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@ciminoj

Scientific Hypothesis Generation in Clinical Research: Cognition, Visualization, and Evaluation

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Director, Informatics Institute

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Hypothesis:

A tentative assumption made in order to draw out and test its logical or empirical consequences typically based on an unexplained observation or desired outcome.

* Adapted from:

https://www.merriam-webster.com/dictionary/hypothesis

Two Models of Hypotheses

- Causation-based: explanation for observation or process to achieve outcome
- Correlation-based: statistically significant association of two observations implies some causal process

Role of Data Visualization in Hypothesis Generation

- Data visualization can produce discernable patterns that can trigger inferences about the world
- Identifying explicit independent and possibly dependent variables allows formulation of testable hypotheses
- The cognitive processes behind causal reasoning varies with expertise and experience
- Data visualization tools have the potential to guide cognition
- This panel will explore the cognitive barriers to and facilitators of successful data-driven hypothesis generation

Panelists

- Vimla L. Patel, PhD – *Cognitive Studies in Medicine and Public Health, The New York Academy of Medicine*
  - Hypothesis generation and medical cognition
- Xia Jing, PhD – *Department of Public Health Sciences, College of Behavioral, Social, and Health sciences, Clemson University*
  - Data visualization and its role in hypothesis generation
- Andrew Georgiou, PhD –*Centre for Health Systems & Safety Research, Australian Institute of Health Innovation, Macquarie University*
  - Evaluation, implications and broader impacts

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@VimlaLPatel

Hypothesis Generation and Medical Cognition

Vimla L Patel

Senior Research Scientist

Cognitive Studies in Medicine and Public Health
The New York Academy of Medicine, NY, USA

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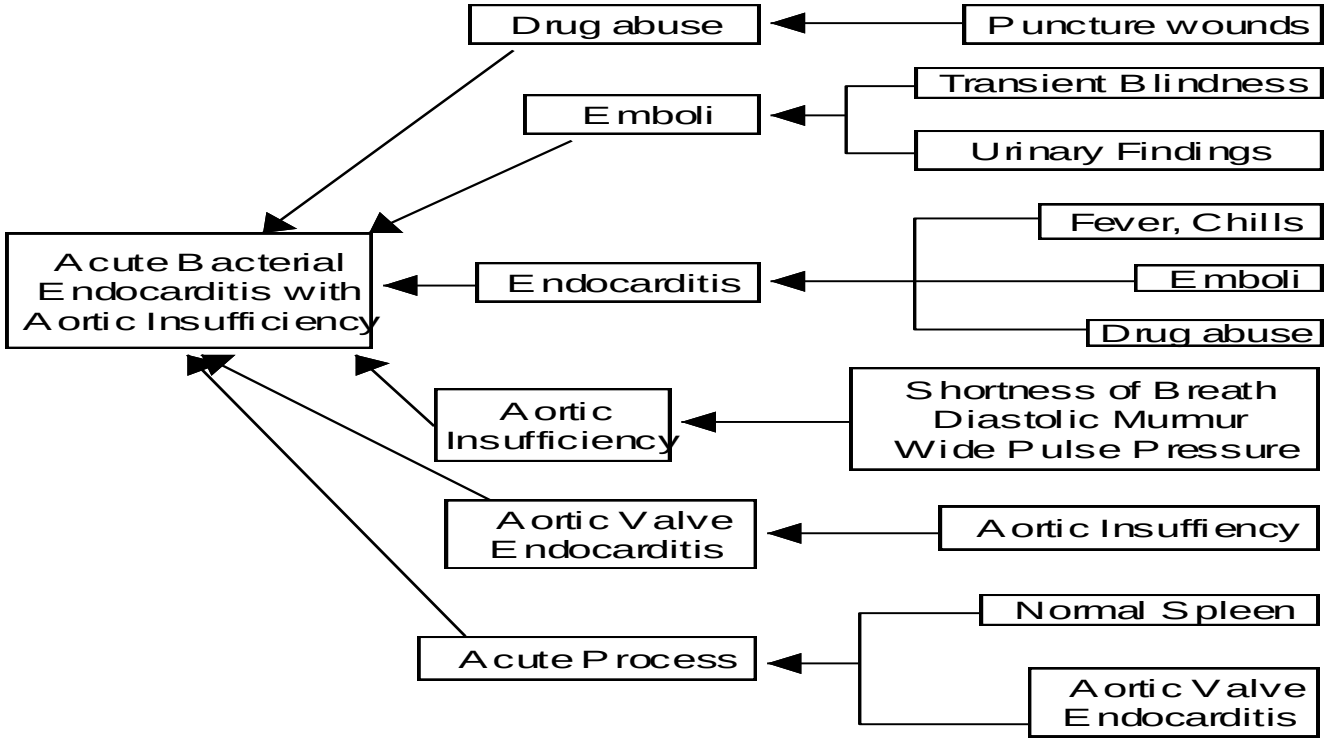
Medical diagnosis is art as well as science

- Medical training:
  - Basic and Clinical science
  - Clinical practice
- Process of generation of diagnostic hypotheses
  - Experts
  - Novices –Trainees

Patel, V.L., Evans, D.A. & Groen, G.J. (1989) On reconciling basic science and clinical reasoning. *Teaching & Learning in Medicine: An International Journal, 1(3),* 116-121.

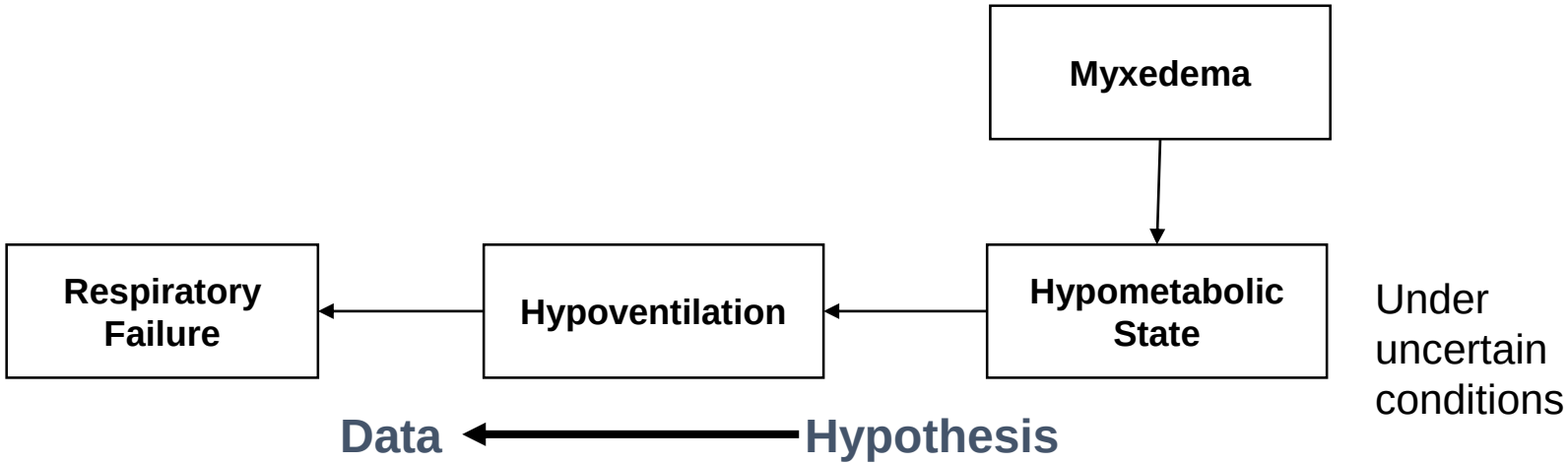
Expert clinicians during practice:

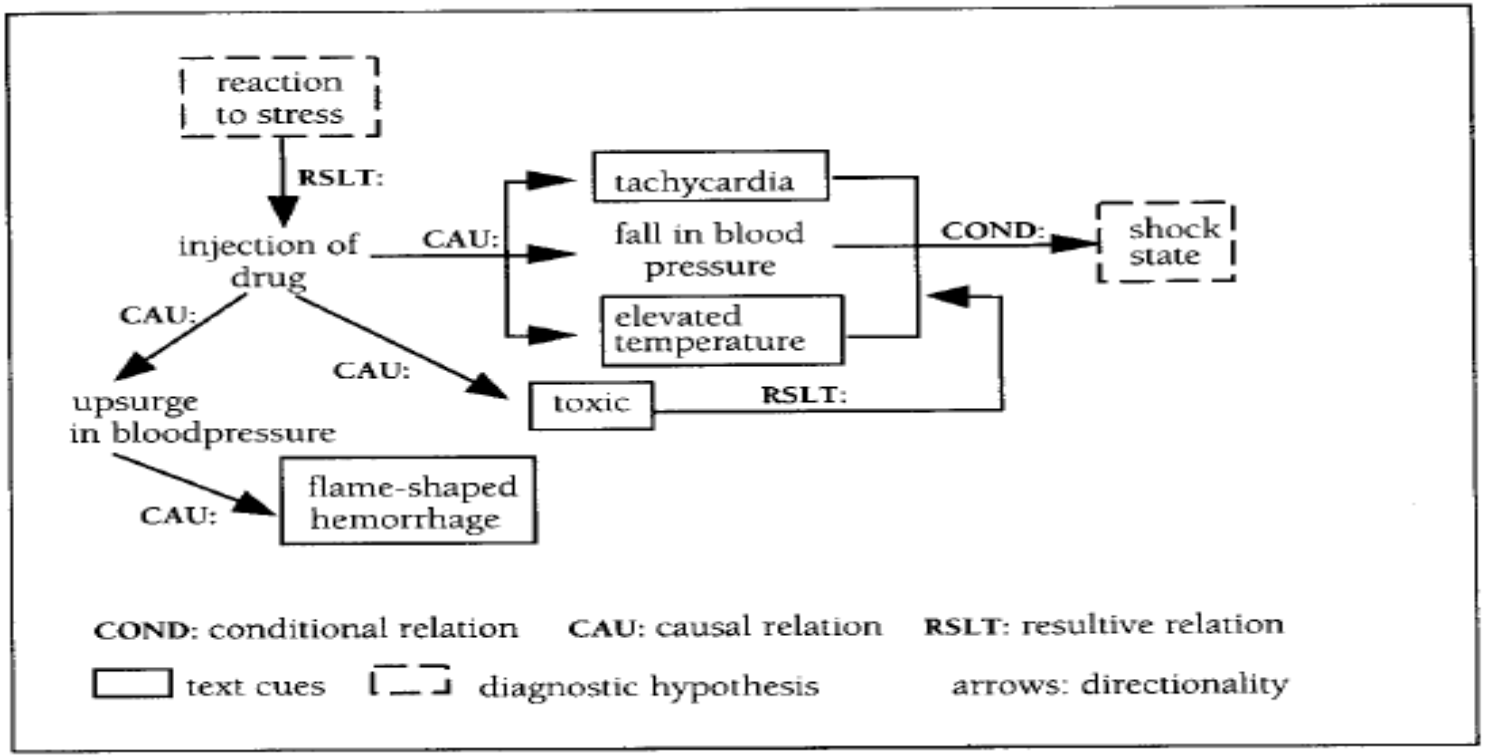
- Use of heuristics with well organized clinical knowledge
- Do not use detailed scientific information during practice
  Details interfere with utility (performance)
- When uncertain, they fall back on clinical science
- Generation of new knowledge through scientific investigation that feedback into clinical practice



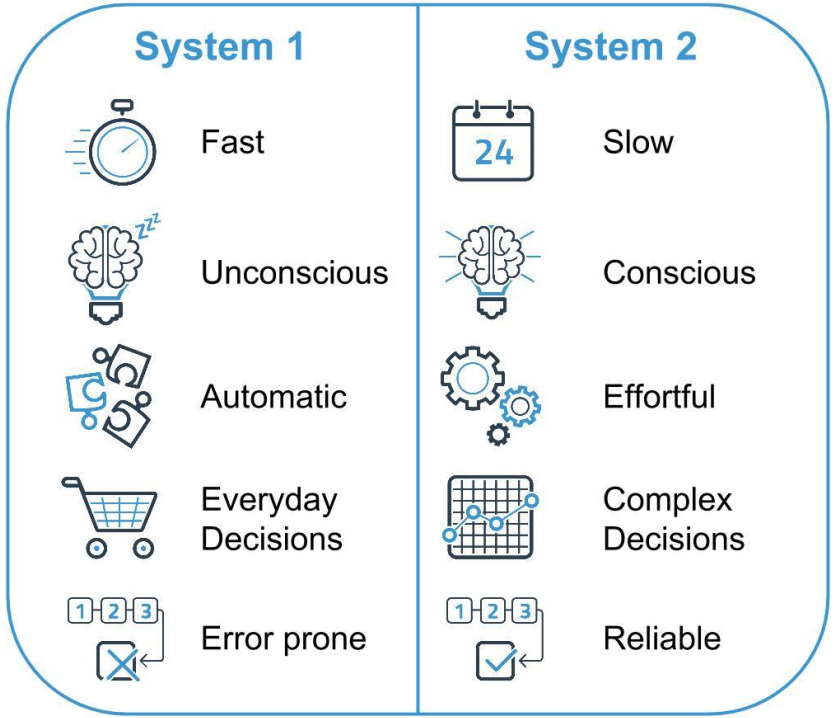
Expert: From Data to Hypothesis with Well-Organized Knowledge

Elderly woman presents with signs of myxedema. She also presents with respiratory failure, which is not normally seen in patients with myxedema




reaction to stress
RSLT:
injection of drug
CAU:
tachycardia
fall in blood pressure
elevated temperature
COND:
shock state
CAU:
CAU:
upsurge in bloodpressure
toxic
RSLT:
CAU:
flame-shaped hemorrhage
COND: conditional relation
CAU: causal relation
RSLT: resultive relation
text cues
diagnostic hypothesis
arrows: directionality

Psychologists recognize that there are two major mechanisms of reasoning, each of which relates to a different approach to problem solving



Daniel Kahneman characterized two Systems in the Brain: System 1 and System 2

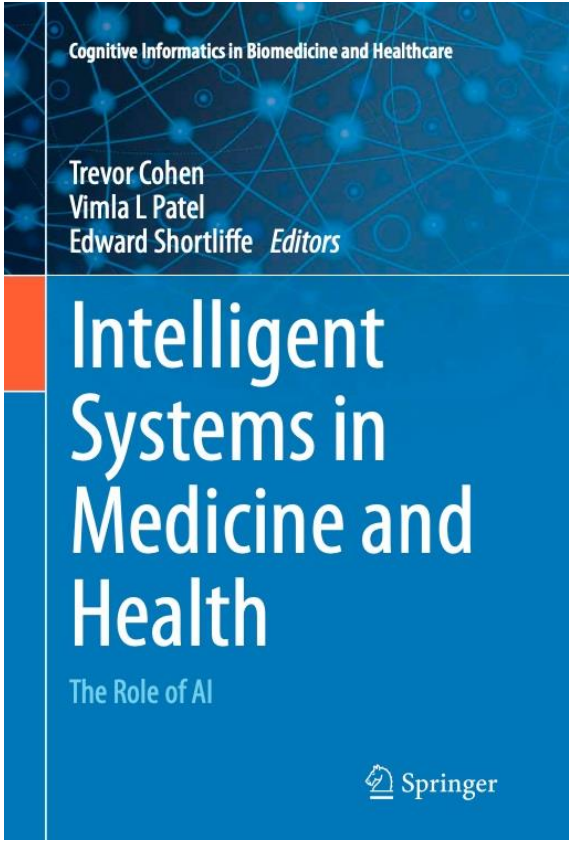
Kahneman D. Thinking, Fast and Slow. New York: Farrar, Straus and Girous (1st edition), 2013.

What are the implications for the cognitive processes used in hypothesis generation?

- Expert clinicians, when asked to explain or justify, use little causal reasoning
  - They provide a minimal justification, based on clinical indicators, not causes: System 1
  - The pattern changes if they are are unsure or uncertain, generating elaborate explanations or showing signs of depth: System 2
- One mechanism is used in routine clinical practice and the other in providing scientific explanation
- In complex clinical practice both mechanisms are used

Clinical cognition and data visualization

- Large volume and complexity of clinical data
  - difficult for our brains to comprehend and process
  - accordingly tends to be time-consuming
- Data visualization tools can help human cognition
  - accelerating data perception through visual presentation
  - reducing cognitive load
- These tools should be well-designed, guided by how human beings think and reason, to support clinicians



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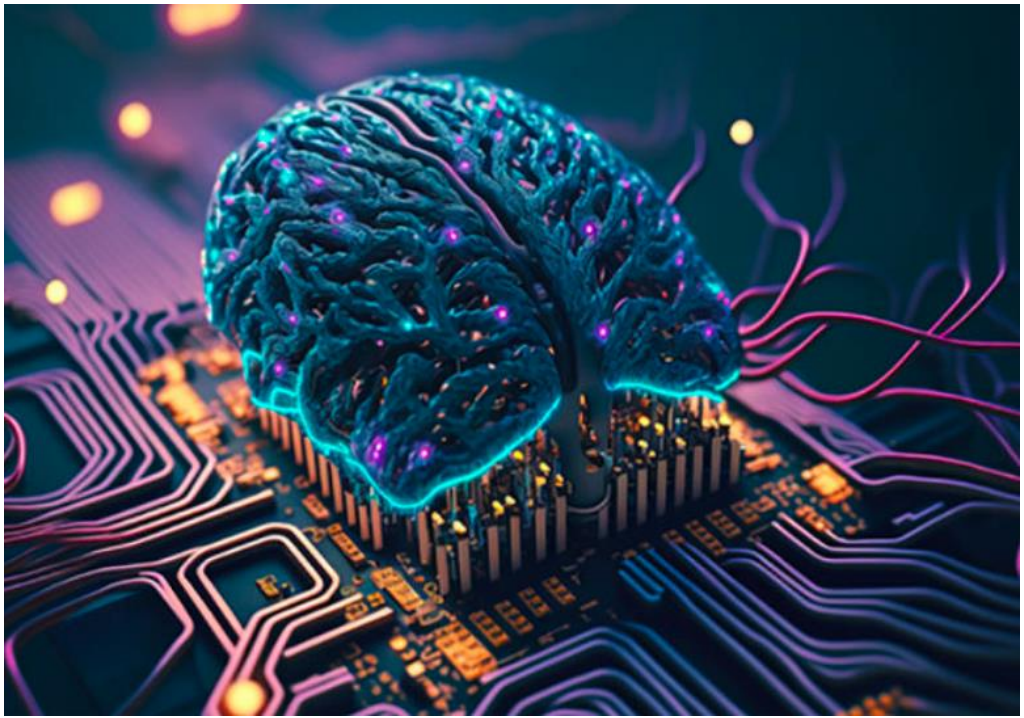

THANK YOU

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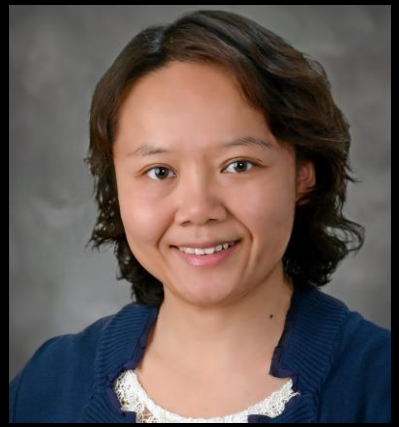

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Data visualization & hypothesis generation

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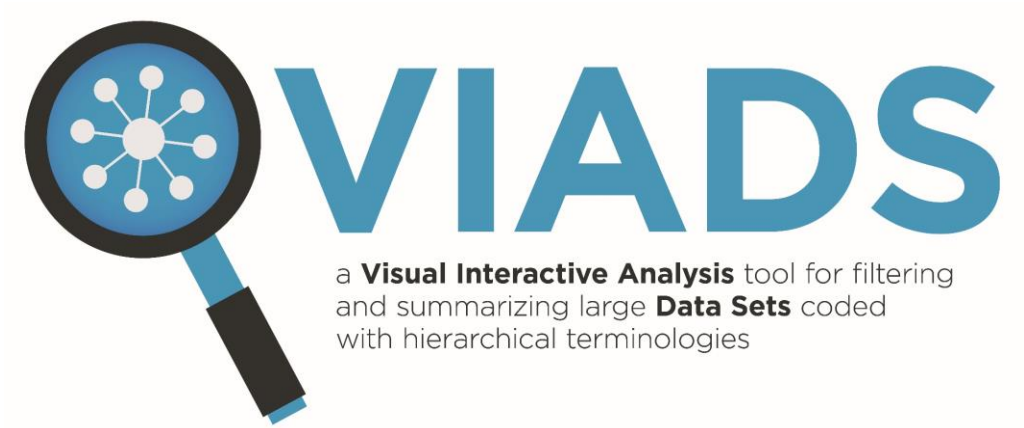
Roles of data visualization

- In daily life
- In healthcare
- In clinical research
- In scientific hypothesis generation
    - While using data visualization

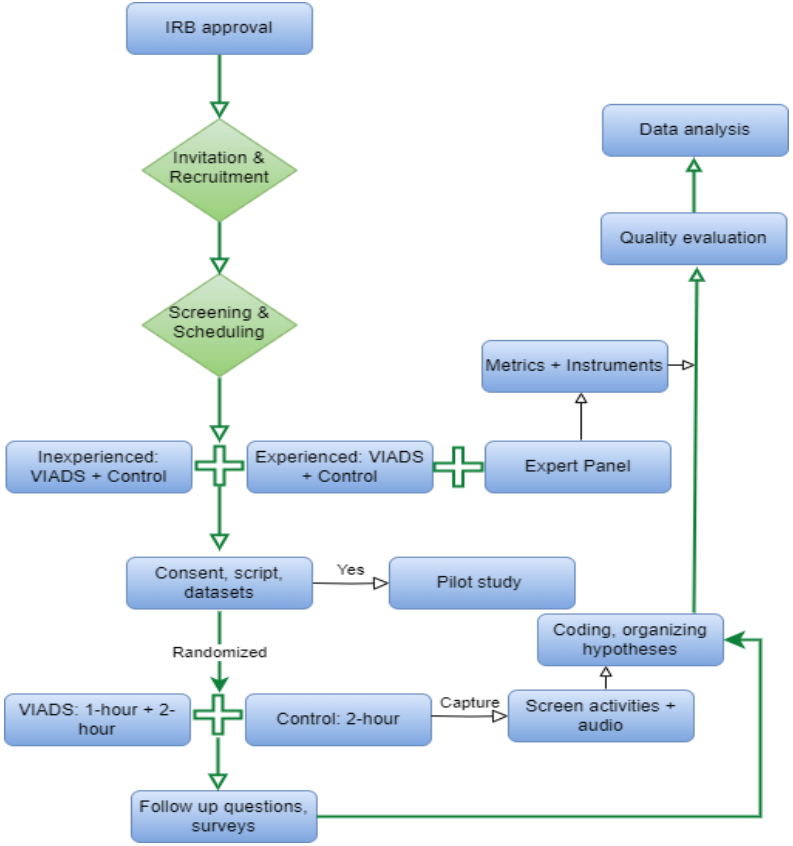
Our study

- VIADS
  - A visual interactive analytic tool for filtering and summarizing large health data sets coded with hierarchical terminologies

- www.viads.info



Study flow


IRB approval
Invitation & Recruitment
Screening & Scheduling
Inexperienced: VIADS + Control
Experienced: VIADS + Control
Expert Panel
Metrics + Instruments
Data analysis
Quality evaluation
Consent, script, datasets
Yes
Pilot study
Randomized
VIADS: 1-hour + 2-hour
Control: 2-hour
Capture
Screen activities + audio
Coding, organizing hypotheses
Follow up questions, surveys

Results

- 20
- 18
- 15
- 7 + 8
- 1-19
- 227
- 279 s versus 358 s

Results

- Quality of hypotheses (junior, valid only)
  - Validity: 2.79 versus 2.85
  - Significance: 3.14 versus 3.15
  - Feasibility: 2.98 versus 3.53 *** ($p < 0.001$)
  - 121
  - 5 (full point for each dimension)
  - 7.04 to 10.55 (out of 15, all three dimensions)

Activities associated to new research ideas

- Reading
- Interactions with mentor, advisor, peer, patient, and students
  - To obtain feedback
- Clinical practice, research, and teaching
  - Observations, connection, contexts
- Conferences

Self-perceived creativity

- Number of hypotheses
- Quality rating of hypotheses
- Quality rating of individuals

- Small sample

In summary

- Visualization & hypothesis generation

- Three pillars
  - Domain knowledge, mechanisms
  - Observation, question/problem
  - Make the connections within contexts

- What is your hypothesis generation process?

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Evaluation, implications and broader impacts

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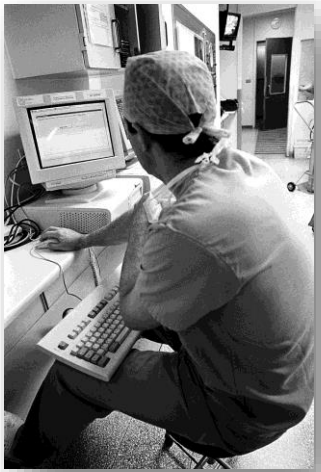
Digital health evaluation

- Evaluation and measurement of digital health tools and systems is required to demonstrate that benefits are being delivered as expected.
- Digital health systems do not work simply because they have been constructed to do so.
- They rely on people to make them work, and the conditions that are conducive to them doing so.
- Evaluation thus plays an important role in adoption, utilisation and sustainability.

Evaluation of VIADS

- Measuring the usability and utility of VIADS is possible
- Determining whether VIADs assists with Scientific Hypothesis generation is a lot more complex.
- Qualitative research can help to understand why a particular intervention or digital health tool works (or not)?



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Research and Applications

Research and Applications

Does health informatics have a replication crisis?

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ABSTRACT

Objective: Many research fields, including psychology and basic medical sciences, struggle with poor reproducibility of reported studies. Biomedical and health informatics is unlikely to be immune to these challenges. This paper explores replication in informatics and the unique challenges the discipline faces.
Methods: Narrative review of recent literature on research replication challenges.
Results: While there is growing interest in re-analysis of existing data, experimental replication studies appear uncommon in informatics. Context effects are a particular challenge as they make ensuring replication fidelity difficult, and the same intervention will never quite reproduce the same result in different settings. Replication studies take many forms, trading-off testing validity of past findings against testing generalizability. Exact and partial replication designs emphasize testing validity while quasi and conceptual studies test generalizability of an underlying model or hypothesis with different methods or in a different setting.
Conclusions: The cost of poor replication is a weakening in the quality of published research and the evidence-based foundation of health informatics. The benefits of replication include increased rigor in research, and the development of evaluation methods that distinguish the impact of context and the nonreproducibility of research. Taking replication seriously is essential if biomedical and health informatics is to be an evidence-based discipline.

Key words: evaluation, replication, evidence-based informatics, research bias

Table 1. Replication Studies Take Many Forms, Depending on the Fidelity of the Replication in Comparison to the Original, and the Hypothesis Being Tested, and Have Different Utility Depending on the Purpose of the Replication[15]

Replication study type	Example study	Utility of replication study design
Exact (or close) replication	A laboratory study of the usability of a specific CPOE system is repeated in a different laboratory using the exact same protocol and system	High fidelity replications test the validity of an earlier study
Partial replication	A clinical trial of a CPOE system is repeated using the same system in a similar clinical environment, using an identical implementation strategy, and enrolling comparable groups of patients and clinicians	Modest level fidelity replications test the validity of an earlier study when it is not possible to undertake high fidelity studies
Conceptual replication	Following a trial of a CPOE system in a clinical setting that shows mortality effects, the general hypothesis that all CPOE systems increase mortality rates is tested by using a different CPOE system, with a different implementation strategy, clinical setting and research subjects	Conceptual studies test the generalizability of past results, by sharing common hypotheses but using different clinical settings or methods
Quasi replication (partial)	To test the impact of implementation strategies on mortality rates after a particular CPOE is trialed, the same CPOE system is now tested in a comparable setting, but use a different implementation strategy	Quasi-replications seek to extend earlier experiments by including novel elements or hypotheses to build on the prior work, not just replicate it
Quasi replication (conceptual)	With evidence that CPOE use is associated with mortality changes, researchers test if this is generalizable to other system classes. They test the hypothesis that many clinical systems can affect mortality rates with an experiment using electronic health records and measuring mortality effects	The lowest fidelity form of replication, these studies help test the generality of prior results, but do not allow strong conclusions when their results conflict with earlier studies

Socio-technical systems

"…work systems delivering products or services, comprise a social system (e.g., the people, working practices and roles, culture and goals) as well as a technical system (e.g., made up of the physical infrastructure, tools and technologies) … can only be fully understood and improved if these parts are treated as interdependent elements. This is because changes to one part of the system can necessitate changes to another. " (Hughes et al. *Ergonomics* 2017)

Multi-method approaches

- Thinking out aloud asks participants to verbalise their thoughts when completing a task.
- Provides an insight into the cognitive processes involved.
- Particular methodologies and techniques are more useful for some functions than others, and so a combination of approaches may be necessary to provide a more comprehensive evaluation.