Human Cognitive Limitations

Broad, Consistent, Clinical Application of Physiological Principles Will Require Decision Support

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Abstract

Our education system seems to fail to enable clinicians to broadly understand core physiological principles. The emphasis on reductionist science, including “omics” branches of research, has likely contributed to this decrease in understanding. Consequently, clinicians cannot be expected to consistently make clinical decisions linked to best physiological evidence. This is a large-scale problem with multiple determinants, within an even larger clinical

decision problem: the failure of clinicians to consistently link their decisions to best evidence. Clinicians, like all human decision-makers, suffer from significant cognitive limitations. Detailed context-sensitive computer protocols can generate personalized medicine instructions that are well matched to individual patient needs over time and can partially resolve this problem.

Keywords: human cognitive limitation; decision support; information overload

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André Cournand, Werner Forssmann, and Dickinson Richards received the Nobel Prize for physiological contributions that enabled the development of modern cardiology, pulmonology, and critical care. Among the seminal contributions of their group, the relationships between blood gas contents and partial pressures are prominent concepts pertinent to many important clinical decisions today (1). Therefore, I noted with dismay the absence of awareness of these concepts at two international meetings in 2016 in North America and in Asia. During the discussion periods, someone asked the audience of experts if a person at sea level with arterial oxygen pressure (P_{aO_2}) of 95 mm Hg and oxygen saturation (S_{aO_2}) of 95% could be hypoxemic. The uniform answer was “no”—not one person volunteered “reduced oxygen content (arterial oxygen concentration),” until anemia was mentioned. At that point in both meetings, the audiences

recognized the link between anemia and the consequently reduced arterial oxygen concentration. Restricting hypoxemia interpretation to S_{aO_2} or P_{aO_2} leads to a fundamental logical inconsistency. A patient with normal P_{aO_2} or S_{aO_2} and high-output heart failure due to low hemoglobin is suffering from severe hypoxemia (low arterial oxygen concentration), with end-organ (heart) failure. Restricting interpretation to a normal P_{aO_2} or S_{aO_2} indicates the patient has no hypoxemia. The logical inconsistency is: hypoxemia (low arterial oxygen concentration) = no hypoxemia (normal P_{aO_2} or S_{aO_2}), that is, “a = not a.” All three reflections of O_2 in the blood should be examined. A decrease in any one of them (P_{aO_2} , S_{aO_2} , or arterial oxygen concentration) indicates hypoxemia.

These two experiences represent particular examples of a large-scale problem—the failure of our educational

systems to enable broad understanding among clinicians of core physiological principles (2). The emphasis of the past several decades on reductionist science, including the various “omics” branches of research, has likely contributed to a decrease in understanding of basic applied physiology concepts. Some academic institutions have, like my own, eliminated their departments of physiology. This educational system failure suggests that clinicians cannot be expected to consistently make clinical decisions linked to best physiological evidence—a large-scale problem with multiple determinants (*vide infra*) that will likely be at least partially resolved by application of detailed computer protocols that include sound physiological logic (3). The current apparent de-emphasis of core physiological principles seems part of a larger clinical decision problem—the failure of clinicians to consistently link their decisions to best evidence (4, 5).

Clinicians do not consistently apply care on the basis of best evidence. For example, critical care clinicians do not currently consistently apply the widely acknowledged life-saving potential of mechanical ventilation to patients with acute lung injury (6) 16 years after a landmark publication (7). Cardiologists do not consistently apply evidence-based treatments for heart failure clinic patients who seem to be appropriate candidates (8). In fact, clinicians' opinions frequently poorly reflect their actual performance. This is a widespread human shortcoming (9). Humans commonly overestimate their performance (9–11). In addition, clinicians fail to perform at desired levels, when assessing data quantitatively. For example, a clear pulmonary artery balloon occlusion pressure tracing was correctly interpreted by expert nurses and physicians only one-half of the time (12–14). Even when clinicians are absolutely certain, their estimation of outcome is imperfect. Sixteen percent of patients in intensive care units, believed by all treating clinicians to be unable to survive their intensive care unit stay, actually survived (15). Similar results were encountered in the Ibuprofen in Sepsis Study when moribund patients, unequivocally expected to die, were excluded from enrollment in the study (16). Thirteen percent of these excluded patients survived (personal written communication, G. Bernard, 2012).

Our failure to link decisions with best evidence is due in part to cognitive limitations of human decision-makers, including, clinician decision-makers. Human short-term or working memory was estimated to be limited to 7 ± 2 variables in the 1950s (17). A more current estimate is 4 ± 1 constructs (18). Decision quality generally becomes degraded once this limit of four constructs is exceeded (18). Because of this limitation most clinical decisions are based on one to three variables. This limitation enables us to develop rational rules for decision-making, because each decision is based on so few input variables (3). The limit of four constructs seems surprising to humans, who commonly overestimate their performance (10). However, this limit of four constructs is reflected in common behaviors. Spirometry is commonly assessed with graphical displays of two pairs of variables (volume–time and flow–volume curves). Even though the forced exhalation involves

only three variables (flow, volume, and time), we do not commonly display the three variables in a three-dimensional plot because it is too difficult for most viewers to interpret. A core physiological construct associated with flow limitation and with size and shape of multiple structures of different body systems involves only four pressures: inlet, outlet, inside, and outside. Pinlet–Poutlet is the flow-resistive pressure drop associated with conducting systems that move material from one point to another. Pinside–Poutside is the transmural pressure difference that determines size and shape of a three-dimensional body with elastic properties. These four simple pressures constitute the foundation of important physiological behaviors of conducting vessels in the vasculature, the airways, and the urogenital tract, among others. One American Physiological Society publication acknowledged the difficulty in understanding this and other core physiological principles experienced by clinical students and practitioners. The publication explored strategies for addressing this low level of understanding of core physiological principles among clinicians (2).

Detailed context-sensitive computer protocols can generate personalized medicine instructions that are well matched to individual patient needs over time (19–24). We developed the initial context-sensitive detailed computer protocols for a clinical trial of extracorporeal CO₂ removal for patients with acute respiratory distress syndrome (19). Such protocols are associated with more favorable clinical outcomes than those associated with unaided clinician decisions (20). The protocols can also serve to readily translate research results into clinical practice (23). The feasibility of developing, validating, and implementing such protocols is no longer in question. However, still unanswered are important questions concerning the fraction of clinical tasks and challenges amenable to such protocol decision support, and the ability to scale implementation of such protocols across large institutions and between institutions. Widespread application would likely be an effective means of ensuring continuous quality improvement and achieving a learning health care system. It would also be a means of incorporating physiological information for both decision-making and educational purposes. This could

enable broad distribution of the important physiological contributions of Cournand, Richards, Riley, and colleagues to a community of clinicians.

To explore one source of clinician information overload, I counted the number of variable categories for an intensive care unit patient supported with mechanical ventilation. I limited the count to those variables easily identified in the medical record, and ignored doctors' notes, nurses' notes, therapists' notes, consultants' notes, all imaging and pathology reports, and other sources of information. I counted 236 variable categories being considered by the intensive care unit clinicians. Decisions about sepsis-induced acute respiratory distress syndrome might, for example, involve multiple mechanical ventilation, arterial oxygenation, circulatory, renal, pharmacological, and intravenous infusion variables, in addition to multiple consultant suggestions. Although information overload of clinicians has been recognized for over a century (25, 26), many perceive that medicine always required doctors to handle enormous amounts of data and that the ability to manage complexity sets good doctors apart from the rest (27). It seems correct, on face value, that having a greater ability to handle multiple items in short-term or working memory will contribute to superior performance. Working memory capacity accounts for a large component (one-third to one-half) of general intelligence (28). Nevertheless, the working memory capacity of even those clinicians with superior performance is very small relative to the number of variables faced by clinical decision-makers in common complex clinical settings. Even the best clinicians make errors and perform inconsistently (4).

If patient outcomes were uninfluenced by variations in clinician decision-making, the aforementioned observations would be unimportant. However, medical error is estimated by the Institute of Medicine to be responsible for more deaths than are produced by many feared disease or injury categories (5). More recent estimates are even higher (29), with one report estimating medical error to be the third leading cause of death in the United States (30). To make matters worse, the Institute of Medicine estimates that one-third of our \$3 trillion national health care expenditure is disbursed for unnecessary or

ineffective care. That is an expenditure of about \$1 trillion, or about 1.4 times our total national defense budget. Efforts to reduce or eliminate unwarranted variation in care should, therefore, be a national priority (31, 32). In fact, it is the object of a number of business process strategies, intended to ameliorate this set of problems and challenges (33). Unfortunately, the widely applied business process strategies that include continuous quality improvement, total quality improvement, zero patient harm, Six Sigma, and others do not embrace the core problem of supporting and unburdening the cognitively limited clinician decision-maker. They therefore fail to address a core problem in health care: clinician decision-makers are a major determinant of health care expenditures. One might suspect the problems under discussion would be ameliorated by establishing an integrated system with a single payer (we do not have an integrated health care system in the United States). Of note is a report from the Canadian Institute for Health Information indicating a similar (about 30%) expenditure for inappropriate care in the single-payer Canadian health care system (34, 35). Thus, the health care system organization and payment structure does not appear to be the determining factor. This similarity of performance of the U.S. and Canadian systems regarding inappropriate health care expenditure is consistent with the interpretation that the core problem rests with clinician decision-makers. Yet, I know of no systematic program directed at exploring the rigorous scientific application of detailed computer protocols that could unburden

information-overloaded clinicians, induce consistent decisions linked to evidence, ensure consistent application of sound physiological principles, and even automatically control devices such as mechanical ventilators or extracorporeal renal replacement machines. The fraction of clinical decision-making amenable to closed-loop (automatic) control or open-loop control (a clinician reviews and accepts or declines an instruction) remains unexplored.

I wonder why the extensive physiological modeling of the human body is not embraced widely in such protocols in a systematic national effort, since it seems feasible to do so (19, 20, 24, 36–39). Given the de-emphasis of physiology training for clinicians and the low level of understanding of physiological core principles (2), this seems a logical step for the clinical and physiology communities. However, a systematic effort would require decisions by multiple leaderships, and funding from national agencies. I do not see evidence that this will be forthcoming in the near future. It would require recognition of human cognitive limitations, acceptance of the necessity to pursue physiologically strong decision support for clinical research and clinical care purposes, and restructuring of the retention and promotion infrastructure in academia to enable interested young physicians to take leading roles in this effort. Young physicians supervising the curation of a detailed computer protocol that provides personalized clinical instructions might, I suspect, have few publications per year, relative to their counterparts in reductionist

science laboratories. Curation would likely require monitoring the literature with attention to all related publications; revising logic when new information so indicates; testing, *in silico*, the new logic against validated input data and protocol outputs; reviewing the revised protocol with an appropriate small group of experts; testing and validating revised protocol safety in a clinical environment that can function as a human clinical outcomes laboratory; and finally publishing the revision, replacing extant web copies of the previous version. This is a big commitment that would require assured funding and a major cultural change in the health care community. Central to this cultural change would be a recognition that our health care goals will not likely be reached by continued insistence on the Hippocratic (unaided expert, authoritarian) clinician model. Rather, although we will continue to need experts, those experts should be aided by detailed computer protocols that embrace core physiological constructs and deliver personalized clinical instructions. These protocols could provide effective continuing medical education by reflecting the logic and physiological constructs contained in the protocol rules, at the opportune time for education—when the clinician decision-maker inquires about a protocol instruction. Such education could bring the physiological contributions of Courmand, Richards, and colleagues directly to clinical decision-makers within the broad health care community. ■

Author disclosures are available with the text of this article at www.atsjournals.org.

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