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CHAPTER 1

The Art and Science of the Impossible

For many of us, magic is a portal to the days of childhood. Our earliest experiences with the art of the impossible are often experiences of much fanfare, of circuses with a magnificent and varied cast of artists, or costumed magicians making cards appear from bare hands. Even if you have seen only the occasional magic show, no doubt the following scenario will feel somewhat familiar to you, as the experience of magic in many ways unites its spectators, even as magic itself stands apart from all other art forms.

A magician onstage shows her audience several seemingly ordinary pieces of wood and, in an instant, assembles them into a cube-shaped box. She places the box on a table, nonchalantly opens it, and from it removes a beautiful bouquet of purple and yellow flowers. Her audience applauds this unexpected appearance. The magician then invites an audience member onstage, asking them to thoroughly examine the inside and outside of the box, to verify that there was nothing special about it. The magician again closes the box and immediately opens it again to remove countless colored handkerchiefs. The audience erupts into a loud and synchronized round of applause. Finally, the magician invites the volunteer to examine the box once more, to ensure that it is indeed empty, and this time asks the volunteer to close it after she is done. The magician opens the box and a pair of beautiful white doves emerge and briefly take flight before returning to her hands. The audience starts again to applaud, many looking at each other in disbelief, unable to believe what they have just witnessed.

How did the magician accomplish this feat—the art of the impossible? Magic is an active dialogue between the magician and her audience, but the

language is not one that we understand. In the following pages, we will decipher a little of that language, shedding light on how magic works—and how it manages to fool our brains.

The Art of the Impossible

Juan Tamariz, an influential Spanish magician who enjoys enormous international prestige, has said that “the art of magic must have the purpose of raising the quota of happiness in the world, in others and in ourselves.”¹ Magic is indeed a unique art, capable of making spectators feel that something has happened that is impossible, that defies the laws of nature. Tamariz believes that the outcome of a magic trick must be unexpected, seemingly impossible, and fascinating.² It is *unexpected* in that expectations are shattered, especially in those magic tricks in which no element of the exposition anticipates what will happen at the end. The outcome is *impossible* in that magic outcomes contradict logic or the laws of nature, and it is *fascinating* in that the final effect of good magic is dazzling and extraordinary. For Tamariz, only magic combines impossibility with fascination, while other activities, such as certain acrobatics, may be fascinating but are not perceived as impossible. The essential and specific quality of a magic trick’s climax is the “mystery” of the impossible, as it combines a confrontation with the unknowable with the “mental shock” of seeming impossibility.³

How does magic—illusionism, the art of creating impossible effects that violate our expectations, tricks that conclude with the apparent transgression of natural laws—work?

In this book, we explore the cognitive processes behind the art of magic, an ancient artistic activity that, after centuries of trial and error, has accumulated an important repository of wisdom regarding its techniques.

A magic trick always begins with a demonstration, a story, or a proposition that concludes with a seemingly impossible, fascinating, and unexpected result. As spectators, we are captivated by the disparity between what we assume will happen at the end of the trick and what we finally observe happening. These outcomes are tremendously provocative. They

contradict our hypotheses and make us doubt everything we have learned. They are a cognitive dissonance in and of themselves.

Why are our brains taken by surprise? Why does magic collide with all our mental schemes and often break them? As we will see in the following pages, magic works because it takes advantage of the limitations of the brain's normal processing. Magicians understand how our brains process information. They know where the brain's weaknesses are, and they know how to design tricks that capitalize on those weaknesses by manipulating our attention and perception so that we overlook important details, or making us see or hear things that are not there.

The human brain is a very advanced organ. Its capabilities are highly perfected and adapted to our environment and lifestyle, so much so that we usually are not aware of its limitations, both physical and metabolic. These limitations, however, are very real: every moment our brains receive an enormous amount of information through our senses, far more information than we are aware of. Yet another limitation is speed: the transmission of information between neurons is relatively slow and must overcome several bottlenecks throughout the brain—points at which one part of the brain circuit holds back the potential transmission and processing capacity.

Through evolution, the brain has overcome these limitations by developing extraordinarily effective strategies to process everyday sensory information. For instance, the brain may build an illusion of a continuous experience where there isn't one, or it may make inferences based on limited data, as when we recognize a person from afar simply by the way they walk.

In computer terms, we could say that magic, surprisingly, has learned to hack into some of these strategies using the brain's "back doors." Magic reveals the tricks and automations that characterize the functioning of our brains, interfering and, above all, playing with our unconscious processing.

Magic most often enters the brain via the sense of sight, because a human being is an extremely visual animal, so much so that more than one-third of the cerebral cortex is dedicated to processing the information captured by the retinas. Through the process of paying attention

and using our short-term memories, the brain filters and selects only that information it considers useful at any given moment. This information is incomplete, captured in a fragmented way in both space and time, yet the brain must use its complex resources to create the illusion of continuous reality. Thus, when we perceive a scene in front of us, our brains do not see an accurate reflection of reality but rather infer it. To do this, our brains rely heavily on the prior knowledge we have accumulated in our long-term memories.

For example, when we observe a bird flying between the trees of a forest, appearing and disappearing as it flies past each tree, our brains do not think that different birds appear in sequence from behind each tree. We know perfectly well that it is always the same bird. It seems obvious that we would perceive the situation correctly, but it actually is not. We have no physical proof that it is the same bird; we could, in fact, imagine the opposite situation: different birds emerging from behind each tree in perfect synchrony. Our previous experience as individuals and as a species, however, accumulated through evolution, allows us to come up with the most plausible explanation.

When magicians trick us, they are interfering with all of the brain's strategies for inferring reality. They take advantage of the fact that sometimes we are blind to certain changes in our environment, and they manipulate our perception and memory in such a way that, even though we look, we do not see what is happening.

In the presentation of a magic trick, a distinction is made between the "external life" of the effect, which is what the audience sees and enjoys, and the hidden "internal life." Happening secretly, the "internal life" is what makes the whole magic experience possible. It is a parallel reality, completely separate from the guiding thread that the magician spins for spectators to follow.

Contrast can be a central mechanism in the external life of a magic trick. Usually, the human brain more easily processes information with some contrast—that is, with changes, differences. For example, there is a very high contrast between this white book page and the black letters on it. If we reduced the black letters to a very light gray,

it would be harder to perceive them, as there would be less contrast against the white page. Sometimes magicians want to create contrast by capturing an audience's attention—such as when they pull a rabbit out of a hat—so that the audience “sees” something. At other times, however, when magicians are performing maneuvers that must go completely unnoticed by the audience, they avoid at all costs the provocation of contrast.

As we will see in this book, magic can also manipulate our memories, condition us, and influence our intuitive decisions, all without our realizing it. Magic tricks deceive us because they are presented with a logic and a naturalness that hardly seem suspicious. Everything is predictable until the surprising outcome that shatters our expectations. This surprising outcome, the climax of the magic act, is the crucial point of the trick. It is very difficult to master, as it requires that the magician challenge our capacity to infer and anticipate, processes that are not under our conscious control. This is why we say that magic speaks to, challenges, and deceives our unconscious brain.

Though this deception can be extraordinarily difficult to achieve, the results are worth the effort. The outcome of a magic trick triggers multiple emotions and intellectual reactions and is an experience unlike any other. In this way, magic is also fundamentally an art, a performance, and as such, it is presented in playful contexts. Perhaps its inherent artistry explains why, surprisingly, magic has been so little studied by science over the centuries.

In the following pages, we show that magic and science have much to offer each other. This book is fundamentally an exploration of neuroscience, through the lens of magic. We explain how magic works through a discussion of the brain's normal, day-to-day processes—which themselves may sometimes seem like acts of magic. Through our discussion, it will become clear that there is much about the intersection of magic and neuroscience that remains unexplored territory. We hope to show the great potential not only for neuroscience to shed light on how magic works, but for the world of magic to open new and unexpected doors of knowledge for neuroscience.

Where We Will Go in This Book

Although magic uses many techniques and devices drawn from scientific disciplines as varied as mathematics, physics (including optics), mechanics, electronics, chemistry, and new materials, in this book we will focus on cognition.

When we refer to “cognitive processes,” we mean those tasks or operations that the brain executes continuously to process the information we receive from the environment: attention, perception, memories, emotions, decision-making, reasoning, planning, problem-solving, and learning (focusing here on those processes that the magician usually controls or manipulates). It is through our cognitive processes that we create, analyze, and interact with reality, all the while relying on our prior experience and knowledge. Cognitive processes thus allow us to be flexible and to adapt our behavior almost immediately based on the changes and demands imposed by the different situations of everyday life.

When we discuss “magic tricks,” we are focusing exclusively on the mechanisms of magic tricks that provoke the “illusion of impossibility”—the ones that audiences consider impossible because what happens at the end goes against the laws of nature. We do not cover the techniques used by “psychics” or any other practitioner of a method of divination; their universe of knowledge is different from—but not alien to—the procedures, resources, and methods used by magicians.*

Magic has its own schools, experts, and centuries of accumulated experience. Beyond its deceits, magic is a scenic art that combines resources from theater and other sources to achieve successful effects, always at the service of a surprising outcome. After centuries of tests and empirical trials, today’s magic is the result of a wisdom accumulated over time, based on experience and the perfecting of an immense catalog of materials and methods that magicians have created and baptized with their own names or unique characteristics.

* We use the word “magician” and not “illusionist” to refer to the person who performs magic tricks, although the two terms are synonymous. Some theorists of magic propose a distinction between the two, but we have ignored it here for practical reasons. Similarly, we use the word “magician” to refer to the person who performs magic, regardless of the genre.

In the past, the world of magic was responsible for discovering and validating these techniques. Today neuroscience wants to learn from this wisdom. The American magician Persi Diaconis, a scientist and professor of statistics, has verified that original contributions from magic have helped open new pathways of knowledge in the mathematical fields of cryptography and the analysis of DNA sequences.⁴ Our aim is to follow the lead of mathematics and facilitate an equally fruitful dialogue between magic and neuroscience.

The Grammar of Magic

To perform good magic, magicians rely on solid principles based on experience, most of which respond to cognitive processes. During the second half of the twentieth century, some theorists of magic, like the Spanish magicians Arturo de Ascanio and Juan Tamariz or the American Darwin Ortiz, developed authentic “grammars” of their language. In this book, we often refer to concepts coined by Arturo de Ascanio. Ascanio was born in 1929, and in the 1950s, after meeting the great Dutch magician Fred Kaps, he created a vast work on magic that he continued to build and elaborate on until his death in 1997. One of our goals has been to interpret and “translate” this language coined by magicians into concepts that cognitive neuroscientists can use to explain how the brain works. As the following pages demonstrate, we are convinced that exploring how magic works can bring new perspectives to neuroscience.

Your Journey with Us

In part I, we lay the foundation for understanding the neuroscience of magic. Chapters 2 and 3 present a simplified model of the structure and function of the brain, with special emphasis on the visual pathway, because magic enters through the sense of sight.

In part II, we examine the different cognitive processes involved in magic tricks. In chapter 4, we describe how the brain creates an illusion of continuity to compensate for the fact that we capture external information in a fractured way in both space and time. We’ll see that magic

takes advantage of this phenomenon in multiple ways. In chapter 5, we describe the key concept of contrast: magicians can either avoid or provoke contrast as a tool for attention control.

In chapter 6, we turn to attention, one of the brain processes that magic has learned to control with great precision. Through our attention, we continuously filter and select from the enormous amount of information we receive. Chapter 7 explores the creative world of perception, arguing that perceiving is literally a process of interpretation.

The neuroscience behind magic does not stop with information processing. As we will see in chapter 8, magicians are actually able to manipulate our memories during the few minutes that a magic trick lasts.

Chapter 9 looks at how magicians can condition us and take advantage of the multiple mechanisms of the unconscious brain. Moreover, as chapter 10 shows, magicians, unbeknownst to us, also know how to induce certain responses and decisions.

Part III of the book opens with chapter 11, a reflection on the magic experience and different audience reactions to it. We should note that all discussions of the magic experience in this book refer mainly to the Western culture with which we are familiar. In other cultures, the illusionist or magic experience may be interpreted differently: some may conclude that the magician possesses divine powers, while others may react to inexplicable effects with fear and aggressiveness. In this book, however, we do not delve into these other perspectives.*

To close the book, chapter 12 recognizes the pioneering research efforts on magic that were made at the end of the nineteenth century and details how much more is still to be done.

* An eloquent example of the importance of cultural context in magic was provided by the magician Jean Eugène Robert-Houdin in 1856. Having retired, he was required by the French colonial government of Napoleon III to travel to Algeria and demonstrate “his magic powers” before the Marabouts, the spiritual and religious leaders of the Arab tribes. The local inhabitants’ belief that the Marabouts were endowed with magic powers posed a challenge to the authority of the colonists, and Napoleon wanted Robert-Houdin to help neutralize the influence of the Arab leaders by showing that French magic was stronger. Robert-Houdin toured and performed several shows in Algeria, and among his tricks (or “powers”) was the lifting of a box secretly attached to the ground at will by an electromagnetic charge; see Prevos, *Perspectives on Magic*.

We hope we have conveyed in this first chapter that magic is able to seduce us with its effects because of the way our brains understand the world around us. Knowing how the brain works and understanding the cognitive processes involved in magic effects can help us develop a full appreciation of magic—and help theoreticians of magic create the best possible magic.

At the same time, the empirical knowledge that magic has accumulated over time is a valuable source of knowledge for neuroscience. Though some techniques used in magic tricks correspond to well-known mechanisms in the field of cognitive neuroscience, scientists do not yet understand the processes that underlie other magic techniques. These techniques therefore offer very attractive research opportunities. Many neuroscientists believe that artists in general—and magic is no exception—have intuitively discovered, after years of trial and error, how the brain works and how it interprets the world. Artists use this knowledge to enhance the impact of their work.

Jorge Wagensberg expressed that idea when he said: “The least banal relationship between science and art occurs when an artist offers scientific intuition to a scientist or when a scientist offers artistic insight to an artist.”⁵

Finally, this book is a recognition of the scientific foundations of magic and of those who practice it honestly and with good intent, as opposed to those who use its methods for illegitimate purposes or to make the public believe that they are endowed with supernatural powers, as some psychics do. Partway into the twenty-first century, we believe that there is no artistic endeavor important enough to justify deceiving spectators. We do well enough constantly deceiving ourselves.

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