Special Review

How Radiologists Think: Understanding Fast and Slow Thought Processing and How It Can Improve Our Teaching

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Scholars have identified two distinct ways of thinking. This "Dual Process Theory" distinguishes a fast, nonanalytical way of thinking, called "System 1," and a slow, analytical way of thinking, referred to as "System 2." In radiology, we use both methods when interpreting and reporting images, and both should ideally be emphasized when educating our trainees. This review provides practical tips for improving radiology education, by enhancing System 1 and System 2 thinking among our trainees.

Key Words: Education; dual process theory; cognitive science.

WHY THINK ABOUT THINKING?

The human brain is a complicated instrument. Decades of research, from modular studies to the social sciences, have helped us understand how we learn and function. Research in cognitive sciences has taught us that "thinking," eg, making decisions or solving problems, is not a single process. There are different ways of "thinking." For example, analytical and nonanalytical ways of thinking have been distinguished and referred to as the "Dual Process Theory" in the literature (1,2). Both ways offer strengths and weaknesses and both are used by radiologists in their daily practice. Herein, we aim to review these two main forms of thinking, and more specifically we aim to show how thinking about "thinking" can make us better teachers as well as better physicians.

TWO WAYS OF THINKING: SYSTEM 1 AND SYSTEM 2

The two thinking processes described in "Dual Process Theory" are called System 1 and System 2, and they refer to a fast, nonanalytical way of thinking and a relatively slow, more analytical way of thinking, respectively (1,2). Although the theory describes two distinct systems, they are rarely used in pure form (3), and many clinical problems are solved using a combination of both. One may derive a hypothesis intuitively for example, but then proceed in an analytical mode to test the hypothesis. Some authors advocate that there is a cognitive continuum with the two systems representing the extremes (4), whereas others debate that the two systems run in parallel (5).

System 1 is described as an *automatic* and *intuitive* thinking process, primarily based on instantaneously noting similarities between something observed and prior examples stored in our memory. This process can be so fast we may not even notice that we were "thinking." For example, chest radiologists seeing their 200th case of cystic fibrosis may immediately identify the disease on a new chest radiograph. This thinking process can also be described as pattern recognition (6,7). This fast form of thinking tends to be highly developed in experts (8). For example, a pneumothorax tends to be quickly recognized by an expert radiologist, not requiring any deliberation over other differential considerations.

System 2 is a *deliberate* and *analytical* thinking process. In System 2 thinking, we are reasoning to get to a solution, for example by weighing supportive and opposing evidence for one or multiple hypotheses. In contrast to System 1, System 2 thinking tends to be slow and easily recognized as active "thinking." The pneumothorax case mentioned previously could also be approached with a System 2 way of thinking, for example when a first year radiology resident considers whether the line visualized represents a skin fold, a bone edge, or a pneumothorax. Such a leaner would probably analyze factors such as whether the sharpness and the course of the line fit better with one consideration or another.

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WHY ARE BOTH SYSTEM 1 AND SYSTEM 2 IMPORTANT FOR RADIOLOGISTS AND RADIOLOGY LEARNERS?

System 1 thinking can be time-efficient. When a number of similar cases have been encountered (ie, experience), System 1 often results in the correct answer, and the time and effort of a detailed analytical process can be avoided. However, this fast way of thinking is less likely to work in novel situations or for unusual cases (9).

If a diagnosis is not immediately recognized, due to difficulty of the case or lack of experience, System 2 is often used (10). The slow and analytical System 2 thinking helps us to try to find diagnoses when none come to mind, or when the diagnosis that comes to mind does not seem "quite right."

Instead of relying on either System 1 or System 2 thinking, we use a combination of both in clinical reasoning (11): System 1 thinking is often more pronounced in straightforward cases or decisions, whereas System 2 thinking is dominant in difficult or indeterminate cases (12,13). Of course, whether a case is straightforward or not also depends on the knowledge and experience of the observer. The ultimate balance needs to be found; using the time-efficient System 1 thinking when you can, and using the analytical System 2 thinking when you have to. In other words, "slowing down when you should" (9). Encouraging trainees to explicitly use a combination of analytical and nonanalytical ways of thinking can improve diagnostic accuracy (14,15). As educators, it is our role to provide learners with the knowledge and experience that are needed to support both thinking systems, and we should guide learners on how to apply them (16).

ERRORS RELATED TO EACH TYPE OF THINKING

Relying too much on one way of thinking can cause errors. When we think too fast and only trust on our first impression, we may arrive at the wrong diagnosis, simply because things are not always what they look like at first sight. A typical error related to System 1 thinking is due to *availability bias* (17): diagnoses that occupy a more prominent place in our memory are more likely to be considered than others, for example a diagnosis that was recently made or missed, or a diagnosis suggested by a colleague in a previous report. System 2 thinking can also be prone to errors. Some pieces of evidence may be weighed more heavily than they should, for example because they confirm our hypothesis, known as *confirmation bias* (17). Or someone may simply make a reasoning error for example due to a lack of knowledge.

TIPS TO IMPROVE YOUR TEACHING WITH SYSTEM 1 AND SYSTEM 2 THINKING

How to Support System 1 Thinking

"Pattern recognition" is the basic foundation of System 1 thinking, and it is part of everyday life. It is not exclusive to human beings; interestingly, a very recent article discussed the ability of pigeons to show some signs of System 1 learning (ie, pattern recognition) with radiological images (18). Thus, it could be argued that System 1 thinking develops automatically with experience and that teaching has no substantial role in its development. However, System 1 teaching can be especially useful in novices. Because all medical students and residents experience a different curriculum depending on the cases they encounter by happenstance, some conditions may be rarely or never be seen by certain learners. Teaching can fill that gap and build some early examples in their minds. Building a mental repertoire can be accomplished by showing or providing multiple practice cases. The most successful form of teaching in System 1 is providing many examples *with* feedback, provided *over a period of time* (19). For example, identification of ankle fractures improves after seeing many cases interspersed with nonfracture cases, over multiple sessions (20). This cannot be achieved in one lecture or reading session, but can be achieved over the course of a teaching program, eg, residency rotations or intensive training courses. Achieving high volume exposure to prevalent diseases can be accomplished during clinical work with little effort, although less prevalent diseases may lack adequate repetition. Teaching files and lectures can help fill this gap. Finally, "Aunt Minnie's," "rules of thumb," and "radiological signs" can be taught as clues to quickly reach particular diagnoses (with caveats of course, as some signs can be misleading).

How to Support System 2 Thinking

Teaching System 2 thinking requires reflecting on when the learner would need to use deliberate analysis. For junior learners, many decisions require deliberate thought. For example, novices frequently mistake growth plates for possible fractures, and may need to assess the edges and shape of the bones or compare the image with an anatomy atlas for a correct diagnosis. Experts tend to rely more on System 1 thinking (21). However, they rely on analytical thinking when facing challenging cases (22). They may even profit more from System 2 supportive education because, as a result of experience, their System 1 thinking has already developed for a broad range of medical conditions. Presentations designed to bolster System 2 thinking in experienced readers can include atypical cases, unknown cases, mimics of diseases, and cases in which the "expert got it wrong." In these cases, the goal of the teaching is the *approach* to diagnosis, rather than to prime pattern recognition. Such presentations can be introduced by discussing when using the approach is needed as opposed to pattern recognition ("when you see hypermetabolic mediastinal lymph nodes on FDG-PET in a lung cancer case, you may immediately think the patient has metastases, but in every case you should pause and closely evaluate the level of metabolism and the pattern of lymph nodes because diffuse low-level metabolism may represent reactive lymph nodes only"). System 2 thinking requires analyzing features that both support and refute a potential diagnosis. For example, teaching a System