JIM DAVIES

IMAGINATION

The Science of Your Mind's Greatest Power

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A NOTE FROM THE AUTHOR

When I set out to write this book, I wanted to write something that bright high school graduates and university students could understand, but would also be a volume that scientists would appreciate, too.

This book uses information gleaned from hundreds of studies and scholarly works. In my field, many papers are coauthored, sometimes by six or more people. To reduce excess verbiage, I mention only the first author for a study in the text. The endnotes have all of the authors' names. This does not necessarily mean that the first author did all or most of the work, though, in general, this is true. In science, the person in charge of the laboratory is usually the last author listed.

Furthermore, most of the scientists I cite here are psychologists. If I mention a name without referring to their field, assume they are a psychologist. When I cite someone from another field, such as philosophy or computer science, I will mention it.

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Imagination: What It Is

Imagine a jar of peanut butter.

When you do this, you're creating, in your mind, something that doesn't exist—even if you're imagining the jar you actually have in your cupboard, you're creating something new. There's the actual jar of peanut butter, and then there is a separate thing in your mind: a representation of the jar, here and now, not where and when the physical thing actually is. The actual jar of peanut butter is made of plastic and peanut butter. The thing in your head, the "imagining," is some pattern of neurons firing in your brain. Even when you use your imagination to remember something that actually happened to you, you're creating a simulation of a time and place that no longer exists.

This is the essence of imagination: the creation of ideas in your head, composed from ideas, beliefs, and memories. Often, they are not simple ideas, but complex structures. The most spectacular use of imagination is in creativity, but this book isn't about creativity, which requires the generation of something new and effective in some way. Acts of imagination need not be new or useful. Imagination also has great uses in more mundane tasks we do every day, such as planning the day. When you think of what route you want to use to get home, or you go through the logistics of where to park your bike, or figure out what order you should run your errands in, you're thinking of possible realities that do not yet exist. Though we don't often call these acts "creative," they are fantasies, possible futures that don't currently exist outside your mind. Even the simple act of considering what to do next is using your imagination.

When you picture a jar of peanut butter, if you're like most people, you have an experience that is kind of like, but not exactly the same as, seeing it in real life. Likewise, when you have a song stuck in your head, or when you're having a vivid dream, it can be a profoundly sensory experience. It's called your "mind's eye," because it feels like you're actually seeing things in your head. Likewise, we have a mind's ear, nose, and tongue.

MENTAL IMAGERY

For most people, imagination in its clearest and most obvious form is mental imagery. You have the experience of "seeing" in both perception and in imagination, but in perception, the light or sound comes in from the outside world, and for imagination, the information comes from your memories.

Coming up with a precise definition of mental imagery is difficult, but coming up with a vague definition is pretty easy. Mental imagery tends to have some common characteristics: first, it is *like* experience with the senses. That is, if you create a mental picture of a boy chasing a fox, or imagine the sound of what the fox says, the experience is like a less-vivid version of actually looking at a boy or listening to a fox in the real world. Second, it happens in the absence of input from the environment that would normally cause it—it's created by your own mind.[1] Or, put more simply, the image in your head is not caused by what you're currently perceiving.

This bit is important because even when your eyes are open, your mind can rope in memories and project imagination into the scene you're seeing in the world. You might look at your living room and imagine how a red couch would look in it, in a kind of organic augmented reality. Imagining doesn't have to be in the absence of *all* perceptual imagery, just in the absence of the stimulation that would *normally* produce the experience—in this case, an actual red couch.

In these examples, we generate imaginings with an act of will, but sometimes imagery comes automatically. For example, many people get spontaneous images when they're reading novels. I've described disturbing things to people to have them tell me, sarcastically, "Thanks for that image." People who experience trauma sometimes imagine the event, again and again. Not only do they not decide to reimagine the trauma, they can't stop.

But can we imagine without imagery? It's easy to think of visual imagination as being nothing more than mental imagery, but we have what we might call "conceptual imagination" as well that doesn't really have much to do with the senses. I'll give a few examples.[2]

Imagine a triangle. Now add one side to make a square. Now add so many sides that there are 2,001 of them. The picture of it in your mind's eye is wrong—either the polygon has far fewer than 2,001 sides, or it looks just like a circle, because the details are too fine to make out with the resolution of your mental imagery.[3] Just like a computer screen or a photograph, your visual mental imagery has a limited resolution.

So how is imagining a 2,001-sided polygon different from imagining a circle? Because you *know* that it's a polygon, not a circle. Now, remove one side of the polygon, so that it only has 2,000 sides. It doesn't look any different in the image! Both a 2,000-sided polygon and a 2,001-sided polygon will look just like a circle in your mental imagery. The difference is only in your belief about the polygon. Both of them look like circles, but you *know* that they have a different number of sides. These beliefs are part of your imagination, too, even if they don't particularly look like anything. The difference is conceptual, not visual. This is one example of how you can have a nonsensory imagining.

There are lots of states of being that don't particularly look, sound, or smell like anything at all: owning a bike, thinking that *Kiki's Delivery Service* is a great movie, having $49,000 in your bank account, having a goal to chew more gum, wanting to eat a spoonful of peanut butter, being part of the in-group at work, and so on. Often, our imaginings are a combination of mental imagery (sensory imagining) and conceptual imagining.

And this ability is extraordinarily powerful.

Our ability to imagine things is a surprisingly important ingredient for the special sauce we have that makes us the only species on Earth that have things like money, the arts, cities, moon landings, and Laurie Anderson's *Big Science* album.

Let's take social organization as an example. Many of our relationships with other people are one-on-one relationships. You know your lovers, your friends, your parents, your rivals, the other people at your workplace, and so on. Many other animals also have these kinds of relationships. Even bats remember other individual bats in terms of who did and who didn't help out when food was scarce, and respond accordingly, punishing the jerk bats.[4]

But we humans have lots of relationships that go beyond our *personal* histories with other people. We can feel a kinship with (or a hatred for) people we've never even met. We might feel a nationalistic affiliation with our fellow citizens. We might want to help out other people who belong to our own religion, political party, or are also Beastie Boys fans—or hurt those who we believe hold different values. Other animals can't do this. Chimpanzees can't have groups of more than about fifty individuals. Any more than that and the group splits. Their brains don't have the carrying capacity to keep track of that many one-on-one relationships. Nonhuman animals can't know who to trust without having some significant interaction with specific individuals. But with human imagination, we can construct these abstract concepts of social groups that include people we've never met. When we perceive someone else to be in some social group or other, we know how to treat them.[5]

The very idea of a social group that includes people you've never met requires using conceptual imagination. Social groups have no physical existence, or, more accurately, they exist only because lots of people believe they do. Without this imagination, we could not have money, or countries, or religions.[6]

We can see other examples of conceptual imagination in our dreams. You might dream of someone who looks like a nun with a nicotine habit that you *know* is your mother. From a sensory perspective, it's a nun. You knowing that it's your mother is using a nonsensory imagination.

So we can imagine without using imagery, but it's a little bit harder to get our minds wrapped around this. If you're like most people, when I ask you how many windows were in your childhood home, you will do a mental walkthrough of the house, counting the windows as you go. But if I ask you whether the roof of a house is above the door of a house, you can probably answer that without making a mental picture. You *might* make a picture, but you probably don't need to. Why do you use mental imagery for one and not the other?

The fact that roofs are above the door of a house is just that, a fact. In psychology, it's what we call a "semantic declarative memory." It's sentence-like, but it's not about any particular event. Now, when I say sentence-*like*, I don't mean that it's stored in your brain as a sentence in the language you speak. But it's *like* a sentence in that it has symbols that are arranged in a meaningful structure. Think of a pair of shoes you own. You know you own them, but the fact that you do doesn't look or sound like anything in particular. It's just a fact about the world. You can picture your friend borrowing and wearing your shoes, and that image doesn't make the shoes theirs. Knowing someone is jealous, or married, or likes the taste of peanut butter, also doesn't look like anything either,[7] but you can imagine these things easily.

Just about all psychologists believe that *all* of our long-term memories of things are connected symbols. This is true even for your visual memory. It's made up of symbols for objects and shapes, textures, distances, and so on, and the relationships between these objects is encoded in these sentence-like entities. In cognitive science, we call them "propositions." But it certainly doesn't feel that way. It feels like we have pictures in our memory that we can recall pretty well. So why would psychologists think that our long-term memories don't have pictures?

Think of the last large dinner party you attended, and picture it in your head. Doesn't it feel kind of like you had that picture somewhere in your memory, and you simply brought it to mind? That the picture was in your head, fully formed, and you are just directing your attention to it? It kind of feels like pulling a photograph out of a drawer and looking at it. But as much as it feels like this, it's almost certainly not what happens—that would be like having a photographic memory, which is exceedingly rare, if it exists at all. If someone you know thinks they have a photographic memory, find a book they've read recently, open to a random page, and ask them to tell you the last five words on that page. They won't be able to do it.[8]

Suppose you reminisce with a friend, and your friend reminds you that someone you'd forgotten about had also been at the dinner party, your forgettable friend Erika. That is, the image you saw in your head was missing Erika. If your long-term memory of that scene were really like a picture, there wouldn't have been a person missing from the mental image.

A true photographic memory might make some mistakes, but the mistakes would be of a different kind than those we *actually* make: Think about what was in that image where Erika *should have been.* It's not like a blurry or pixelated part of a photo, or a part ripped out, or a big black space. Those are the kinds of errors you get if that person were missing from a photograph or a digital image. Rather, your mind made (what you thought was) an apparently complete, coherent picture of the dinner scene. There wasn't someone obviously missing from it. You'd have noticed something like that. Instead, you just omitted Erika, and the picture looked fine and complete to you in your head. Which is really kind of amazing. You reconstructed a picture, or something like a picture, from nonpicture memories. You just failed to recall Erika, so she didn't get cast in your inner picture.

So what's going on here? To the best of our knowledge, you have a long-term memory of the dinner party that is interpreted, made of symbols connected in propositions. When you are called upon to engage in memory recall, your mind can *construct* a mental image based on the information in long-term memory, the fact-like information about who was there, where they were seated, what was for dinner, and so on. It's a little like a description you might give to an illustrator. Because individual facts can be forgotten, the resulting picture might be experienced as complete, yet still have inaccuracies.

Then, when somebody reminds you about Erika, you just slip her seamlessly into an already pretty good picture. It's like doing a great Photoshop edit in your mind. It feels so natural and happens so effortlessly, we hardly notice that it happens this way. But this is important, because it means that *even what feels like simple memory retrievals are, in some sense, acts of imagination.*

When you update the facts, a new picture emerges. And you might remember this new picture as what happened—but you never store the image itself, just another description of it.

Of course, we don't *have* to use mental imagery. Sometimes you can rattle off a list of the people at the party without making a picture of it. You are still engaging in imagination. The mental imagery part comes afterward and is, in many cases, optional.

When I talk about imagination, I'm not just talking about imagery—you can *imagine* things with or without *imaging* them.

I should say here that although scientists agree that people can *experience* mental imagery, there is some disagreement about what's actually happening in your mind when this happens.

PSYCHOLOGICAL DISTANCE

Although most of us can generate (and be conscious of) pictures in our heads, we don't always do it. Suppose you're planning errands with someone you live with and discussing which of you will go buy that jar of peanut butter. Many people can engage in planning like this without actually picturing anything in their heads. But if they choose to, they can. Sometimes we can turn a conceptual imagining into a mental image with an act of will. You can generically imagine having a jar of peanut butter, but if you create a mental image of it, you need to make a picture with a specific place, with a certain point of view—something that is unnecessary when you're just hypothetically imagining "I have peanut butter."

So when do we engage in mental imagery and when do we just stop at conceptual imagination? It depends, in part, on what is being imagined. Imagining some things makes us more likely to create mental imagery than others. For example, we tend to think more in pictures for things that seem physically close to us. If you talk about a (hypothetical) birthday party that's nearby, people will have more vivid imagery than if you're talking about the same birthday party that's really distant.

But this closeness can also be metaphorical. There also seems to be an association between actual distance from you and what we might call "psychological distance." A good example of something that is psychologically distant is an event far in the future. Elinor Amit has a theory that we think more in pictures for things that are psychologically close and think in terms of words and propositions for things that are more psychologically distant.

To test this, she used a version of the Ponzo illusion, which involves two diagonal lines that converge near the top. Two equal-length horizontal lines will appear to be of different lengths depending on how high they are placed on the image. Think of a photo of train tracks going into the distance: even though each railroad tie has a different length on the page or screen, they look to be the same length because the rails give the impression of lines converging in the distance. Your mind adjusts for the foreshortening that you expect from distant objects.

In her experiment, she placed words or pictures either high or low on the image of the two converging lines. Then she measured how quickly people could recognize them. Things higher in the image look farther away, and things near the bottom of the image look closer. People were relatively faster at recognizing words when they appeared far away, and pictures when they appeared close.[9]

In other studies, she asked people what they would prefer for bathroom labels: iconic pictures of men and women (the kind we see on restrooms all over) or the words “men” and “women.” If the signs were to be put up next week, people showed a preference for the pictures. If the signs were to be put up a year from now, they preferred the words. She also found that people were more likely to use pictures (versus words) with people perceived to be socially close to them, and words for those further away—you're closer to your mother than to the CEO of Disney.

These distance effects work for physical distance, distance in time, and even social distance. People are even more likely to follow sent instructions when the medium and distance are congruent. That is, if you're communicating instructions to someone about how to deal with something close to them, they are more likely to follow those instructions if you present them in pictures. If the instructions regard something far from them, you're better off using words. Effective communication depends on whether your use of words or pictures corresponds to how distant the subject matter feels to the person you're communicating with.[10]

I find these effects pretty remarkable. It makes sense that our minds would naturally think in terms of space: we, as well as most of our animal ancestors, need to navigate space to survive, so it makes sense that we'd be pretty good at it. But it seems like we use the concept of distance in space to help us understand more abstract ideas like time and social connection. It's a very deep metaphor. This stuff doesn't only work for distance. It turns out that human minds work with metaphors all the time.

METAPHORS AND THE MIND

Let's talk about how we think about time. Suppose your coworker tells you that the meeting on Wednesday has been moved forward by two days. When do you think the new meeting is going to be held? On Monday or on Friday?

The answer might seem obvious to you, or you might not be too sure. People differ on whether they think the new meeting is going to be on Monday or Friday. What's interesting is that the one they pick depends on how they imagine time, and what metaphor they use.

Some people think of time as moving around them. It's as though they are standing still in a fast-moving river, facing upstream, and imagine time flowing around their bodies. So the idea of an event in time being moved "forward," means, to them, closer to the present, coming up sooner, and earlier in the timeline. These people tend to think the new meeting is happening on Monday.

Others view time as static, like the still water in a pool, and they are the ones wading through it. To them, "forward" is the direction they're moving in, placing the new meeting on Friday. So be careful when you tell people you're moving an event forward or backward in time. The different metaphors for time, which they don't even realize they have, will make them interpret the new date differently.

But it's not that each person has only one way to think about time. We all can imagine time with either metaphor. We understand what it means when we hear things like "Winter is coming," which suggests that time itself is moving, and we also understand things like "when we get to the end of the year, we should have money saved up," which suggests that we're the ones moving through time.

What we're doing can affect which metaphor we choose. Lera Boroditsky asked people in lunch lines whether the Wednesday meeting pushed forward two days was on Monday or Friday, and their answers seemed to depend on where they were in the lunch line! People at the front were more likely to say "Friday." Those at the back of the lunch line were more likely to say "Monday."

Boroditsky's explanation for this is that people at the front of the line feel like they're moving. We've all felt this. At the end of the line you feel like you're not getting anywhere, and as you get closer to the front, the movement is steadier. So it seems that the ones at the front had their minds primed to think of the self-moving metaphor of time, while the people at the end of the line, who felt like they were barely moving at all, felt like they were just waiting for time to pass.[11]

Notice that for both of these metaphors, people are thinking about time in terms of space. This is just one example of how we think about abstract things like time in terms of more concrete things, such as handling physical objects. We do this a lot. More abstract things tend to be understood in terms of more concrete things. Our imagination affects our understanding of these concepts.

So why do our minds think in terms of metaphor so much?

To understand why, I need to tell you a bit about brain evolution. If we look at lizards, and other creatures that have simpler brains than humans, we can see that they have brain structures similar to humans. They have limbic systems for running basic fight and flight mechanisms, perception, body control, and so on. Lizards don't have language, so they don't have the brain areas that are specific to language.

But humans diverged from lizards in the evolutionary tree a very long time ago, and we've both continued evolving since. So why would we still have recognizably similar brain structures?

If you want a new boat, you can tear down the old one and build a new one that's completely different. But evolution can't completely overhaul the brain plan of a species in the same way. As a brain changes over time, those creatures still have to be able to stay alive. To continue the analogy with the boat, it's as though you're in the boat out on the ocean and you have to change it, but you can't make changes that would make it sink *at any moment*. What this means, for boat building, as well as for brain evolution, is that a lot of the brain parts that are necessary for survival *can't* be changed all that much. Evolution works incrementally, and you can't tear down your ability, say, to digest protein and build a new one, because you have to digest protein. All the individuals in the population would die and wouldn't be able to reproduce.

The situation for evolution is even harder than for a boat. You might be able to build something on deck and not use it until it's finished, such as a new sail. You put the sail up only when it's done and probably going to work. But evolution can't look ahead like that. A system can't evolve unless it's useful *every step of the way*. So, in this analogy, you would have to subtly make changes to the sail, making it incrementally better with every single change.

In evolution (of anything, not just brains), just about nothing will stick around unless it's useful. That's why wings didn't start out as wings, our ear bones didn't start out as things we hear with, and so on.

Our brains can't stop using the functions they need to keep us alive and reproducing, and evolution can't create new functions unless they are useful every step of the way. So instead of rebuilding the brain, evolution ends up building additions to what's already there. There is no "closed for renovation" in living species.

The brain areas at the top of our brain stem (the bottom of the brain) are the oldest. Things like sex, escaping predators, perception—evolution can't really mess with these systems, so it builds new ones and tacks them on like extensions built onto a house. For us, these additions happened on top and in the front. I'm speaking as though evolution has a plan in mind, but, of course, it does not. It's easier to explain evolution if we treat it as a designer with constraints, but eventually you have to let go of that scaffolding, because evolution can't plan anything.

These new structures are added onto the old ones and, indeed, *use* those old ones without changing them much. And when you have several new structures relying on the behavior of a single old one, changing the old one becomes impossible. Too many other systems are relying on it working exactly the way it does. If eight systems are using one more–primitive system, then all eight are expecting that old system to work with particular inputs and outputs, and changing that old system would cause a catastrophic system failure.

We can think about it in terms of a company using an outdated computer or software. A company might get a database system, and over the years, more and more parts of the business are created that need to access and use it. These new systems are designed to efficiently make use of the way this database software works. But when new, better database software becomes available, the company sticks with the old one. Why? Because so many other systems in the company need it to work the way it always has. To upgrade the database software, all of the other systems would also need to be changed before the company could run properly.

It's the same with evolution. The perceptual systems are like that old database software. Newer parts of the brain, those that evolved fairly recently in evolution, which we share with fewer animals, use the outputs of the visual system in a very rigid way.

Should the old system change, the newer systems would need to change at the same time. A company can, at some expense, upgrade *all* the software at once, changing everything and creating a whole new information processing system, but this is something that is just about impossible in evolution. Note that the opposite is not true—one of the new systems can change without the old system changing, because the old system does not depend on the inputs and outputs of the new systems. As a result, newer brain systems can evolve more rapidly than older ones.

The old brain is a complex hodgepodge of special-purpose mental machines. There's an area for recognizing faces, for detecting color, for feeling basic emotions, and so on. It's efficient, fast, and rigid.

The new brain is much slower, more conscious, and does things systematically. It is specialized in deliberate action. It behaves more like a general-purpose learner. When you are doing long division on paper, you are heavily taxing your new brain. The new brain is more frontal, where old brain structures tend to be at the top of the brain stem, in the middle of the brain, and closer to the back.

Another distinction between these old and new systems is that the new brain tends to work on things one at a time, step by step, and the old brain works in parallel. As a result of this, the old brain is much better at taking in a great deal of information at once and responding to it. The new brain is just too slow for so many things at once. For some tasks, it's better to rely on new brain processing, and for others, it's good to use old brain processing.

So "older" brain areas are ones we share with other animals. They're not exactly the same, of course, but they are similar enough that we can learn a hell of a lot about the human brain by studying, say, cat brains. The binary classification of "old" and "new" is a bit crude. It's more of a continuum, starting in the middle of the brain, at the top of the brain stem, and curling to the back and over the top to the forehead, going from older to newer. But for the sake of explanation, referring to processes as old and new can be clear and instructive.

Neuroscientist Michael Anderson tested this new/old brain idea by looking at large-scale brain activity. It turns out that when you are using old parts of the brain (emotion, motor control, vision) only those parts are excited. (The whole brain is active all the time, so we're talking about relative activation here.) Because those old brain areas evolved before the new ones appeared, they don't need to use the new ones to work. But the new brain areas are just the opposite—they use the brain areas that came before them, kind of like using tools. So when you look at language use, which evolved very recently, the whole brain lights up, but for simple vision tasks, the activation is restricted to older areas in the back of the head.[12]

When people talk about your "lizard brain," it's more literally true than you might think. So that's why we can talk about the old brain and the new brain. The old brain structures are like old buildings on a college campus—still kept up and modified, but their basic structure was determined long ago, and can't change much.[13] The old brain is also more important. If you're going to get hit in the head, you're better off getting hit in the front than in your lizard brain. It's hard to live with a reptile disfunction.

The visual system, and thus, a good part of the visual mental imagery system, is very old, because our ancient ancestors needed to be able to see more than they needed to be able to concoct long-term plans. As such, it works mostly with other old systems like emotion, and things that deal with the world in front of us, as opposed to hypothetical notions. In contrast with conceptual imaginings, visual images are concrete, visceral, and emotional. As we might expect, people who make more vivid mental images also experienced stronger emotions, as found by my colleague Eve-Marie Blouin-Hudon.[14] So perhaps it should not come as a surprise that visual representations are more emotional and related to more concrete, close things. Vision is part of an old, primitive part of the brain, and visual imagery associates more closely with other older parts of the brain.

Now that we have a basic picture of the brain, we can return to metaphor. Why might the brain think of time in terms of space? In general, nonhuman animals think about simpler, more concrete stuff like jars, drinking, and geese. As humans evolved to think about more abstract concepts, we tended to use concepts we already had—that is, more concrete ideas, such as space and our navigation through it. That's why we think about love as a journey, and up being good, and darkness being bad. We think about abstract concepts in terms of concrete ones, and that helps us understand why we imagine time the way we do.

When we think of sensory imagination, we tend to think of pictures in the head. Indeed, of all of the senses, sight is the most important for human beings, and most of the discussion in this book will be about visual imagination. But technically, we can image in any of the sensory systems we have.[15] Imagery in our minds can be multimodal.

We are all familiar with auditory imagination. We get songs stuck in our heads, and about one quarter of conscious experience is "inner speech," or talking to yourself in your own head.[16] Rather than pixels, sound is imaged as nonsymbolic bits of sound. Similarly, we have imagination for smell, touch, and taste, though most people cannot imagine smells with any vividness. I know what peanut butter smells like, but when I try to imagine that vividly, I can't do it. Your mind's eye is sharper than your mind's nose.[17]

We also have what's called "motor imagery." Your motor system controls your muscles, and motor imagery is when you imagine doing something with your body without your body actually moving. You might dream of running, or mentally practice a dance routine, or vividly imagine going out and buying several copies of this book to give as gifts. In these cases, your motor system is going through the same processes as it would if you were actually doing these things, but the signal gets stopped before it reaches your muscles. We use motor imagination to anticipate other people's actions,[18] and some have argued that when we move our bodies, we are often playing out an action sequence already planned out in the imagination.[19]

Most people immediately know what I'm talking about when I mention pictures in the mind or other kinds of imagery. But if you're someone who doesn't, you're not alone. People vary in the amount of visual mental imagery they experience, and the detail and vividness of those images.[20] Some people can have imagery so vivid that they sometimes have trouble telling their imaginings from reality. Neuroscientist Adam Zeman calls these people "hyperphantasics."[21]

Although some scientists claim that imagination is central to consciousness,[22] many people (including two from my imagination laboratory, ironically) report that they have no conscious experience of imagery at all, even in dreams.

As mentioned above, most people, when asked to count the number of windows in their childhood home, do a virtual walk-through in their mind's eye, counting as they go.[23] "Imagers" report that they have a vision-like experience in their minds, and that they can read information off of this image similarly to how they do it with things they're seeing in the world.[24] Most people are vivid imagers, and only about 3 percent of people have very low imagery ability. Some people start out as imagers, but, usually due to brain damage, no longer experience these images. One woman reported that, after a car accident, she had trouble understanding speech because she could not picture what was being said. But after six months she had learned to associate words with auditory imagery and regained her full comprehension abilities.[25]

APHANTASIA AND HYPERPHANTASIA

Although we've known about differences in imagery vividness between people for a very long time, the phenomenon of having no imagery experience at all has only recently been appreciated, so we don't have lots of data on it yet. Adam Zeman got some media attention for his research on what he called "aphantasia," and as a result, twenty-one people contacted him, telling him that they also had no imagery experiences. Of these twenty-one people, nineteen were male. This gender difference might be a function of the readership of the magazine where the original article appeared, *Discover*, which skews male. For ten of them, *all* senses were affected. That is, they could not generate imagery for vision, sound, smell, or anything else. Nine had "substantial" reductions, and ten could generate absolutely no imagery at all, though most had occasional involuntary images, and seventeen had imagery during dreams. When asked how they accomplished tasks that more people used imagery for, such as reporting how many windows were in one's house, they reported using knowledge and memory, rather than visual information.[26]

Learning about this feels revelatory for many people, because we tend to assume that everybody else has the same experiences we do—and we assume that experiences we don't have, others don't have either. Aphantasics assume that nobody has imagery, and people with really vivid imagery have a hard time picturing anybody being different. This even extends to scientists, who are more likely to believe in scientific theories that match their own experience with imagery.[27]

An aphantasic from my lab said ". . . not only is it possible to imagine something without images, but that's about all we can do. I don't consider myself as a person leading an impoverished internal life, nor do I think of myself as not creative or unimaginative. I simply don't have the pictures." She also said that she has no auditory imagery either—for example, she can't "hear" a song in her head when she imagines it. You know how sometimes you get a song stuck in your head? Never happens to her.

A friend of mine, the philosopher Jeanette Bicknell, also appears to have aphantasia. She read an article about it and told me that "on the question where you were asked to imagine a thunderstorm, I could 'hear' thunder and 'felt' shivery from the rain, but I didn't actually 'see' much. And I imagine music so vividly that it is like really hearing it. Ian [her husband] told me that when he imagines a visual scene, it is like he is replaying a video tape that he took previously. I've never experienced anything like that. And (like the guy in the article) when I imagine a person, I imagine facts about them. . . . Like another person quoted in another article, I also remember directions as a set of instructions. (Actually didn't know there was another way to understand them.) And I used to get frustrated by the visualization exercises at the end of yoga classes, so I started tuning them out."

Jeanette's experience shows that aphantasia is not necessarily cross-sensory. She has vivid auditory imagery (in fact, her specialization is in philosophy of music!) and tactile imagery. She is *only* lacking in the visual. So aphantasia isn't all or nothing.

One task that seems to *require* imagery is to ask someone what shape is made in the negative space of a capital letter A. Most people use visual imagery to do this, but aphantasics can do it, too, they just do it with motor imagery, imagining drawing the letter A with their hand and noting that it feels like drawing a triangle. But because imagery is completely an internal experience, and people can often use more than one kind of imagery to do a task, this area is very difficult to study. For example, we might want to study how someone without visual imagery does on a task. But they end up doing well on the task because they figure out a way to use some other kind of imagery to do it.[28]

Imagery scholar Bill Faw writes that when he tries to image things, it doesn't feel quite like conceptual imagination, but more like "subliminal imaging." He writes: "When I am trying to 'picture' the face of my wife (now of 48 years!), for example, I try to remember seeing it—but don't 'see' it. It is almost as if I try to draw her profile, nose, and mouth on water—sort of outlining it but leaving no visual trace . . . "[29]

But most people have *some* amount of imagery experience, and they differ in how vivid it tends to be. That is, the capacity for the vividness with which you imagine things tends to be stable over time,[30] even though one person's imagery might be more or less vivid for one imagining versus another—depending, in part, on effort, the subject matter, and whether there is distracting information from the environment. For example, it's harder to have a vivid visual image if you're watching a movie at the same time. I ride my bike to work, and while I do, I sometimes sing albums to myself. This isn't difficult, in part, because the parts of the brain used for singing and verbal communication aren't really important for cycling, which instead requires great visual and motor attention. One of the albums I sing is Paul Simon's *Graceland*, and I have a visual memory cue to help me remember the track order and lyrics. But I can't really vividly visualize these cues very well, because when cycling your eyes are highly stimulated with a constantly-changing environment. Because visual perception and visual mental imagery use many of the same brain areas, I get interference. This is why it's often easier to image something with your eyes closed, or when you look up at a featureless ceiling.

On the other end of the spectrum from aphantasics are the superimagers, the hyperphantasics, whose mental images are experienced as extremely detailed, vivid, or accurate. Good imagery is typically thought of as being vivid, or subject to excellent control by the imager. Powers of vividness and control usually go together, though through injury some people still have imagery, but can no longer control them.[31]

So, it's clear that people differ in their inner experience. Some people have very vivid sensory-like experiences in their imagination, and others have none at all. Most of us fall in between.

When we talk about imagination, we're talking about generating something in the mind. At its most basic, every memory recall is imagination, because memories are reconstructed every time they are retrieved. But better examples of imagination are when one generates a hypothetical situation—maybe a plan for the future, or a fantasy. These imaginings start out as fact-like ideas, and then they *might* be turned into sensory-like experiences we call "images." When I talk about imagination, I'm talking about all of these. When I talk about imagery, I'm referring only to the creation of what is experienced as sensory-like imaginings.

It looks like what happens is that when you imagine something, you are drawing on and reusing memories to form something new to think about. Because imagination is so dependent on the memory and perception systems, let's get into them a bit.

2

Perception and Memory

Your imagination system has a lot to do with your perceptual and memory systems, so I want to spend some time talking about how they work.

As you go about your day, your eyes are open, and you effortlessly understand most of the information going into them. It feels like the simplest thing in the world. But, like the song "MMMBop" by Hanson, the apparent simplicity is an illusion.[1] The human vision system is really complex. It just doesn't feel complicated because our conscious minds are spared just about everything except the final product. It's kind of like buying a jar of peanut butter. It feels simple, but that's because you don't have to think about growing peanuts, harvesting them, shipping them to a processing plant, turning them into peanut butter, the manufacture of a plastic container, the printing of the label, the shipping, and so on. Your interface only needs to be a store and some money. Similarly, your conscious mind enjoys a rich interpretation of what's in front of you without having to concern itself with the details of how it was generated. But there's a lot going on under the hood.

Light enters the eye and gets focused onto the retina, a screen of cells at the back of your eye. You're probably used to hearing about neurons in your brain, but you have neurons in your eyes, too. They are sensitive to light—that is, when light hits them, they fire more frequently, or, as we often say, they get more "active." When we say a neuron "fires," what we mean is that it's sending a signal on, usually to another neuron. Neurons communicating through firing accounts for the lion's share of how the brain works, at a cellular level.

But what they're communicating is *information*, which has no fixed biological reality. Information is abstract, which can make it a little harder to understand than, say, the processes of your circulatory system. We're not going to get anywhere talking about this neuron, firing or not firing, and causing or preventing firing in the next neuron. It's like trying to describe how a word processor works by talking about circuits in the computer. So we talk about information. If you see the edge of an object, it's the information about that edge that gets passed around the brain. It's done by neurons, of course, but it's more comprehensible to talk about the information rather than the biology of it.[2]

And even this early in the vision system, retinal neurons are processing some of the information, turning it into something useful for the later neurons.[3] From there, the information goes through several brain areas, each of which does some kind of processing to it, extracting important, new information from it. The next bit is a little technical. The brain is intimidatingly complex, even more complex than "MMMBop," but I have to describe at least some of the complexity to preserve this book's scientific integrity. You don't have to understand how the brain works to get a lot out of this book, so just skim it over this next part if it gets to be too much brain for your brain.

One of the first places image information goes is called "visual area one," or V1, in the back of the brain.[4] The information that was on the retina is more or less reproduced here. We know this because of an experiment that was done on monkeys, who have visual systems a lot like ours. Neuroscientist Roger Tootell trained a monkey to look at a pattern of blinking lights, and injected the monkey with a radioactive sugar. The idea is that neurons that are more active will absorb more sugar, because neurons consume sugar and oxygen as fuel. Then they sacrificed the monkey (that's science-talk for "killed it for the good of science") and looked at its brain, specifically area V1. Then they read where the radioactivity was most active. In effect, this shows us a picture of which neurons were doing a lot of firing. Looking at the picture, you can easily see the pattern the monkey was looking at (a grid pattern), actually visible on the slice of brain. What this means is that the pattern of activation caused by light on the retina is re-represented more or less intact in V1 for further processing.[5] Stephen Kosslyn calls this area the "visual buffer" ("buffer" is a computer-science term for a temporary memory).

Now your eyes are always moving. The big moves you can feel, but the little moves, called "saccades," are unconscious and frequent. This means that your retinas are getting a completely new picture about forty times every second, and V1 is, too. So the images re-represented in the visual buffer quickly fade—the reason the monkey experiment worked was because the sugar's radioactivity takes a long time to decay. But the increases in activation last a very short time. If they lasted very long, we'd see a smear every time we moved our eyes, like trying to fill a whiteboard with new diagrams before erasing the old ones.

What does this all have to do with imagination? Well, V1 is also the site of visual mental imagery. That is, when we image something visually, it shows up in V1 as a pattern of activation that resembles what it would look like on the retina. But it lasts a very short time. If you want to keep a mental image in mind, it needs to be frequently refreshed from a longer-term memory, just like a TV screen needs to be constantly refreshed by a signal from elsewhere to keep a picture.

Back to vision. V1 is just the beginning of visual information's long safari through your brain's jungle of neurons. Visual perception re-represents information in one brain state after another, and the further along it goes, the less the pattern resembles the original picture on the retina. It gets more and more abstract. Broadly speaking, from V1, the information takes two paths—one for visual processing and the other for spatial. Visual processing (done in the inferior temporal lobe, near the bottom of the brain) deals with shape, depth, color, intensity, and object recognition. Spatial processing (done in the posterior parietal lobe, near the top of the brain) deals with orientation, size, and where things are in space—either objects in space, or where the parts of a single object are in relation to each other. The visual path is casually referred to as the "what" pathway, and the spatial path the "where" pathway.

People with brain damage to one of these paths have trouble with those corresponding parts of perception. For example, if someone has a problem with their temporal lobe, they might know that some object is in front of them (because the spatial system is working) but have no idea *what* that object is! Conversely, someone with a problem in their parietal lobe might know what's in front of them but have no idea where it is.

Medical scientist David N. Levine describes a patient with damage to his "where" pathway. He could name the colors of large objects, but could not track them with his eyes. He could name objects and colors in front of him, but not reach for them, nor describe where they were. If presented with two things, he could not tell which one was closer, or above, or farther left.[6]

In case that didn't startle you, let me say it again: there are people with neurological problems who can know what object they are looking at, but have no idea where it is. For people with intact visual perception, this is hard to imagine, because our visual experience feels so seamless—we really don't know what it's like to look at an object and know what it is without also knowing where it is, and it certainly doesn't *feel* like two completely different parts of the brain are dealing with "what" versus "where" information.

But you can get a hint of knowing where something is without knowing what it is. The neurons that take care of the outskirts of your visual field specialize in motion detection, and not so much in high-resolution details. Try this: look straight forward at the wall or whatever's right in front of you. Put your arm straight out to your right side, back so far that you can't see your hand. Then, wiggling your fingers, slowly bring your arm forward so that your wiggling fingers gradually come closer to the edge of your vision. Do it slowly, and don't move your eyes. At some point, you will get a sense that motion is there, but you won't be able to really see your fingers enough to, say, know how many you are wiggling. You're seeing motion, seeing that something is there, without seeing what it is. People with certain disorders have experiences like this, but for their whole visual field —they have vague notions of where things are, but not what they are.

Information goes though these processing stages, and the further in it goes, the more complex perceptions the mind pulls out of it. Eventually, the mind knows what objects are there and where they are. It tries to find matches between the information coming in and stored memories of what things look like. When there's a good match, the mind says, in effect, "Aha! There's a jar of peanut butter!" It also can detect events, such as doors opening, and it is combined with how we understand people, such as when we perceive someone as trying to open a tight jar.

This process, as I've described it, is "bottom-up:" how the mind extracts reflected in how poorly people can remember images from them. Anthony Wright wanted to run an experiment on pigeons and monkeys in which he exposed them to photos and investigated how well they could remember them. But when he ran a version of the experiment with people, he couldn't use regular travel photos because people remembered *all* the photos. The task was too easy, because people were so good at recognizing and remembering the things in them. So he used pictures from kaleidoscopes instead.[10] Even if you see the same kaleidoscope picture later, it's hard to tell if you've seen it before or not, because no large patterns jump out at you. There's little for your mind to hold on to.

Another reason our minds need to create high-level symbols is because they need to be used by a wide variety of systems in the mind, not just vision.[11] To take a simple example, suppose you look in the cupboard and see peanut butter. Later, you are asked if there is peanut butter in the cupboard. The question is posed in language, but the experience you use to answer the question was visual. There has got to be some way for your mind to connect the sounds of the words "peanut butter" to the image of peanut butter that you saw. It does this by making a symbol that is independent of any particular sensory system. Your visual system is a machine that turns light into symbols.

It's important to distinguish the symbols we use to do general reasoning from actual words that we use in language. Each word is represented by a complex collection of symbols, but not every symbol our mind uses has a corresponding word. Different languages attend to different aspects of visual scenes, and speakers of different languages attend to different aspects of scenes, though there are some cross-language similarities.[12] But there are lots of visual symbols we don't have words for. For example, although we can distinguish the faces of Audrey Hepburn and Natalie Portman with ease, we would have a very hard time describing in words what those differences are.[13] Experts create their own symbols and jargon to describe things the rest of us don't—or can't. One time, I went clubbing with a bunch of dental students. Outside the club, they talked about the various cute guys they saw in the club. At one point there was confusion about exactly which guy they were talking about, and someone resolved it by describing the characteristics of his incisors. "Oh yeah, him," the other women said.

How does the symbolic nature of perception and memory affect our imagination? We tend to populate our imaginings with symbols, things we know and have experience with. The symbols we have in our memories affect the imaginings we are able to make. Creative imaginings are new, interesting combinations of these symbols.

When called upon to imagine a particular symbol, like a bird, and we picture one in our heads, what do we do? There are two basic possibilities: we might bring to mind some specific instance of a bird we saw at some point in our past, or we also might imagine a sort of average bird.

So picture a bird, if you can (I know not everybody can). What does it look like?

Most people picture a small songbird, rather than some unusual bird like an ostrich or an emu. One theory of why we do this is called "prototype theory." It holds that for every concept, as we experience instances of that concept (for example, each new bird we see), we slightly modify an averaged representation called a "prototype." It claims that we all have a prototypical bird somewhere in memory, which is the average size, color, and has the average beak length of every bird we've ever experienced.[14]

This theory is controversial. But whatever the underlying structure of our concepts are, it seems pretty clear that when people imagine objects and scenes, they behave *as though* they had a prototype in mind. Think of a birthday party. For most people, the birthday party they bring to mind has kids, presents, cake, and maybe games. People don't tend to think of four guys celebrating a birthday at a sports bar, shooting tequila. But that's a birthday party as much as a Himalayan goldenbacked three-toed woodpecker is a bird.

So when we think about how imagination works, we need to think about prototypes. Our memories are structured in such a way, or are accessed in such a way, that people will tend to populate their imagined scenes with prototypical instances of objects. They don't think of weird examples of things unless they have a specific reason to do it.

We can also distort shapes in our memory to be more prototypical—like the autocorrect I mentioned before. For example, if we look at the shape of a river on a map, unless the particular shape of it has a special meaning to us, we'll store it in memory as being more of a simple straight line or a curve.[15]

I've been talking about prototypes in terms of visual features, but it's likely that we also have prototypes of spatial relationships. When we think of a restaurant, we can bring to mind a generic place, and have an idea of where all of the important elements would be placed.

SPATIAL REPRESENTATION

One of the fascinating things about memory is that the mind uses more than one representation of space. Just like you might give someone directions with a map, or with left-and-right turn directions based on landmarks, the mind itself has several ways of remembering where things are. We even seem to have specialized systems for remembering the locations of our own body parts.[16]

When we look at a scene, we pull out spatial relationships between the objects in it, mostly without even having to try.[17] When we remember a scene, we can remember it as though we were in it. But there are a couple of ways our minds might pull this trick off: perhaps we remember all of the things that were around us equally well, no matter where they are in relation to us, as we might if our minds represented everything in a viewer-independent coordinate system. So, for example, the things behind us would be recalled (in our imagination) just as well as the things in front of us. Or, perhaps we store something like a picture of the scene remembered, as though we were actually looking at it (which would exclude certain parts of the scene, such as the things behind us). Or, perhaps we tag the location of objects in the scene according to where they are *in relation to us*, rather than in some more objective location (the jar of peanut butter is to my right, and the door is behind me).

Nancy Franklin ran an experiment to see which one of these was right. The experimenters described scenes (in words) to the participants. For example, the participants might hear, among other things, "in front of you is a plaque." Then they asked the participants to, in their imaginations, turn 90 degrees to the right. Then they were asked about the locations of the objects described.

If no spatial locations were privileged, then they should have been able to respond with object locations equally fast, no matter where the object was in relation to their imagined self—whether it was behind them, above them, or right in front of them. But that's not what happened.

If they were using a mental picture (of what would be seen from a particular point of view) to represent the scene, then they should be faster when responding about objects that would be visible—for example, they should be slower for things behind them, because those objects would not be visible in the picture. That didn't happen either.

What happened was that they were slowest at describing things that were either on the right or the left, a bit faster for things in front of them versus behind them, and fastest for things above or below them. What the —?

According to Franklin and Tversky, when we do an exercise like this, we are coding locations according to three axes: up-down, front-back, and left-right. The speed at which we are able to retrieve locations from memory depends on which axis is most important. Some axes are easier to distinguish than others. Our world has a strong up-down asymmetry because of gravity. Things that are up in the air tend to fall, they tend to be smaller, and so on. The fact that things up high behave differently means that it's very important to be able to distinguish between what is up and what is down. This is why the locations of things either above or below are identified the fastest.

The next most important asymmetry is front-back. This asymmetry is personal. You can see and more easily interact with things in front of you. What's in front of you changes as you turn around, but what's above and below you does not. This asymmetry makes it the second fastest.

Finally, we have the left-right axis, which changes as you rotate, but has no other significant asymmetries (aside from the direction we read and write—we'll get to that later), and as such, it's less important, and thus, more difficult and slow to distinguish things on the left from the right.[18]

So if we were remembering objects in 3-D space according to some objective, three-dimensional coordinate space, we'd be just as fast retrieving everything, no matter where it was in our imagination. If we were using a mental *picture*, we'd be slower at identifying things behind us than things left and right, but that doesn't happen either. It appears that we place objects in locations according to where they are in relation to our bodies.

Or, at least, that's one way we do it.

Franklin and Tversky also found that if the scene is described from the perspectives of two different people in the same scene, people would show no response time differences at all, suggesting that people can also create a 3-D, perspective-neutral version of the scene! It looks like people represent scenes in memory differently, as needed for different tasks.

We also seem to represent locations in terms of continuous space, but also in terms of categories for general locations. Jannelen Huttenlocher had people study the locations of dots on a screen, and then asked them to remember, later, where they were. She found that people got the locations subtly wrong—they drifted toward the center of the categorical areas in the visual field: top, bottom, left, and right. It's as though, at some level, we think "that dot is on the right," and then put it closer to the center of where we think of as the right side like an auto-correct.[19]

Thus, it appears that we use place categories for the locations of objects. But how do we represent the relationship between two objects? In terms of coordinates, or simple relations like "above" and "next to," these questions are very difficult to answer, because the mind creates new representations as needed. Sometimes, when people are asked about something they remember, they give answers that suggest that they have a categorical, relations-based memory of space, but at the same time, they can reproduce a map they memorized, as though the quantitative distances between objects were memorized. The answer seems to be that we understand space in many ways and can, on the fly, transform that understanding into other formats as needed. Some of these even have different neural signatures when studied with brain imaging.[20] It's a powerful, wonderful thing, but it makes it fiendishly difficult to study in experiments because you can't always know (let alone control) what people are or are not doing in their heads.[21] When people behave differently in different situations, it could be that they are relying on fundamentally different kinds of memories and even creating new representations on the fly.

These representations of space we have are also distorted in interesting ways. For example, most people think of Europe as being east of the United States—which, of course, it is. But that's only the most obvious directional difference. What's easier to forget is that a lot of Europe is also *north* of the United States. But in our memories, the north-south axis is not the first organized according to the locations, and each location was populated by a number of objects.

Think of it like a filing system. The mind creates a file folder for each location and puts a file in each folder for each object. What people don't seem to be doing is making a folder for the objects and putting locations in them. If I'm asking you about the contents of one folder, it takes less time than if I ask you about things in multiple folders.[26] You can probably relate to this yourself: it's easier for you to list the objects in your living room than to list all of the locations you've ever seen a plush dog toy.

3-D OR 2-D?

I've been talking a lot about how we remember the locations of objects in scenes. But visual memories also have information about the objects themselves—most objects are complex, consisting of parts. A tree, for example, has a trunk, roots, branches, bark, and leaves, and we know not only that trees have these parts, but the spatial relationships between them: the trunk runs up through the middle, and leaves are attached to branches. An interesting question is whether our visual memories of the parts of objects are stored as two-dimensional pictures or as three-dimensional structures.

This question is full of subtleties that must be unpacked. As I discussed in the first chapter, we're pretty sure that we don't store "pictures" in long-term memory at all—they are symbolic structures that could be used to create pictures. But if the things in memory are symbolic structures, not pictures, then what sense does it make to ask if they are stored in two or three dimensions?

Let's take a television as an example of how we might represent its parts symbolically. We might have symbols describing its shape (rectangular), the fact that there are six little round buttons on the bottom right, and a platform beneath the screen to hold it up. This is a frontal view of the television. It has no information about what's on the back, such as the cord, or the various input ports. This is what it might look like to have a symbolic description of two-dimensional information.

Research by Michael Tarr suggests that people's memories of objects are that might not be tied to a specific event, such as your knowledge of the order of letters in the alphabet. You have in your memory the letter order, but can't recall a specific where or when you learned it. More abstract knowledge like this, or the fact that the Beastie Boys are ill, is called "semantic memory." Another kind of memory allows you to walk and ride a bike—these memories of how you do things are called "procedural memories." Very young children can remember the *semantic* content of events, but the ability to remember past *episodes* emerges at around age four.[29] In fact, until that age, children cannot even mentally consider a state that they are not currently experiencing.[30]

But as we've learned, our long-term memories are made up of symbols, not pictures. When we recall these sets of symbols, they get reconstituted and filled in with information from other memories. Then, if they are imaged, they get fleshed out further with other information that wasn't from that memory at all, but from memories of other things. Because the images you create from episodic memories are reconstructions, the process is prone to errors, and ends up being slightly different every time a particular memory is recalled.

Recalling an episode from your life might be better described as an episodic reconstruction—bits of true episodic content liberally fleshed out with semantic knowledge.[31] For example, suppose Fatima remembers eating dinner with her parents, and pictures the scene in her head, experiencing the memory vividly.

Suppose that when she actually ate dinner with them, she never looked up at the ceiling. What this means is that what the ceiling looked like *at the time of the event* is not stored with that episode. Nevertheless, a week or so later, when she imagines the dinner, she can "look upward" in her mind's eye and see the ceiling. But if she hadn't paid attention to the ceiling at the time, she wouldn't have encoded an episodic memory of the ceiling in the first place. There might have been a big spider up there, but that spider would not be in her memory of the ceiling. Her "memory" of the ceiling would be that it was empty, as it normally is. How is she able to "remember" it, then, if she didn't look at it? Why does her mind put an empty ceiling in there?

Because she *knows* that the room in question has a ceiling, and she might even know from other episodic memories what that ceiling looks like, from

differently. By asking you to focus on the color, I'm subtly tricking you into *not* focusing on the orientation of the shape, which is the point of the exercise (color has nothing to do with the point I'm making, but people feel they can express their individuality through color choice, and let their choices about the shape of the triangle go to a default). Get you with your guard down!

62 Prototype theory: Rosch, E. (1975). "Cognitive Representation of Semantic Categories." *Journal of Experimental Psychology*, 104, pp. 192–233.

Prototypes in mathematical concepts: Armstrong, S. L., Gleitman, L. R., and Gleitman, H. (1983). What some concepts might not be. *Cognition*, 13(3), pp. 263–308.

Prototypes are processed faster: Winkielman, P., Halberstadt, J., Fazendeiro, T, and Catty, S. (2006). *Psychological Science*, 17(9), pp. 799–806.

63 Lakoff, G., and Johnson, M. (1999). *Philosophy in the Flesh*. New York: Basic Books.

64 Richardson, D. C., Spivey, M. J., Edelman, S., and Naples, A. J. (2001). "Language Is Spatial": Experimental Evidence for Image Schemas of Concrete and Abstract Verbs. In *Proceedings of the Twenty-third Annual Meeting of the Cognitive Science Society*, Erlbaum. pp. 873–878.

65 Davies, J. (2014). *Riveted: The Science of Why Jokes Make Us Laugh, Movies Make Us Cry, and Religion Makes Us Feel One with the Universe*. New York: St. Martin's Press. p. 190.

66 Tversky, B. (2005). "Functional Significance of Visuospatial Representations." In P. Shah and A. Miyake (Eds.). *The Cambridge Handbook of Visuospatial Thinking*. Cambridge, UK: Cambridge University Press. p. 19.

67 Tversky, B., Kugelmass, S., and Winter, A. (1991). "Cross-Cultural and Developmental Trends in Graphic Productions." *Cognitive Psychology*, 23(4), pp. 515–557.

68 Kosslyn, S. M., Thompson, W. L., and Ganis, G. (2006). *The Case for Mental Imagery*. Oxford: Oxford University Press. pp. 118–120.

69 Kosslyn, S. M., Thompson, W. L., and Ganis, G. (2006). *The Case for Mental Imagery*. Oxford: Oxford University Press. pp. 128, 137.

70 Kosslyn, S. M., Thompson, W. L., Kim, I. J., and Alpert, N. M. (1995). "Topographical Representations of Mental Images in Primary Visual Cortex." *Nature*, 378(30), pp. 496–498.

71 Kosslyn, S. M., and Schwartz, S. P. (1977). "A Simulation of Visual Imagery. *Cognitive Science*, 1, pp. 265–295.

Funt, B. V. (1980). "Problem-solving with Diagrammatic Representations." *Artificial Intelligence*, 13(3), pp. 201–230.

72 Oswald, I. (1957). "After-Images from Retina and Brain." *Quarterly Journal of Experimental Psychology*, 9(2), pp. 88–100.

73 Kosslyn, S. M., Thompson, W. L., and Ganis, G. (2006). *The Case for Mental Imagery*. New York: Oxford University Press. p. 71.

74 See page 58 of: Mast, F. W., and Kosslyn, S. M. (2002). "Visual Mental Images can be Ambiguous: Insights from Individual Differences in Spatial Transformation Abilities." *Cognition*, 86, pp. 57–70.

People have also found evidence of people reinterpreting haptic (touch) imagery: Pouw, W., Aslanidou, A., Kamermans, K., and Paas, F. (2017). "Is Ambiguity Detection in Haptic Imagery Possible? Evidence for Enactive Imaginings." In G. Gunzelmann, A. Howes, T. Tenbrink, and E. J. Davelaar (Eds.). *Proceedings of the 39th Annual Conference of the Cognitive Science Society* (pp. 2925–2930). Austin, TX: Cognitive Science Society.

75 Kosslyn, S. M., Thompson, W. L., and Ganis, G. (2006). *The Case for Mental Imagery*. New York: Oxford University Press. p. 84.

76 Kosslyn, S. M., Thompson, W. L., and Ganis, G. (2006). *The Case for Mental Imagery*. New York: Oxford University Press. p. 42.

77 Kosslyn, S. M., Thompson, W. L., and Ganis, G. (2006). *The Case for Mental Imagery*. New York: Oxford University Press. p. 42.

78 Kosslyn, S. M., Thompson, W. L., and Ganis, G. (2006). *The Case for Mental Imagery*. New York: Oxford University Press. p. 81.

79 Hasson, U., Chen, J., and Honey, C. J. (2015). "Hierarchical Process Memory: Memory as an Integral Component of Information Processing." *Trends in Cognitive Sciences*, 19(6), pp. 304–313.

80 Pearson, J., Clifford, C. W., and Tong, F. (2008). "The Functional Impact of Mental Imagery on Conscious Perception." *Current Biology*, 18(13), pp. 982–986.

81 Specifically, these possible paths are represented in CA3, a part of the hippocampus.

Johnson, A., and Redish, A. D. (2007). "Neural Ensembles in CA3 Transiently Encode Paths forward of the Animal at a Decision Point." *Journal of Neuroscience*, 27(45), pp. 12176–12189.

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IMAGINATION

Pegasus Books Ltd.
148 W. 37th Street, 13th Floor
New York, NY 10018

First Pegasus Books cloth edition November 2019

Interior design by Maria Fernandez

Library of Congress Cataloging-in-Publication Data is available.

ISBN: 978-1-64313-203-7

ISBN: 978-1-64313-288-4 (Ebook)

Distributed by W. W. Norton & Company