



Dual process models of clinical reasoning: The central role of knowledge in diagnostic expertise

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Abstract

Rationale: Research on diagnostic reasoning has been conducted for fifty years or more. There is growing consensus that there are two distinct processes involved in human diagnostic reasoning: System 1, a rapid retrieval of possible diagnostic hypotheses, largely automatic and based to a large part on experiential knowledge, and System 2, a slower, analytical, conscious application of formal knowledge to arrive at a diagnostic conclusion. However, within this broad framework, controversy and disagreement abound. In particular, many authors have suggested that the root cause of diagnostic errors is cognitive biases originating in System 1 and propose that educating learners about the types of cognitive biases and their impact on diagnosis would have a major influence on error reduction.

Aims and Objectives: In the present paper, we take issue with these claims.

Method: We reviewed the literature to examine the extent to which this theoretical model is supported by the evidence.

Results: We show that evidence derived from fundamental research in human cognition and studies in clinical medicine challenges the basic assumptions of this theory—that errors arise in System 1 processing as a consequence of cognitive biases, and are corrected by slow, deliberative analytical processing. We claim that, to the contrary, errors derive from both System 1 and System 2 reasoning, that they arise from lack of access to the appropriate knowledge, not from errors of processing, and that the two processes are not essential to the process of diagnostic reasoning.

Conclusions: The two processing modes are better understood as a consequence of the nature of the knowledge retrieved, not as independent processes.

KEYWORDS

diagnosis, diagnostic reasoning

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'The situation has provided a cue; this cue has given the expert access to information stored in memory, and the information provides the answer. Intuition is nothing more and nothing less than recognition'. H.A. Simon

Simon, H. A. (1992). What is an 'explanation' of behaviour:

Psycho logical Science, 3, 150-161.

1 | INTRODUCTION

In the past few years, there has been increasing attention to the prevalence of diagnostic errors and its impact on health outcomes.¹ A number of tools to mitigate diagnostic errors have been proposed, ranging from checklists² to electronic diagnostic support systems.³ Empirical studies, typically in controlled settings, have demonstrated consistent, albeit moderate, success in reducing diagnostic error using these approaches.⁴⁻⁶ However there are limitations to implementation in clinical practice.⁷ Clinicians are reluctant to accept and apply diagnostic supports. Additionally, Sibbald and colleagues demonstrated that the benefit of an electronic diagnostic support system varies with the clinician's experience and whether it is accessed early or late in the diagnostic process.⁸

Recent contributions of Sibbald and colleagues,^{2,8-10} on the potential error reduction benefits of checklists and electronic diagnostic support tools, while few in comparison to the nearly 5 decade long research programme on diagnostic reasoning,¹¹⁻¹⁵ have the potential to lead to meaningful improvements. Unfortunately, efforts to implement error reduction strategies have not been sufficiently aligned with our understanding of clinical and diagnostic reasoning processes. This misalignment between empirically tested error reduction strategies and theories of the diagnostic reasoning process has significantly slowed progress in reducing diagnostic errors. Error reduction strategies must integrate with naturalistic clinical reasoning^{16,17} to be effective and sustainable.

In this paper we briefly review the conclusions of research aimed at delineating diagnostic reasoning processes. We examine three common assertions about the relationship between reasoning processes and error. We critique the influential role of dual process theory (DPT) on clinical reasoning research and the key assumption that the most effective error reduction strategies lie in the delineation of reasoning itself. Finally we propose a way forward that builds on evidence and theory.

2 | DUAL PROCESS DIAGNOSTIC REASONING

Classic studies of clinicians' diagnostic reasoning by Elstein^{4,14} and Barrows¹⁸ demonstrated that diagnostic reasoning has two distinct components: an early phase where the clinician advances one or more diagnostic hypotheses, and a later phase where these hypotheses are systematically tested. Subsequent research linked these two components to DPT, advanced by cognitive psychology, which recognises two

simultaneous and parallel cognitive processes.^{5,19} Fast processing, sometimes referred to as 'System 1' or 'Type 1', is viewed as an intuitive process that involves unconscious and rapid retrieval of diagnostic hypotheses based on minimal information. The slower process, referred to as 'System 2' or 'Type 2', is characterised by analytical, logical, conscious application of formal knowledge to the diagnostic problem. Thousands of papers in various disciplines (psychology, economics, medicine to name a few) have been published on dual processing theory. In medicine alone, a search of PubMed identified 2500 articles.

It seems self-evident that System 1—fast, unconscious, intuitive—may be highly error-prone, and System 2—slow, methodical, analytical, and rational, is far more likely to resist errors. Indeed, this apparently obvious assertion is present in much of the literature, particularly in emergency medicine. One need not look farther than titles to see examples: 'The Rational Diagnostician and Achieving Diagnostic Excellence',²⁰ 'Becoming Less Wrong (and More Rational) in Clinical Reasoning'.²¹ Indeed the prevalent view, as expressed by Kahneman, is that 'errors of intuitive judgement involve failures of both systems: System 1, which generated the error, and System 2, which failed to detect and correct it.^{22,23} Many authors in this tradition go one step further, and assert that errors arise in System 1 as a consequence of short cuts (i.e., heuristics) employed in the service of the rapid and relatively effortless reasoning, which in turn leaves it vulnerable to cognitive biases, which in turn lead to judgement errors. We will examine these assertions below:

2.1 | Dual processing and diagnostic error

2.1.1 | Is system 1 reasoning the source of diagnostic errors?

The brief answer is no, the source of errors does not primarily lie in System 1 reasoning, but in the lack of experience and knowledge.²⁴

While the mantra in medicine is that error is attributed primarily to the flaws of the intuitive System 1, the evidence is nowhere near as uniform as this suggests, either in psychology or medicine. Many recent papers in psychology have emphatically rejected this claim. For example, Evans and Stanovich,¹¹ in a comprehensive review, state:

Perhaps the most persistent fallacy in the perception of dual-process theories is the idea that Type 1 processes (intuitive, heuristic) are responsible for all bad thinking and that Type 2 processes (reflective, analytic) necessarily lead to correct responses. Thus, various forms of dual-process theory have blamed Type 1 processing for cognitive biases.

In medicine, there is evidence, even in the early studies published 40 years ago, that is inconsistent with this view. As one example, Barrows et al.,¹⁸ studied the thinking of internists and family physicians faced with diagnostic problems. They discovered that when clinicians thought of the correct diagnosis early on, they had a 96% chance of arriving at a correct diagnosis; conversely when they did not think of it early, their likelihood



of success was only 13%. In another study, Gruppen et al.,²⁵ followed 119 cases in an outpatient setting and queried the physician about their diagnosis (a) after receiving the nurse's note containing age, sex and chief complaint, (b) after the history, and (c) after physical examination and diagnostic test data. The differential diagnosis was correct after the nurse's note in 79% of cases; history added 16% to accuracy; physical exam and diagnostic tests only 1%. Again, rapid processing based on minimal information carried the day: analysis of the 'complete' data added little to accuracy. A more recent study by Sherbino²⁶ used 20 written protocols of internal medicine cases with residents, who were instructed to 'go as quickly and accurately as you can' found a -0.75 correlation between accuracy and response time. In a similar study, Staal et al.,²⁷ found that residents reached a correct diagnosis faster than an incorrect diagnosis. These observational studies cannot claim that the impressive accuracy of first impressions and the inverse relation between time and accuracy resulted from System 1 processes, but the data are consistent with this view.

2.1.2 | Can system 2 reasoning reduce or eliminate errors?

The brief answer is no, System 2 reasoning cannot singularly correct errors, in part because analytic reasoning is driven by unfamiliar problems.

Qualitative studies^{28,29} have found that expert surgeons, when confronted with a problem in the course of surgery, will 'slow down'. This evidence has been used to advance recommendations that learners should 'slow down' as a strategy to reduce errors. The impact of instructions to slow down was directly tested in an extension³⁰ of the Sherbino et al.,²⁶ study. In this study a second group was introduced, who were told to 'be careful and thorough.... Do not miss anything... consider all the data'. The second cohort was indeed slower, 90s versus 69s, but accuracy was identical (44% vs. 45%). A similar study by Ilgen et al.,³¹ administered 12 cases to nearly 400 participants at three levels—medical student, resident, staff physician. Again participants were tested under fast or slow conditions. Times were very different—29 min versus 88 min, but accuracy between the two conditions was nearly identical—68% versus 67%. A study in dermatology³² used participants at five levels of expertise, from preclinical medical student to dermatologist. Not surprisingly, accuracy covered a wide range, from 20% for preclinical students to 90% for dermatologists. When diagnoses were correct, time to diagnosis followed a monotonic negative trend with expertise, from 12s for students, to 8s for dermatologists. Conversely, incorrect diagnoses took 11s for students and 17s for dermatologists, and 'don't know' took 10s for students and 24s for dermatologists. Thus, with increasing expertise, the extra time for incorrect selections increased. The phenomenon of increasing time associated with errors has also been noted in responses to multiple choice questions.^{33,34}

An incremental role of System 2 in possibly correcting errors made by System 1 reasoning was also tested in two studies using longitudinal designs. Monteiro et al.,³⁵ had medical residents quickly view a series of 16 written cases and offer a diagnosis. They were then permitted to

review each case, decide whether they wished to review it in more detail, and then offer a revised diagnosis. On the first pass, accuracy was 41%. Residents chose to examine only 60 (8%) of the 423 incorrect diagnoses, and accuracy went up by only 2%. Mamede et al.³⁶ did a similar study, but looked at different conditions of reflection—no instructions, only confirmatory evidence, only contradictory evidence, and both confirmatory and contradictory evidence. Initial accuracies ranged from 19% to 22%. Improvement over all interventions was 4%. Thus, when clinicians must assess their own accuracy and decide to pursue further analysis (System 2) they are suboptimal in recognising when they have erred and gains in accuracy derived from more careful inspection are minimal. The result should not be surprising; a large body of research shows that people in a diversity of situations, including medical diagnosis, are very poor at self-assessment.^{33,37}

A very different approach to investigating the role of System 1 and 2 systematically varied viewing time.³⁸ In this study, residents and staff physicians diagnosed ECGs and chest xrays after exposure at varying times. The first study involved exposure times from 125 ms to 1 s, where only System 1 processing could arise (reaction times are typically about 200 ms); the task was to declare normal or abnormal. Both residents and staff were able to complete the task with about 70% true positive and 20% false positive rate with some improvement up to 250 ms, but no change after 250 ms. The second study extended times from 1 s to 20 s, and asked for a diagnosis. No improvement in true positive rates or accuracy of diagnosis occurred after 5 s (the time when System 2 processes may begin to occur). What was most striking was that from 5 to 20 s staff physicians showed a moderate decline in false positives, whereas residents showed a large *increase* in false positives (from about 8% to about 30%). Presumably, this occurred because the extended time for System 2 processing enabled them to identify 'features' that were not, in fact, clinically important. In this case, System 2 processing did not lead to higher accuracy; in fact, the additional viewing time led residents to incorrectly identify normal variants as clinically important. While this is the first study to control viewing time, the finding that less skilled radiologists tend to overcall normal variants as pathology has been demonstrated in other studies.³⁹

2.1.3 | What is the role of cognitive bias in diagnostic error?

At the level of a cognitive mechanism, a cognitive bias is a mechanism that influences attention, conscious or subconscious, to associations between two or more pieces of information.⁴⁰ For example, availability is a mechanism that influences the commitment to an immediately available association, making it unlikely that additional associations will be considered.⁴⁰ So in the event that attention is drawn to an association that is not appropriate for that diagnostic problem, the potential for diagnostic error may increase. Consequently, many clinical reasoning researchers⁴¹ maintain that errors originate in System 1 as a consequence of cognitive biases.^{24,42,43} Yet cognitive processes occur in parallel so it is possible for both correct and incorrect associations to occur simultaneously.⁴⁰



To what extent are errors attributable to cognitive biases?

Hundreds of papers have been written implicating cognitive bias as a cause of judgement errors in many fields; there are now over 225 judgement biases.⁴⁴ Interestingly, relatively few have any empirical support, and even fewer have been demonstrated in medicine. There have been three systematic reviews of cognitive biases in medicine, which identified a total of 25 biases^{45–47}; however many of these relate to management and prognosis as well as biases of patient perceptions. Only seven pertained to diagnostic errors and only three—availability, confirmation, and hindsight—were common to all reviews. The contrast between 225 hypothesised biases and three empirically verified and replicated biases is stark. Moreover, the notion that students should be able to identify the presence of particular biases, when there are 225 to choose from, becomes ludicrous.²⁴

Much of the evidence of bias is derived from experimental studies, where cases are presented that contain specific biases. Perhaps the most investigated bias is 'availability', since it is easily amenable to experimental designs. Typically these are 2-part studies, where examples similar to the test cases are learned in one context, then in a second delayed session, test cases are administered, and the effect of the prior priming assessed. As an example, Schmidt et al.,⁴⁸ showed residents Wikipedia descriptions of rare diseases, then 6 h later had residents diagnose a series of cases, some of which were matched with the Wikipedia cases. Cases that resembled a case seen earlier were more likely to be misdiagnosed. However, not all studies are successful in inducing a cognitive bias. Monteiro et al.,⁴⁹ attempted unsuccessfully to induce availability bias in medical students, residents and physicians. Staal et al.,²¹ was similarly unsuccessful in inducing availability bias among residents.

Studies of this type can induce bias (sometimes), but cannot provide insight into the prevalence or magnitude of bias in clinical practice, since in experimental studies, the prevalence is typically set at 50% or 100%. One epidemiological study did document the magnitude of availability bias in clinical practice. Ly et al.,⁵⁰ studied 416,000 cases referred for shortness of breath in the Veteran's Affairs healthsystem, and determined the likelihood that tests for pulmonary embolus (PE) would be ordered based on the attending physician having seen a previous patient with PE a short time earlier. If the physician had diagnosed a PE within the previous 10 days, the prevalence of use of a PE test increased by 1.4%, however the effect was no longer observed after the 10 day period.

In sum, the evidence supporting cognitive bias as the primary source of diagnostic error is sorely lacking.

Can experts consistently identify particular cognitive biases?

There is little evidence that even experts in diagnostic reasoning can consistently recognise and label biases that arise. One study⁵¹ examined this issue by creating standard scenarios and asking a group of clinicians with special expertise in cognitive biases to identify which of six biases were present in each scenario (The six biases were chosen on the basis that they had empirical support and were also commonly described in the literature). Inter-rater agreement on presence or absence of individual biases was close to zero for every bias. There was also an experimental manipulation in the scenarios unknown to participants. Each case contained data to support two equiprobable diagnoses. The last line of

each scenario described a test result or outcome that suggested that the clinician's diagnosis was right or wrong. When the test was inconsistent with the proposed diagnosis, participants identified twice as many biases. The only consistent bias identified in the study was hindsight bias on the part of the expert participants.

How does cognitive bias change with experience?

Returning to the previous definition of cognitive bias as an association between pieces of information, the efficiency and accuracy of associations tends to improve with more experience. It is important to recognise that much of the evidence connecting cognitive heuristics and biases to error arose from data collected from the ubiquitous first year psychology classroom, where participants (students) are asked questions about issues for which they are unlikely to have any specialised knowledge or particular interest. In that context, where all problems are unfamiliar to the participants, System 2 reasoning is essential. By contrast, when cognitive biases are studied with participants who already have domain expertise (i.e. clinicians in medicine), a consistent finding is that participants with more clinical experience show less influence of cognitive bias. As one example, Weber and colleagues⁵² found little evidence of base rate neglect among experts. They also found a strong relationship between self-reported experience with similar cases and the likelihood and speed of generating a correct diagnostic hypothesis, which they interpreted as a positive effect of availability. In another study, Hatala et al.⁵³ found that cardiologists were substantially less susceptible to the effect of a biasing history than residents, who were in turn less vulnerable than students.

Does knowledge influence impact of cognitive bias?

A number of studies have examined the relation between diagnostic performance and measures of knowledge. Sherbino et al.,²⁶ showed a correlation of 0.4 between a test of diagnostic accuracy and performance on a national licensing examination. Ilgen et al.³¹ showed positive correlations between diagnostic accuracy in a diagnostic task and national medical student certification exams. Notable, in this study, which was based on a two group design with one group encouraged to use rapid, automatic reasoning and the other to use analytical reasoning, correlations with exam scores of the automatic group were substantially larger (0.33 vs. 0.10 for residents, 0.53 vs. 0.30 for faculty).

However, these studies did not directly examine the association between knowledge and the effect of cognitive bias. Mamede and colleagues⁵⁴ induced availability bias with physicians in a two-step process, then tested their knowledge of the relation between symptoms and diagnoses. They found that high knowledge physicians were less susceptible to availability bias than low knowledge physicians. In a study by Mamede,⁵⁵ 'immunising' physicians with relevant knowledge for discriminating between specific diseases was sufficient to eliminate the availability effect of a salient prior case.

Can instruction on cognitive bias reduce diagnostic errors?

Some studies^{56,57} have shown that instruction about cognitive bias enables students to recognise these biases when present in written test materials. However, this does not address the central thesis: errors are caused by cognitive biases, therefore instructing students to be aware of

biases will reduce diagnostic errors. Only three studies appear to examine this question; all used a similar methodology,^{58,59} where students were taught specific biases and were then tested on cases that contained these biases. None of the studies showed any effect on error rates.

Like Graber,³ we are surprised at the dissociation between the number of papers advocating cognitive interventions based on dual processing and cognitive biases, and the few studies that have actually demonstrated the effectiveness of such interventions in actually reducing diagnostic error.

2.1.4 | What about critical thinking, metacognition and reflection?

Complex activities like medical diagnosis involve many dimensions of thinking. In particular, the above discussion highlights only the processes of associating clinical signs and symptoms to diagnoses. Many writings about clinical reasoning have highlighted the importance of a monitoring cognitive function, variously called critical thinking, metacognition or reflection. One definition is 'the art of analysing and evaluating thinking with a view to improving it'.⁶⁰ However defined or labelled, these processes appear qualitatively different from the processes we have examined to now. Our thesis to this point, to be expanded further below, is that diagnostic reasoning is critically dependent on accessing knowledge relevant to the diagnostic task. Commentaries about metacognition completely discount knowledge and view metacognition as a stable, almost invariant characteristic of an individual, which can be equally well applied across all problem situations, familiar or not. For example, 'the robust critical thinker relies on cognitive skills to ask questions critically, cogently and creatively. For a critical thinker is one who is open to the evidence and evaluates it through rational thinking and discourse. And the thinker does not follow authority in an uncritical manner'.^{61,62}

Most research on metacognition assumes that, like critical thinking, it can be taught, so students learn to 'monitor, reflect upon, and improve their strategies for learning and problem solving'.⁶³ While metacognition originated in cognitive psychology, 'reflection' in medicine clearly dates from Schon's 'The Reflective Practitioner',⁶⁴ but follows a similar line of reasoning, extolling the virtues of 'reflection in action'—self monitoring and introspection.

While there is an extensive literature in health sciences related to reflective practice, metacognition and critical thinking, most of the literature is an evidence-free discussion of the importance of these concepts⁵⁸ or an exploration of the various dimensions underlying the global concept.⁶² Conspicuous by its absence is any evidence of a relation between metacognitive or reflection skills and improved diagnostic accuracy, or any evidence that instructional interventions directed at improving metacognition/reflection actually improve diagnostic accuracy.⁶¹

Closely related to reflection, although rarely overlapping in the literature, is self-assessment—the ability to monitor one's process and identify errors. The literature on self-assessment is very clear; without assistance people are incapable of identifying good from bad performance in themselves.⁶⁵ Specific to diagnostic reasoning, broad

admonitions to be systematic, be careful, and so forth, have no effect other than to slow the process down.^{31,66} Even an intervention designed to make people revisit their performance on a second pass through test cases had minimal effect on accuracy in one study³⁵ although it did prove marginally beneficial in another.³⁶

However, it is important to separate (general) reflection and self-assessment from an alternative—deliberate reflection. This highly structured strategy mobilises clinician knowledge relevant to the diagnostic process by explicit consideration of features of the case that support or go against the selected hypothesis and plausible alternatives. The research programme of Mamede and Schmidt¹⁵ has shown deliberate reflection (systematic mobilisation of knowledge, not general self-monitoring and nonspecific introspection) to improve diagnostic accuracy. Of note, the literature rarely considers the additional cognitive load required by these metacognitive processes, particularly when the clinician's working memory is near-saturated by the diagnostic process. Perhaps metacognition, including deliberate reflection, hampers diagnostic accuracy in complex cases in the clinical environment?

2.2 | Summary

This review of the evidence related to the causal role of System 1 processes and cognitive biases in diagnostic errors has revealed inconsistencies between evidence and rhetoric. The evidence shows that errors do not originate solely in System 1 processes and are corrected by System 2 processes. Quite the reverse; in some studies, increased analytical processing is associated with more, not fewer, errors. Further, despite the accepted view that most errors are a consequence of cognitive biases, the link between errors and cognitive biases is tenuous. Finally, there is no evidence that teaching students to identify cognitive biases results in fewer diagnostic errors.

Clearly we have to look elsewhere to resolve the dissociation between theory and evidence. One possibility may be that theory itself is wrong. An alternative view is that DPT is a theory describing two systems of processes for accessing prior knowledge and experience, and the appearance of two processes arises from retrieving different kinds of knowledge. The two observed processes are an epiphenomenon; they are neither a cause of errors nor a strategy to mitigate errors; instead, they are a consequence of the nature (i.e. quantity and quality) of experience and knowledge retrieved.

3 | A REINTERPRETATION OF THE CENTRALITY OF DUAL PROCESSES

The application and relevance of DPT across the majority of clinical reasoning research rests on a basic meta-assumption that the key to understanding expertise resides in the reasoning process. This basic idea, that expertise is manifested in superior approaches to thinking, has a long history in education.^{64,65} The emphasis on the primacy of two distinct thinking processes is simply the latest variant of the quixotic quest for a universal problem-solving process. However, a substantial body of



evidence in psychology, dating back several decades, challenges this view.⁶⁷ Logan,⁶⁸ in a paper exploring the nature of automaticity, strongly challenges the primacy of thinking processes.

The theory relates automaticity to memorial aspects of attention rather than resource limitations. It construes automaticity as a memory phenomenon.... Automaticity is memory retrieval (italics ours): Performance is automatic when it is based on single-step direct-access retrieval of past solutions from memory. The theory assumes that novices begin with a general algorithm that is sufficient to perform the task. As they gain experience, they learn specific solutions to specific problems, which they retrieve when they encounter the same problems again. Then, they can respond with the solution retrieved from memory or the one computed by the algorithm. At some point, they may gain enough experience to respond with a solution from memory on every trial and abandon the algorithm entirely. At that point, their performance is automatic. Automatisations reflects a transition from algorithm-based performance to memory-based performance. (p.493)

In brief, if you are able to retrieve a workable solution, you do. The process is fast and accurate, and does not tax working memory. By 'workable' we mean a solution that corresponds to the solutions expected of the clinician in the context of their professional environment. In this respect, we would point out that even a rank novice is capable of generating diagnostic hypotheses when confronted with a problem.⁶⁸ The difference is that expert solutions are better (more relevant and/or more specific—e.g., novices may identify a 'respiratory problem', while experts identify 'acute heart failure with preserved ejection fraction'). If the identified solutions are deemed by the individual as erroneous or too general or insufficient to explain the features, they will retrieve an algorithm—a set of rules to compute the solution. (Note that we use 'algorithm' and 'compute' in a more general than mathematical sense. Any explicit rule is equivalent to an algorithm; any explicit process of combination and analysis is a computation). The process involves multiple steps, heavily loads working memory, is error-prone, and takes more time. A simple, yet informative example is to contrast people's approach to two basic arithmetic problems – $12 \times 12 = ?$ and $17 \times 17 = ?$ In the former case, almost everyone volunteers 144; a System 1 solution. In the latter, in almost the same time, almost everyone says 'I don't know'. Of course, most can solve it analytically using the rules of long multiplication, a slow, explicit, logical System 2 solution (which is likely far more error prone).

Many of the characteristics ascribed to System 1 and 2 can now be seen as consequences of the different processes associated with solution retrieval and algorithm application, not as fundamentally different processes. Identification of a solution involves few operations, is generally associated with direct retrieval from long term memory, and has no or minimal involvement of working memory. Conversely, retrieval of an algorithm or application of a rule may involve multiple

operations in working memory, increasing cognitive load; this takes time and may lead to computational errors.

Moreover, some of the characteristics of expertise—greater reliance on System 1, speed, immunity to the effect of interruptions⁶⁹—become a straightforward consequence of the observation that one becomes an expert in a domain by acquiring numerous examples of solutions that are automatically and effortlessly retrievable from memory. In the Logan model, experts can rely on automatic processes because they have solved the problem before. Automaticity—direct retrieval of solutions—is a hallmark of expertise, not a consequence of taking shortcuts. Expertise is an evolution from reliance on explicit rules to an ability to recognise solutions derived from an extensive knowledge base of exemplars.³²

This reinterpretation of System 1 as a process of retrieving a solution directly from memory casts the process in a different light. The process is rapid and unconscious, certainly, but describing it as intuitive with the implication that it is somehow less than rational (and therefore more error-prone) is not warranted. The process is rapid because the solution is identified in long term memory without a requirement for further conscious refinement in working memory. Furthermore, the notion that System 2 exists solely to correct errors caused by System 1 processes is narrow and simplistic. In the diagnostic process, initial hypothesis generation is routinely followed by a process of subsequent data gathering, primarily directed at confirming the initial hypotheses. This may occasionally correct errors, but more routinely is directed at increasing confidence in the hypothesised solution.

Logan says one more thing—use of algorithms (System 2)—is a characteristic of novices, which is consistent with the findings above. As one acquires expertise, one has available more and more specific solutions, and need not compute a solution. So in this model, reliance on System 2, rather than being invoked to correct errors caused by System 1, is an indicator that no solutions were identified in memory. There is some evidence in medicine to support this observation. Regehr⁷⁰ and Kulatunga-Moruzi⁷¹ conducted a series of studies in dermatology focussed on either holistic rapid processing or feature-by-feature analytic processing. They concluded that '... the results are consistent with the theory that as clinicians develop more experience they move from a more analytic approach to a more similarity-based approach'. This has been recognised by others.^{72,73} Dreyfus, acknowledged as the guru of artificial intelligence, wrote.⁷⁴

'We must be prepared to abandon the traditional view that runs from Plato to... Piaget... Chomsky... that a beginner starts with specific cases and... as he or she becomes more proficient, abstracts and interiorises more and more sophisticated rules. It might turn out that skill acquisition moves in just the opposite direction: from abstract rules to particular cases'.

If diagnostic error occurs, it is a function of insufficient knowledge, either clinical practice inexperience (i.e., no previous, relevant patient encounters) or gaps in general medical knowledge (e.g., physiological mechanisms, illness scripts, management strategies, etc.).^{75,76}

4 | FUTURE RESEARCH

A large body of experimental research, performed over decades, has laid the groundwork for a reformulation of the interpretation of the cognitive processes that support diagnosis in medicine. Much of this work has involved experimental settings, where groups of learners at different levels, and sometimes experienced practitioners, were presented with clinical problems under varying conditions.

Diagnosing patients accurately and efficiently is challenging and, for many patients, the stakes could not be higher. Given the high cost and stress of diagnostic errors to both patients and clinicians, it is understandable that educators would seek expedient fixes such as lists of cognitive biases which, once learned, will lead to error reduction. The perspective offered here discourages emphasis on general heuristics to reduce error. Error is not a function of bias or incorrect system function; diagnostic error is an absence of the knowledge required for a correct solution. Either the physician lacks a specific solution from past clinical practice or the algorithm to develop a novel solution is insufficient to correctly diagnose the patient.

Clinicians, learners and educators need to recognise that increasing contextualised, experientially-based, clinical knowledge holds the key to enhancement of both systems of diagnostic skill. Further research is needed to validate this reformulated theory of diagnostic cognition, as well as the effectiveness of specific pedagogical approaches aimed at accelerating the development of diagnostic expertise of physicians in training.

AUTHOR CONTRIBUTIONS

All authors have jointly discussed about the structure and content of the article. Thierry Pelaccia and Jonathan Sherbino wrote a first version of the article, which was critically reviewed by the other team members. Geoff Norman wrote a revised version of the article. All authors approved the final version of the manuscript.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Not applicable.

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