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Excerpt
More Information

CHAPTER ONE

What We Know about Intelligence from the Weight of Studies

[T]he attack on tests is, to a very considerable and very frightening degree, an attack on truth itself by those who deal with unpleasant and unflattering truths by denying them and by attacking and trying to destroy the evidence for them.

Barbara Lerner (1980)

Intelligence is surely not the only important ability, but without a fair share of intelligence, other abilities and talents usually cannot be fully developed and effectively used … It [intelligence] has been referred to as the "integrative capacity" of the mind.

Arthur Jensen (1981)

The good thing about science is that it's true whether or not you believe in it.

Neil deGrasse Tyson, HBO's *Real Time with Bill Maher*, February 4, 2011

The University of California will no longer consider SAT and ACT scores.

Los Angeles Times, May 15, 2021

Learning Objectives

- How is intelligence defined for most scientific research?
- How does the structure of mental abilities relate to the concept of a general intelligence factor?
- Why do intelligence test scores estimate but not measure intelligence?
- What are four kinds of evidence that intelligence test scores have predictive value?
- Why do myths about intelligence persist?

Introduction

When a computer beats a human champion at games such as chess or Go that require strategy, or a verbal knowledge game such as *Jeopardy*, is the computer smarter than the person? Why can some people memorize exceptionally long strings of random numbers or tell the day of the week for any date in the past, present, or future? What is artistic genius and is it related to intelligence? These are some of the challenges to defining intelligence for research. It is obvious that no matter how you define it, intelligence must have something to do with the brain, and that is why this book is about neuroscience research.

Among the many myths about intelligence, perhaps the most pernicious is that intelligence is a concept too amorphous and ill-defined for scientific study. In fact, the definitions and measures used for research are sufficiently developed for empirical investigations and have been so for over 100 years. This long research tradition used various kinds of mental ability tests and sophisticated statistical methods known collectively as psychometrics. The new science of intelligence builds on that database and melds it with new technologies of the last two decades or so, especially genetic and neuroimaging methods. These advances, the main focus of this book, are helping to evolve a more neuroscience-oriented approach to intelligence research. The trajectory of this research is similar to that in other scientific fields, which has led from better measurement tools to more sophisticated definitions and understandings of, for example, an "atom" and a "gene." Before we address the brain in subsequent chapters, this chapter reviews the current state of basic research issues regarding the definition of intelligence as a general mental ability, the measurement of intelligence relative to other people, and the validity of intelligence test scores for predicting real-world variables.

1.1 What Is Intelligence? Do You Know It When You See It?

It may seem odd, but let's start our discussion of intelligence with the value of pi, the circumference of a circle divided by its diameter. As you know, the value of pi is always the same: 3.14 … carried out to an infinite, nonrepeating sequence of decimals. For our purpose here, it's just a very long string of numbers in seemingly random order that is always the same. This string of numbers has been used as a simple test of memory. Some people can memorize a longer string of the pi sequence than others. And a few people can memorize a very long string.

Daniel Tammet, a young British man, studied a computer printout of the pi sequence for a month. Then, for a demonstration organized by the BBC, Daniel repeated the sequence from memory publicly while checkers with the computer printout followed along. Daniel stopped over five hours later after correctly repeating 22,514 digits in the sequence. He stopped because he was tired and feared making a mistake (Tammet, 2007).

In addition to his ability to memorize long strings of numbers, Daniel also has a facility to learn difficult languages. The BBC arranged a demonstration of his language ability when they moved him to Iceland to learn the local language with a tutor. Two weeks later, he conversed on Icelandic TV in the native tongue. Do these abilities indicate that Daniel is a genius or, at least, more intelligent than people who do not have these mental abilities?

Daniel has a diagnosis of autism and he may have a brain condition called synesthesia. Synesthesia is a mysterious disorder of sensory perception where numbers, for example, may be perceived as colors, shapes, or even odors. Something about brain wiring seems to be amiss, but it is so rare a condition that research is quite limited. In Daniel's case, he reports that he sees each digit as a different color and shape, and when he recalls the pi sequence, he sees a changing "landscape" of colors and shapes rather than numerical digits. Daniel is also atypical among people with autism because he has a higher-than-average intelligence quotient (IQ) score.

Recalling 22,514 digits of pi from memory is a fascinating achievement no matter how it is accomplished (the official record is an astonishing 70,000 digits – see Chapter 6.2). So is learning to converse in the Icelandic language in two weeks. There are people with extraordinary, specific mental abilities. The term savant is typically used to describe these rare individuals. Sometimes the savant ability is an astonishing memory or the ability to rapidly calculate large numbers mentally or the ability to play any piece of music after only hearing it once or the ability to rapidly create sophisticated artistic drawings or sculptures.

Kim Peek (1951–2009), for example, was able to remember an extraordinary range of facts and figures. He read thousands of books, especially almanacs, and he read each one by quickly scanning page after page. He could then recall this information at will as he demonstrated many times in public forums in response to audience questions: Who was the 10th king of England? When and where was he born? Who were his wives? And so on. Kim's IQ was quite low and he could not care for himself. His father managed all aspects of his life except when he answered questions from memory.

Stephen Wiltshire has a different savant ability. Stephen draws accurate, detailed pictures of city skylines and he does so from memory after a short helicopter tour. He even gets the number of windows in buildings correct. You can buy one of his many city skyline drawings at a gallery in London or online. Alonzo Clemons is a sculptor. He also has a low IQ. His mother claims he was dropped on his head as a baby. Alonzo creates animal sculptures in precise detail, typically after only a brief look at his subject. The artistry is amazing. Derek Paravicini has a low IQ and cannot care for himself. Blind from birth, Derek is a virtuoso piano player. He amazes audiences by playing any piece of music after hearing it only once, and can play it in any musical style. It is worth noting that Albert Einstein and Isaac Newton did not have any of these memory, drawing, sculpting, or musical abilities.

Savants raise two obvious questions: How do they do it, and why can't I? We don't really know the answer to either question. These individuals also raise a core question about the definition of intelligence. They are important examples of the existence of specific mental abilities. But is extraordinary specific mental ability evidence of intelligence? Most savants are not intelligent. In fact, they typically have low IQ and often cannot care for themselves. Clearly extraordinary but narrow mental ability is not what we usually mean by intelligence.

One more example is Watson, the IBM computer that beat two all-time *Jeopardy* champions. *Jeopardy* is a game where answers are provided and players must deduce the question. The rules were that Watson could not search the web and all information had to be stored inside Watson's 15 petabytes of memory, which was about the size of 10 refrigerators. Here's an example. In the category "Chicks Dig Me," the answer is: "This mystery writer and her archeologist husband dug to find the lost Syrian City of Arkash." This sentence is actually quite complex for a computer to understand, let alone formulate the answer in the form of a question. In case you're still thinking, the answer, in the form of a question is: "Who was Agatha Christie?" Watson answered this faster than the humans, and in the actual match, Watson trounced the two human champions. Does Watson have the same kind of intelligence as humans, or better? Let's look at some definitions to consider if Watson is more like a savant or Albert Einstein.

1.2 Defining Intelligence for Empirical Research

No matter how you define intelligence, you know someone who is not as smart as you are. It would be unusual if you have never called someone an "idiot" or a "moron" or just plain dumb, and meant it literally. And, in all honesty, you know someone who is smarter than you are. Perhaps you refer to such a person in equally pejorative terms such as "nerd" or "egghead," even if in your innermost self you wish you had more "brains." Given their rarity, it is less likely you know a true genius, even if many mothers and fathers say they know at least one.

There are everyday definitions of intelligence that do not lend themselves to scientific inquiry: Intelligence is being smart. Intelligence is what you use when you don't know what to do. Intelligence is the opposite of stupidity (and we all know stupidity when we see it). Intelligence is what we call individual differences in learning, memory, and attention. Researchers, however, have proposed a number of definitions, and mostly they all share a single attribute. Intelligence is a *general* mental ability. Here are two examples:

1. From the American Psychological Association Task Force on Intelligence:

Individuals differ from one another in their ability to understand complex ideas, to adapt effectively to the environment, to learn from experience, to engage in various forms of reasoning, to overcome obstacles by taking thought. (Neisser et al., 1996)

2. Here's a widely accepted definition among researchers:

[Intelligence is] a very general mental capability that, among other things, involves the ability to reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly and learn from experience … It is not merely book learning, a narrow academic skill, or test-taking smarts. Rather it reflects a broader and deeper capability for comprehending our surroundings – "catching on," "making sense" of things, or "figuring out" what to do. (Gottfredson, 1997)

The concept of intelligence as a general mental ability is widely accepted among many researchers but it is not the only concept. What evidence supports the concept of intelligence as a general mental ability, and what other mental abilities are relevant for defining intelligence? How do we reconcile intelligence as a general ability with the specific abilities of savants?

1.3 The Structure of Mental Abilities and the *g*-factor

We all know from our experience that there are many mental abilities. Some are specific, such as spelling or the ability to mentally rotate 3D objects or to rapidly calculate winning probabilities of various poker hands. There are many tests of specific mental abilities. We have over 100 years of research about how such tests relate to each other. Here's what we know: Different mental abilities are not independent. They are all related to each other and the correlations among mental tests are always positive. That means that if you do well in one kind of mental

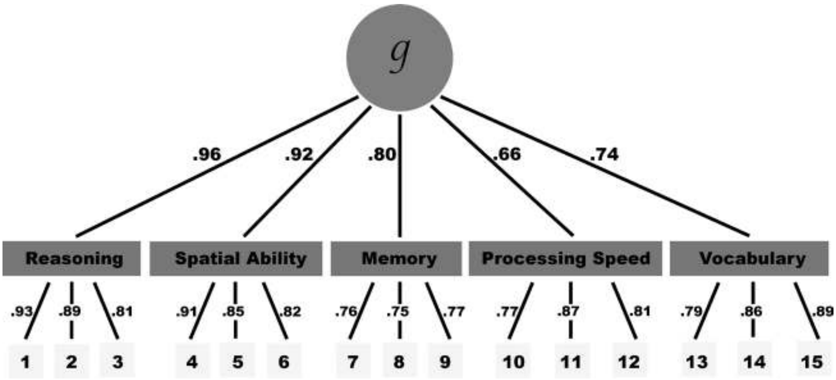

Figure 1.1 The structure of mental abilities. The *g*-factor is common to all mental tests. Numbers are correlations that show the strength of relationship between tests, factors, and *g*. Note all correlations are positive; these are simulated data. (Courtesy Richard Haier)

ability test, you tend to do well in other tests. This may not be the case for any specific person but it is true statistically for populations.

This is the core finding about intelligence assessment and, as we'll see throughout this book, it is the basis for most modern research. Please note this important point: *tend* means there is a higher probability, not a perfect prediction. Whenever we say that one score *predicts* something, we always mean that the score predicts a higher probability for the something.

The relationship among mental tests is called the structure of mental abilities. To picture one possible structure, imagine a three-level pyramid, as shown in Figure 1.1.

At the bottom of Figure 1.1, we have a row of 15 different tests of specific abilities. At the next level up, tests of similar abilities are grouped into more specific factors: reasoning, spatial ability, memory, speed of information processing, and vocabulary. In the illustration, tests 1, 2, and 3, for example, are all reasoning tests and tests 7, 8, and 9 are all memory tests. But all these more specific factors are also related to each other. Basically, people who score high on one test or factor tend to score high on the others (the numbers in the figure are illustrative correlations that show the strength of relationship between tests and factors; see more about correlations in Textbox 1.1). This is a key finding that is demonstrated over and over again. It strongly implies that all the factors derived from individual tests have something in common, and this common factor is called the general factor of intelligence or *g* for short: *g* sits at the highest point on the pyramid in Figure 1.1. The *g*-factor provides a bridge between the definitions of intelligence that emphasize a general mental ability and individual tests that measure (or, more accurately, estimate) specific abilities.

Most theories about factors of intelligence start with the empirical observation that all tests of mental abilities are positively correlated with each other. This is called the "positive manifold," and Charles Spearman first described it more than 115 years ago (Spearman, 1904). Spearman worked out statistical procedures for identifying the relationships among tests based on their correlations with one another. The basic method is called factor analysis. It works essentially by analyzing correlations among tests. You probably already know about correlations, but see the brief review in Textbox 1.1.

Textbox 1.1: Correlations

Many of you know about correlations. Since they are ubiquitous throughout this book, here is a brief explanation so everyone starts with an understanding of the concept. Let's say we measure height and weight in many people. We can graph each person by locating the height and weight as a single point with height ranges on the ***y****-axis and weight ranges on the* ***x****-axis. When we add points on the graph for each person, we begin to see an association. Taller people tend to weigh more. You can see this in Figure 1.2. This association is obvious without needing to plot the points, but associations between other variables are not so obvious. Moreover, correlations quantify the strength of association.*

If height and weight were perfectly related, the points would all fall on a straight line and we could predict one from the other without error. A correlation has a value of +1 if a high value on one variable goes perfectly with a high value on the other variable. A strong but not perfect positive correlation is shown in Figure 1.2. A perfect negative correlation is where a high value on one variable predicts a low value on the other without error. A strong but not perfect negative correlation (also called an inverse correlation) is also shown in Figure 1.2. A perfect negative correlation has a value of minus 1. In the Figure 1.2 example, the higher the family income, the lower the rate of infant mortality. Finally, in Figure 1.2 the bottom panel shows no relationship at all (zero correlation) between height and hours of video game playing.

Correlations between two variables are calculated based on how much each point deviates from the perfect line. The higher the correlation, positive or negative, the stronger the relationship and the better one variable predicts the other. Correlations always fall between plus and minus 1. Here is a critical point: A correlation between two variables does not mean one causes the

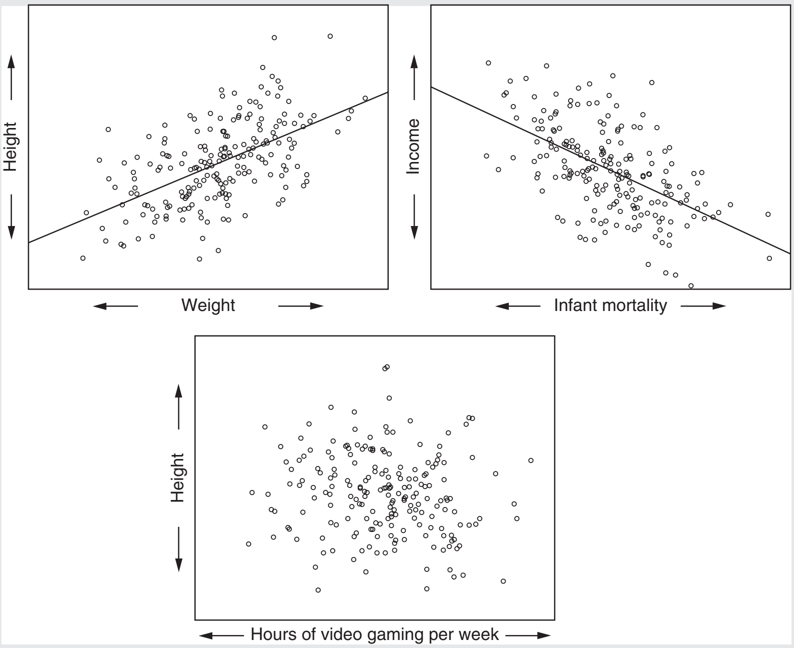

Figure 1.2 An example of a positive correlation is on the left, showing that as height increases weight also increases. A negative correlation is on the right, showing that as family income goes up infant mortality goes down (simulated data). No correlation between height and hours spent playing video games is shown on the bottom. For all of these scatterplots, each circle is a data point. The solid line shows a perfect correlation; the amount that points scatter above and below this line is used to calculate the correlation. (Courtesy Richard Haier)

other. The correlation only means there is a relationship such that as one goes up or down so does the other. To repeat, correlation does not mean causality. Two variables may be correlated to each other but neither causes the other. For example, salt consumption and cholesterol level in the blood may be somewhat correlated but that does not mean one causes the other. The correlation could be caused by a third factor common to both, such as poor diet.

Factor analysis is based on the pattern of correlations among multiple variables. In our case we are interested in the correlations among different tests of mental abilities. So the point of factor analysis is to identify what tests go with other tests, based not on content but rather on correlations of scores irrespective of content. The set of tests that go with each other define a factor because they have something in common that causes the correlation. Studies in this field typically apply factor analysis to data sets where hundreds or thousands of people have completed dozens of tests.

There are many forms of factor analysis but this is the basic concept, the basis for models of the structure of mental abilities such as the pyramid described in Figure 1.1. Going back to that, note that the correlation values show how strong the associations are among tests, factors, and *g*. Note that all the correlations are positive and illustrative of Spearman's positive manifold.

Let's look at some details of this example in Figure 1.1. The reasoning factor is related to *g* with the strongest correlation of 0.96. This indicates that the reasoning factor is the strongest factor related to *g*, so tests of reasoning are regarded as among the best estimates of *g*. Another way of saying this is that reasoning tests have high *g*-loadings. Note that test 1 has the single highest loading of 0.93 on the reasoning factor so it might provide the single best estimate of *g* if only one test is used rather than a battery of tests. The second strongest correlation is between the spatial ability factor and *g*. It turns out that spatial ability tests are also good estimates of *g*. The vocabulary factor is fairly strong at 0.74, followed by the other factors including memory. In this example, memory tests are good but not the best estimators of *g* with a correlation of 0.80, although other research shows much stronger correlations between working memory and *g* (see Section 6.2).

1.4 Alternative Models

Other statisticians and researchers worked out alternative factor analysis methods. The details don't concern us, but different factor analysis models of intelligence were derived using these various methods. Each identified a different factor structure for intelligence. These various factors emphasize that the *g*-factor alone is not the whole story about intelligence; no intelligence researcher ever asserted otherwise or claimed that a single score captures all aspects of intelligence. The other broad factors and specific mental abilities are important. Depending on how researchers derive factors from a battery of tests, a different number of factors secondary to *g* emerge. In the pyramid structure diagram example, there are five broad factors. Another widely used model is based on only two core factors: crystalized intelligence and fluid intelligence (Cattell, 1971, 1987). Crystalized intelligence refers to the ability to learn facts and absorb information based on knowledge and experience. This is the kind of intelligence shown by some savants. Fluid intelligence refers to inductive and deductive reasoning for novel problem solving. This is the kind of intelligence we associate with Einstein or Newton. Measures of fluid intelligence are typically highly correlated to measures of *g*, and the two are often used synonymously. Crystalized intelligence is relatively stable over the life span with little deterioration with age, whereas fluid intelligence decreases slowly with age (Schaie, 1993). The distinction between fluid and crystalized intelligence is widely recognized as an important evolution in the definition of intelligence. Both are related so they are not in conflict with the *g*-factor. They represent factors just below *g* in the pyramid structure of mental abilities.

Another factor analysis model focuses on three core factors – verbal, perceptual, and spatial rotation – in addition to *g* (Johnson & Bouchard, 2005). There are also models with less empirical evidence such as those of Robert Sternberg (Brody, 2003; Gottfredson, 2003; Sternberg, 2000, 2003, 2014) that deemphasize *g*, and Howard Gardner (Ferrero, Vadillo, & León, 2021; Gardner, 1987; Gardner & Moran, 2006; Waterhouse, 2006) that ignore the *g*-factor. Virtually all of the neuroscience studies of intelligence, however, use various measures with high *g*-loadings. We will focus on these, but also include several neuroscience studies that investigate factors and specific abilities other than *g*.

1.5 Focus on the *g*-factor

The *g*-factor is the basis of most intelligence assessment used in research today because it alone accounts for about half of the intelligence test score variability among people. It is not the same as IQ, but IQ scores are good estimates of *g* because most IQ tests are based on a battery of tests that sample many mental factors, an important aspect of *g*. Many of the controversies about intelligence have their origins in confusion about how we use words such as mental abilities, intelligence, the *g*-factor, and IQ. Figure 1.3 shows a diagram that will help clarify how I use these words throughout this book.

We have many mental abilities – all the things you can think of from multiplying in your head to picking stocks to naming state capitals. The large circle in Figure 1.3 represents all mental abilities. Intelligence is a catchall word that means the mental abilities most related to responding to everyday problems and navigating the environment, as per the American Psychological Association and the Gottfredson definitions. The circle labeled intelligence is smaller than all mental abilities. IQ is a