had no problems walking or using her hands to pick things up. In fact, all her motor abilities seemed normal—which is often not the case in other patients who have survived near-asphyxiation. As we shall see in the next chapter, this sparing of Dee's motor system turned out to be highly significant for our further investigations.

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Doing without seeing

The picture painted in Chapter 1 is a gloomy one. Dee's brain damage left her with a profoundly diminished visual life. Not only is she unable to recognize her friends and relatives, she cannot even tell the difference between simple shapes like squares and rectangles or triangles and circles. Indeed, a task as straightforward as distinguishing between horizontal and vertical lines defeats her completely. Given such a profound disability, the prognosis when we first met Dee was discouraging. Most clinicians would have classified her as legally blind, relegating her to a life in which she would need a white cane—or even a guide dog—in order to move about. After all, she could not identify anything on the basis of its shape or form. How could she possibly be expected to use her eyes to do even simple everyday tasks, such as eating a meal? Of course, many blind people can manage such tasks quite well by non-visual means. But would she, like a blind person, have to rely entirely on memory and the sense of touch?

This scenario, happily enough, has not materialized. Quite remarkably, Dee behaves in many everyday situations as though she sees perfectly well. We caught our first glimpse of Dee's preserved visual skills during one of the early testing sessions in St Andrews, back in the summer of 1988. At that time, we were showing her various everyday objects to see whether she could recognize them, without allowing her to feel what they were. When we held up a pencil, we were not surprised that she couldn't tell us what it was, even though she could tell us it was yellow. In fact, she had no idea whether we were holding it horizontally or vertically. But then something quite extraordinary happened. Before we knew it, Dee had reached out and taken the pencil, presumably to examine it more closely (see Figure 2.1). After a few moments, it dawned on us what an amazing event we had just

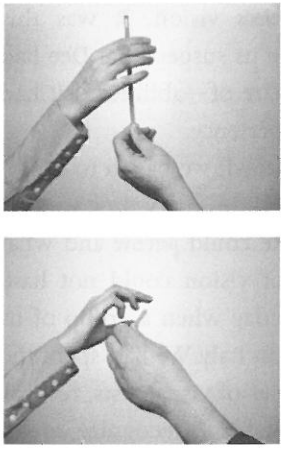

Figure 2.1
The examiner (on the right) held a pencil either vertically (top picture) or horizontally (bottom). Even though Dee could only guess whether the pencil was vertical or horizontal, she always grasped it perfectly.

witnessed. By performing this simple everyday act she had revealed a side to her vision which, until that moment, we had never suspected was there. Dee's movements had been quick and perfectly coordinated, showing none of the clumsiness or fumbling that one might have expected in someone whose vision was as poor as hers. To have grasped the pencil in this skillful way, she must have turned her wrist 'in flight' so that her fingers and thumb were well positioned in readiness for grasping the pencil—just like a fully sighted person. Yet it was no fluke: when we took the pencil back and asked her to do it again, she always grabbed it perfectly, no matter whether we held the pencil horizontally, vertically, or obliquely.

Dee's ability to perform this simple act presented a real paradox. How could she see the location, orientation, and shape of the pencil well enough to posture her hand correctly as she reached out to grasp it, while at the same time she couldn't tell us what she saw? She certainly could not have grasped the pencil accurately *without* using vision. A blind person couldn't have done it, nor could a sighted person wearing a blindfold. For her to have grasped the pencil so deftly, her brain must have had all kinds of advance information about where it was and what it looked like. Since there was no other way she could know how we were holding the pencil, Dee had to be using vision. Yet at the same time it was clear that she wasn't using *conscious* vision. It was this serendipitous observation that first made us suspect that Dee had visual abilities that even she was not aware of—abilities that had survived her loss of conscious visual experience.

Once we had realized what had happened, we began to notice new examples of Dee's amazing visual abilities every time we met with her. The contrast between what she could *perceive* and what she could actually *do* with her sense of vision could not have struck us more forcibly than it did one day when a group of us went out on a picnic while visiting her in Italy. We had spent the morning at her home carrying out a series of visual tests, recording one failure after another. Dee was unable to recognize any of the faces, patterns, or drawings we showed to her. Again it was obvious that the only way Dee could even tell one person from another was by looking at the color of their hair or their clothing. It had been a frustrating morning for her.

To lighten the gloom, Carlo suggested that we all go for a picnic in the Italian Alps, to a popular spot not far from their home.

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We drove high up into the mountains, until the massive peak of Monrosa loomed into view. We parked the car and then set off on foot to reach our picnic site—an alpine meadow higher up on the side of the mountain. This walk provided a good example of a time when the other side of Dee's visual life was strikingly revealed. To reach the meadow, we had to walk along a half-mile trail through a dense pine forest. The footpath was steep and uneven. Yet Dee had no trouble at all. She walked confidently and unhesitatingly, without stumbling, tripping over a root, or colliding with the branches of the trees that hung over the path. Occasionally we had to point out to her the correct route to take, but other than that, her behavior was indistinguishable from that of any of the other hikers on the mountain that day.

We eventually arrived at the meadow and began to unpack the picnic hamper. Here Dee displayed once more how apparently normal her visual behavior was. She reached out to take things that were passed to her with the same confidence and skill as someone with completely normal sight. No-one would ever have guessed that she could not see the difference between a knife and a fork, or recognize the faces of her companions.

The mailbox

Needless to say, scientific colleagues are seldom convinced by anecdotes like these, however compelling they might seem at the time. We had to demonstrate Dee's visual skills in the laboratory. We had to show that even though she was unable to recognize objects or even tell them apart, this did not prevent her from using vision to guide her actions directed at those objects. And this meant introducing both objective measurement and experimental control. Our first attempt to do this was inspired by that remarkable day when she reached out and grasped a pencil during our preliminary tests of object recognition. Refining a test first described by Marie-Thérèse Perenin and Alain Vighetto (see Chapter 3), we set up a simple piece of apparatus where we could ask Dee to 'post' a card into an open slot—like a mailbox, but with the added feature that the slot could be presented at different orientations, not just at the horizontal (see Figure 2.2). On each occasion, she had no way of knowing ahead of time what the orientation of the slot would be when she opened her eyes to look at it.

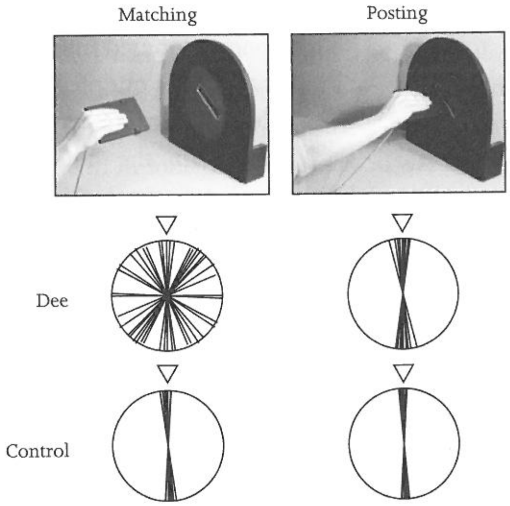
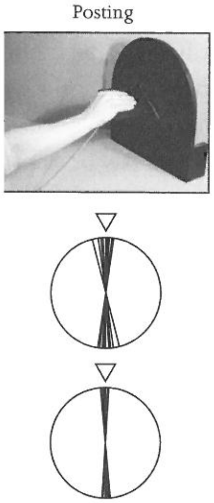


Figure 2.2

Matching and posting tasks. Dee was presented with a vertical display with a slot cut into it which could be rotated to different orientations. In the 'matching' task, she was asked to turn a hand-held card so that it matched with the orientation of the slot, without reaching out toward the display. In the 'posting' task, she was asked to reach out and 'post' the card into the slot. As shown in the diagrams below the pictures, Dee had no problem with the posting task, but performed almost randomly on the matching task. Healthy control subjects, of course, had no problem with either task. (Although the slot was presented in several different orientations, the diagrams always show 'correct' as vertical.) From Goodale, M.A., Milner, A.D., Jakobson, L.S., & Carey, D.P. (1991). A neurological dissociation between perceiving objects and grasping them. *Nature*, 349, 154–156 (Figure 1).

When tested in this way, Dee performed remarkably well, whatever the orientation of the slot. Indeed the accuracy of her behavior was almost indistinguishable from that of several people with unimpaired vision that we tested. Dee moved her hand forward unhesitatingly, and almost always inserted the card smoothly into the slot. Moreover, video recordings revealed that she began to rotate the card toward the correct orientation well in advance of arriving at the slot. In other words, she was using vision right from the start to guide her movements—just as anyone with normal vision would do. Over the years, we have tested her on several versions of this test and her behavior always looks normal, however we measure it.

Given what we knew about Dee's visual abilities, we were pretty sure that she wouldn't be able to tell us about the different orientations of the slot—even though she was inserting the card into it so accurately. But we had to check this formally. In our first attempt to do this, we simply asked her to tell us what the orientation of the slot was—was it horizontal, vertical, or tilted to the



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left or right? Most of the time she appeared to have little idea of the slot's orientation and ended up simply guessing. For example, she was just as likely to say that a vertical slot was horizontal as she was to get it right. But this was still not convincing enough—maybe her problem was not so much a visual one but rather one of putting what she saw into words. So in another test, we asked her to tell us the orientation by simply lifting the card up and turning it to match the orientation of the slot, but without making a reaching movement toward the slot. Here we were not asking her to use words to *tell* us what she saw, but to use a hand movement to *show* us what she saw. But the videotapes we made of her hand movements told much the same story as her verbal descriptions. In other words, the angles at which she held the card showed no relationship at all to the actual orientation of the slot.

Her failure to 'match' the slot correctly using the card was not because she could not rotate her hand properly to indicate a particular orientation. We were able to rule out that possibility by asking her to *imagine* a slot at different orientations. Once she had done this, she had no difficulty rotating the card to show us the orientation she had been asked to imagine. It was only when she had to look at a real slot and match its orientation that her deficit appeared.

These first experimental tests confirmed our suspicions that something very interesting was going on. Dee could turn her hand correctly so that the card would pass smoothly into the slot, but she could not make a similar rotation of her hand to convey to us the orientation of the slot that she saw in front of her. But this was just the beginning of the story.

Grasping size

The posting test showed that Dee had good visual control of her hand movements when confronted with an oriented slot. Of course whenever we pick up a pencil we unthinkingly tailor the orientation of our hand to the orientation of the pencil. At the same time, we also calibrate the separation of our finger and thumb as we move our hand toward the pencil. We do all this quite automatically. In fact, our hand and fingers begin to adopt the final posture of the grasp well before we make contact. In doing this, the advance information we use has to be visual—particularly when we are confronted with the object for the first time and so we have no memory of it to fall back on.

The exquisite tuning of the hand to the target of the grasp was first documented in detail by the French neuroscientist Marc Jeannerod. He made high-speed films of normal individuals reaching out to grasp solid objects like balls and cylinders of different sizes. By then looking at individual frames of film, he was able to reconstruct the entire trajectory of the grasping movement from start to finish. These reconstructions revealed a beautifully orchestrated action. As soon as the hand left the table en route to the object, the fingers and thumb began to open (see Figure 2.3). Then, about two-thirds of the way toward the object, they began to close in on the object so that a smooth and accurate grasp was achieved. Even though the maximum opening between the fingers and thumb was much larger than the width of the object itself, Jeannerod showed that the two were closely related: the bigger the object, the bigger the maximum grip size (see Figure 2.4).

So the obvious next question to ask was this: Would Dee demonstrate the same relationship between grip size and object size that Jeannerod had demonstrated in healthy people—even though she has no conscious visual experience of the dimensions of the objects?

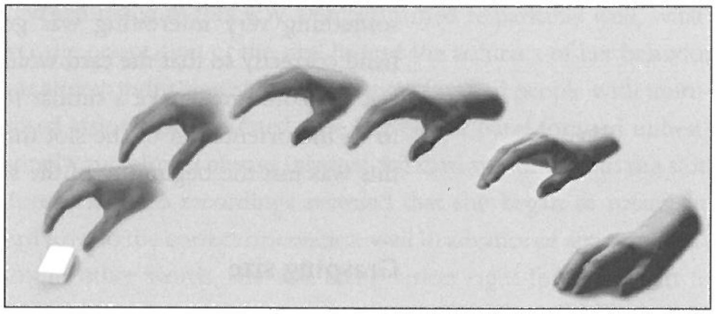

Figure 2.3
This sequence shows a hand reaching out to grasp a rectangular block. Notice that the finger and thumb first open wider than the block and then close down as the hand approaches the block.

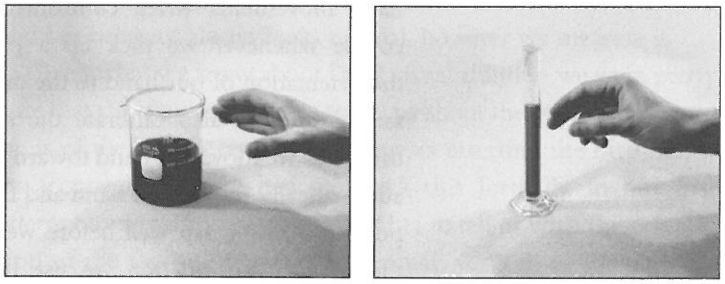

Figure 2.4
Not only do we rotate our hand in the correct orientation as we reach out to grasp an object, but the opening between our thumb and fingers is scaled to the object's size. Thus, we open our hand wider in flight to pick up a beaker than we do to pick up a measuring cylinder.

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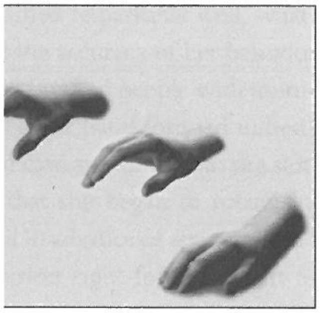

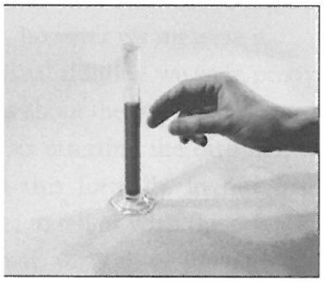

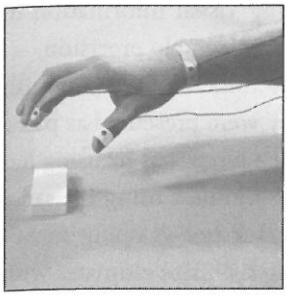

Figure 2.5

A grasping hand open to its widest extent (maximum grip aperture) as the subject reaches out to grasp one of the three-dimensional Efron blocks. Small infrared-emitting markers have been attached to the ends of the finger and thumb and to the wrist. These markers are tracked with infrared-sensitive cameras.

We had already noticed that she had no difficulty picking up everyday objects of many different shapes and sizes, from pencils to coffee cups. But to test this more formally, we had to come up with some objects where the dimensions could be varied but the overall size of the object did not change. Also, it was important to use objects that had no meaning, so that she couldn't simply remember what kind of grasp was required by guessing what the object was. For example, she might guess that she was picking up a pencil from its yellow color, or a coffee cup because she remembered putting it down on the table. The solution we came up with was to make three-dimensional versions of the rectangles devised by Robert Efron that we described in Chapter 1—a set of six rectangular wooden blocks that varied in width (but not in overall area). We already knew, of course, that Dee would have great difficulty distinguishing between these different shapes.

In order to monitor the movements of the hand and fingers as the reach and grasp unfolded, we were able to take advantage of new technology that had been developed in Canada. The technique involved attaching small infrared lights to the tips of the index finger and thumb. The three-dimensional coordinates of these lights could then be tracked with two infrared-sensitive cameras and stored in a computer as the hand moved out to pick up a target object (see Figure 2.5). Special computer software could then be used to plot how the finger postures changed as the hand moved toward its goal. These techniques were already in use in the visuomotor laboratory at the University of Western Ontario where one of us (Mel Goodale) was now working.

So in the spring of 1990, Dee and Carlo made their first trip to Canada, spending a week visiting London Ontario. We gave Dee a day or two to get over her jet lag, and then we brought her into the laboratory where we carried out our first test using the 'Efron blocks'. Small infrared lights were attached with adhesive tape to Dee's fingers, thumb, and wrist. We placed the shapes in front of her, one by one, and asked her simply to reach out and pick them up and put them down again. When we tracked how she opened her hand as she reached toward the object, we found that she showed exactly the same scaling of her grip 'mid-flight' as the normally sighted individuals we tested. In other words, the wider the block, the wider her hand opened. It was clear then that like anyone else, she was unconsciously using visual information to program her grasp, and doing so with considerable precision.

As expected, however, Dee found it difficult to distinguish between these solid rectangles when they were presented as pairs. She could not even show us how wide each block was by using her finger and thumb, which we were able to monitor using the same recording equipment we had used to track her grasping movements. For most people, of course, making such size estimates with the finger and thumb is a simple thing to do. But it was not for Dee. Her estimates were wildly inaccurate, and showed no relationship at all to the real width of the blocks. Yet she understood perfectly well what we were asking her to do—when we asked her to imagine a familiar object, like a Ping-Pong ball or a grapefruit, she had no trouble showing us how big that object was using her finger and thumb.

So we arrive at a similar conclusion as before: Dee seems to have no trouble in using visual information to program her grasping. Yet, at the same time, she does not have any conscious visual experience of the dimensions of the objects she is picking up so skillfully.

Grasping shape

Dee can deal proficiently with the size and orientation of objects when she has to use those features in simple behavioral actions. But what about their *shape*? Could she use the outline of an object, the very thing whose absence robs her visual experience of its essential structure, to guide her actions? For example, the rectangular shapes we had used earlier to probe her ability to scale her grasp varied not only in width but also in shape. In that earlier study, the blocks had always been placed in the same orientation and she had been instructed to pick them up front to back. This meant she did not have to use the shape—only the width—to pick up the blocks successfully. But what if they were placed in unpredictable orientations from one occasion to the next and she was given no instructions as to how to pick them up?

When we carried out a test like this, Dee did just as well as she had done when the blocks were always in the same orientation (see Figure 2.6). This meant she must have processed not only the dimensions of the object but also its orientation. In other words,

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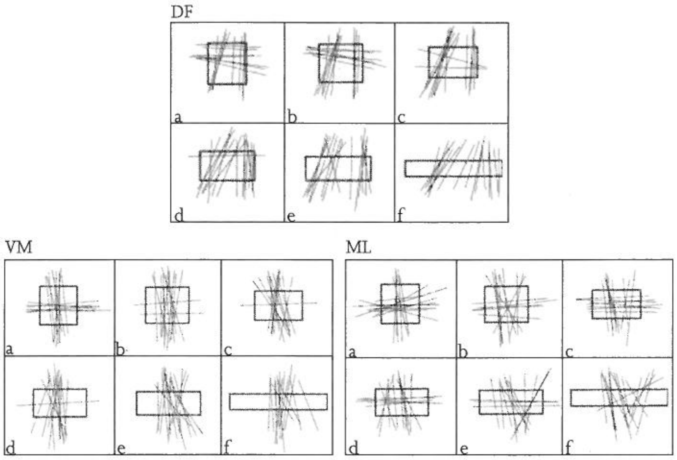

Figure 2.6

These diagrams show how Dee and two healthy control subjects picked up blocks placed in different orientations on a table in front of them. The lines connect the points where the index finger and thumb first made contact with the block. (The results at the different orientations are all shown together on a standard drawing of the block.) Just like the control subjects, when Dee reached out to pick up the block that was nearly square, she was almost—though not quite—as likely to pick it up lengthwise as widthwise. But with more elongated blocks, she and the control subjects were progressively less likely to do that. None of subjects ever tried to pick up the most elongated block lengthwise. In short, Dee was able to take both the orientation and the shape of the block into account in planning her movement, just like people with normal vision. From Carey, D.P., Harvey, M., & Milner (1996). Visuomotor sensitivity for shape and orientation in a patient with visual form agnosia. *Neuropsychologia*, 34, 329–337 (Figure 3).

she had to scale her grasp and at the same time rotate her wrist in flight to get her finger and thumb in the right positions. We noticed as well that she nearly always picked up the blocks widthwise rather than lengthwise, even though we gave her no instructions to do this. Obviously, we will pick up a square block equally often either way, because the length is the same as the width. Less obviously, but perhaps not unreasonably, the more elongated the block, the more we go for the width in preference to the length (other things being equal). Dee is no exception to this. This simple fact shows that the undamaged part of Dee's visual brain can not only tailor her grasp to one of the dimensions of the block, but it can work out which dimension is the shorter of the two. This computation then allows her to choose the most appropriate grasp points, generally at right angles to the principal axis of the shape. In short, her actions can still be guided to some degree by visual shape.

But we were interested to go further and find out whether Dee's visuomotor system could do more than simply compute the dimensions and orientation of regular objects. For many shapes, the visuomotor system must also take into account other geometric properties, such as the curvature of the object at different points around its edges. This is a problem that roboticists have had to address in the development of control systems for so-called 'autonomous' robots that can work in unfamiliar environments. In such situations, the robots will often be required to pick up objects that neither they nor their programmer could have anticipated. To do this the robot, like the human, has to use its optical sensors to compute not only the object's width, orientation, and principal axis but also the curvature at different places around the object's boundaries. Only by computing the convexities and concavities around the object, would the robot (or the human) be able to select the most stable grasp points—points where the robot's grippers (or the human's finger and thumb) could clasp the object securely.

Discussions with a German colleague, Heinrich Bülthoff, brought to our attention the work of Andrew Blake, an engineer at Oxford University. Blake had developed a series of abstract shapes to evaluate the performance of different computer programs he had designed to guide robotic grasping of novel objects. With Bülthoff's help we constructed what we came to refer to as the

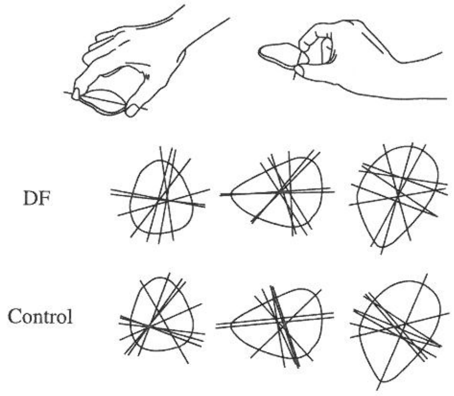

Figure 2.7

The Blake shapes. The drawings at the top show a stable (on the left) and an unstable (on the right) grasp for these irregular shapes. For shapes of this kind, the lines joining the index finger and thumb for a correct grasp would pass through the center of the shape and would be positioned on stable points on the edge of the shape. As the grasp lines shown on the outlines of three typical shapes illustrate, Dee grasped the shapes just as well as the control subject. From Goodale, M.A., Meenan, J.P., Bülthoff, H.H., Nicolle, D.A., Murphy, K.J., & Racicot, C.I. (1994). Separate neural pathways for the visual analysis of object shape in perception and prehension. *Current Biology*, 4(7), 604–610 (Figure 5).

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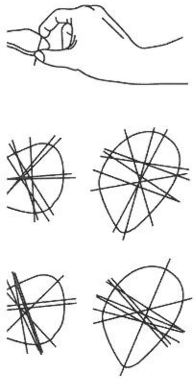

a stable (on the left) and an unstable For shapes of this kind, the lines ct grasp would pass through the n stable points on the edge of the of three typical shapes illustrate, l subject. From Goodale, M.A., hy, K.J., & Racicot, C.I. (1994). of object shape in perception and e 5).

'Blake shapes', a set of smooth, flat, pebble-like objects, for testing Dee's ability to select stable grasp points on unfamiliar shapes.

When we presented these shapes one by one to Dee, she had no difficulty whatever in picking them up (see Figure 2.7). As she reached to pick up each Blake shape, she made subtle adjustments in the positioning of her finger and thumb in flight so that they engaged the object at stable grasp points on its boundary. Just like people with normal vision, or one of Blake's robots, she would choose stable points the first time she was presented with each object. Yet, needless to say, she was totally at a loss when it came to saying whether pairs of these smooth objects were alike or different.

Walking around

As we saw at the beginning of this chapter, Dee is able to hike over difficult terrain as skillfully as the next person. When walking through a room, she never bumps into furniture or doorways. In fact, this apparently normal navigation through her immediate environment, coupled with her ability to reach out and shake your hand or take objects that are offered to her, makes many people who meet her for the first time doubt that she has any visual problems at all. She talks to them intelligently about her journey and she even appears to recognize people she knows in the laboratory. As a result, some colleagues who have come to test her have initially been so skeptical as to feel they were wasting their time—they could test such an apparently normal person any time!

Of course, as all psychologists should know, appearances can be deceptive. For example, Dee's recognition of people that she has met on previous occasions need not be due to any *visual* ability, but rather to her ability to remember what someone's voice sounds like. (Though it is true that she can use certain visual cues, like color. We had a colleague in St Andrews with a penchant for dyeing his hair bright colors—often more than one. Dee never had any difficulty recognizing him.) A skeptic (as psychologists are by nature) could argue likewise that in the anecdote with which we started this chapter, Dee's ability to negotiate the trail at Monrosa might owe much to her previous experience with this popular picnic spot.

So we needed a way to test her ability to walk around an unfamiliar environment, in which we could specify beforehand the precise nature of the obstacles placed in her path. Fortunately, at the University of Waterloo, only an hour away from the University of Western Ontario, a colleague of ours, Aftab Patla, was studying just this kind of locomotor skill in people with normal vision. Patla had constructed a special laboratory in which he could place obstacles of particular heights at specified points along a route that his volunteers were asked to follow. With the help of the same kind of opto-electronic equipment that we were using at Western, he was able to measure the adjustments that people automatically make to their gait as they step over such obstacles.

On one of Dee's several visits to Canada, we drove her to Waterloo where she was quite happy to try Patla's test. She walked through his test environment absolutely confidently and without tripping over any of the obstacles, which varied in height from less than an inch up to fifteen inches (see Figure 2.8). In fact her behavior was indistinguishable from that of other volunteers. Just like them, she effortlessly raised her foot just enough to clear each of the obstacles. It will come as no surprise to the reader, however, that when asked to estimate the height of the obstacles in a separate test, Dee was much less accurate than the normal volunteers.

Figure 2.8

A foot going over an obstacle. Note that the toe of the leading foot just clears the top of the obstacle; the same is true for the toe of the trailing foot as well. In other words, we leave just enough clearance to make sure that our foot doesn't touch the obstacle—rather than leaving a large safety margin whatever the height of the obstacle.

How does she do it?

All the laboratory testing confirmed our informal observations: In one sense, Dee sees perfectly well. She uses visual information about the size, the orientation, and to some degree the shape, of objects to execute skilled movements. Yet in another sense, Dee sees nothing at all—and can certainly tell us nothing—about these attributes of the objects.

So what was the essential difference between the situations in which she succeeded and those where she failed? As pointed out earlier, it is not simply the case that she is unable to put her visual experience into words. Nor is it the case that whenever she makes some kind of skilled limb movement in response to a visible object she gets it right. Take, for example, the posting test. Her ability to insert the card into the slot cannot simply be put down to the fact that she was making a manual action. She had to make a hand movement in the matching test as well—yet she failed completely. The critical difference therefore is not that a movement was made in one case but not in the other. It is the *purpose* of

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the movement that matters. When we asked people to use their hand to show us what they saw in the matching test, they were reporting on their conscious perception of the slot in front of them. Turning the hand in this case was an act of communication. The fact that the communication happened to be manual was arbitrary—the same information could have been conveyed by a variety of different means. They could have drawn a line on a piece of paper, for example; or picked the correct orientation from a number of alternatives in a multiple choice test; or of course they could simply have told us in words. Dee could do none of these things—not because she couldn't communicate but because she had nothing visual to communicate. She had no conscious experience, no conscious visual experience at least, of the orientation of the slot to share with us.

The action that Dee had to make in the original posting test had a very different purpose. To get the card into the slot, she had no choice but to turn her hand in a particular direction. This rotation was an obligatory part of the action rather than being an arbitrary act of communication. Dee had to make the same kind of rotation of her wrist when she reached out to pick up a rectangular block or a pencil placed at a particular orientation. Such movements are part of an ancient repertoire that we share with our present-day primate cousins, the monkeys and apes, and presumably also with our own primate ancestors. For example, when we are standing in a crowded subway train and it suddenly jerks to a stop, we may find ourselves quickly reaching out to grasp a handrail to steady ourselves. We do this without thinking, yet our brain has to do some complex processing so that our hand can turn rapidly and accurately so as to grasp the rail. This echoes the kinds of unthinking hand movements our arboreal ancestors would have had to make when grasping branches and when foraging for food.

The most amazing thing about Dee is that she is able to use visual properties of objects such as their orientation, size and shape, to guide a range of skilled actions—despite having no conscious awareness of those same visual properties. This contrast between what she can and cannot do with visual information has important implications about how the brain deals with incoming visual signals. It indicates that some parts of the brain (which we have good reason to believe are damaged in Dee) play a critical role in giving us visual awareness of the world while other parts (relatively undamaged in her) are more concerned with the immediate visual control of skilled actions.

Perhaps this should not be too surprising. On the one hand we need vision for the on-line control of everyday actions—particularly for those actions where speed is at a premium and we do not have time to think. But on the other hand we need vision to make sense of the world around us, when we do have time to think! In fact, for most people, including most vision scientists, this perceptual experience of the world is the most important aspect of vision. What perception does for us is to translate the ever-changing array of 'pixels' on our retina into a stable world of objects that exists independent of ourselves. This allows us to construct an internal model of the external world that enables us to attach meaning and significance to objects and events, to understand their causal relations, and to remember them from day to day. Perception also allows us to plan our future actions, and to communicate with others about what we see around us.

Summary

The studies with Dee highlight the two distinct jobs that vision does for us: the control of action on the one hand, and the construction of our perceptual representations on the other. As we will see in the next two chapters, these two different functions of vision have shaped the way the visual brain has evolved. Rather than evolving some kind of general-purpose visual system that does everything, the brain has opted for two quite separate visual systems: one that guides our actions and another, quite separate system, that handles our perception.

Thinking about vision this way certainly helps us to understand Dee's predicament. The anoxic episode (see Box 1.1) profoundly affected her vision for perception but left her vision for action largely unscathed. What was lucky for us as scientists, and also of course for her, was that the damage was so specific that her vision-for-action system has continued to operate remarkably successfully in isolation. What the damage did was to uncover in Dee a system that we all use, but one that is normally overshadowed and outshone by our concurrent visual experience of the world. Her tragic accident has allowed us to bring this visuomotor system out of the shadows, and to explore its operating characteristics and scope.