



Do Health Systems Need an Operating System?

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W.H. Duncan Professor of Public Health Systems

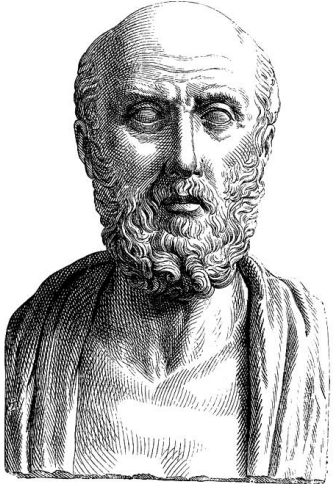
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[@profbuchan](#)

EPSRC Distributed Algorithms Centre for Doctoral Training Showcase
Liverpool, 29 November 2023

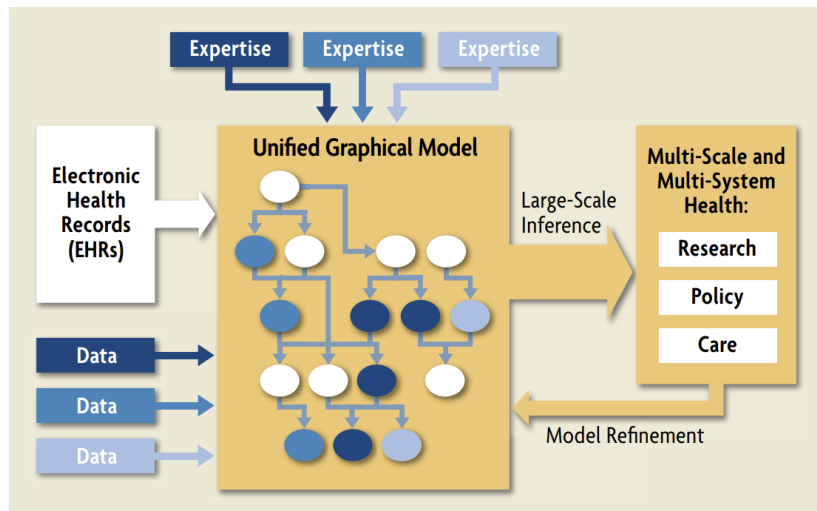
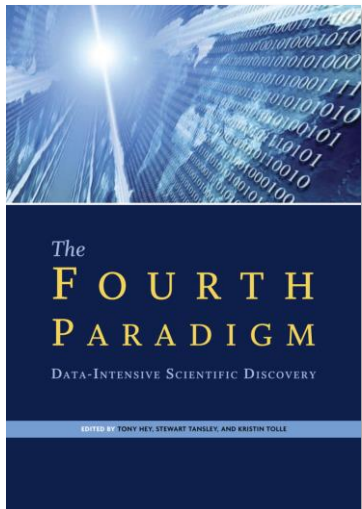
From Hippocrates to AI: Medical Paradigm(s)?



Biology not the gods cause disease

If you want to learn about the health of a population, look at the air they breathe, the water they drink, and the places where they live

Hippocrates, 5th Century BC

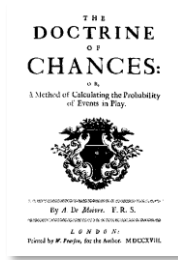
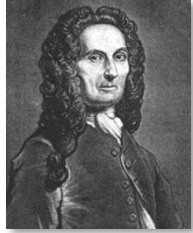


Gaps after two millennia of ‘medicine’

Unified, cross-disease understanding

Shift from records (doctor-to-doctor) to avatar (need-service broker) for personalised and preventive care

Medicine-Maths-Engineering Complex History

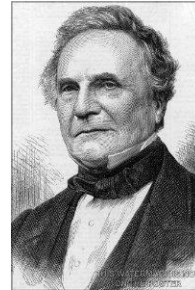


1700s: Bernoulli & DeMoivre introduce **probability theory** to quantifying (health) risks



Early 1800s: Laplace then Louis apply **probability theory to showing some treatments to be ineffective**
– rebuked by medical profession
– Quetelet's concept of 'the average man' adds fuel to the fire

Letting the data speak computationally...



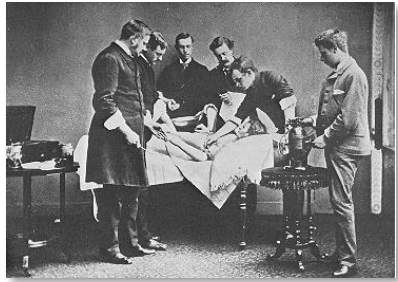
Babbage
(1791-1871)



Farr
(1807-1883)

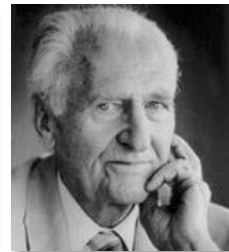
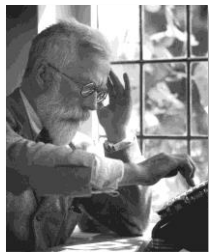
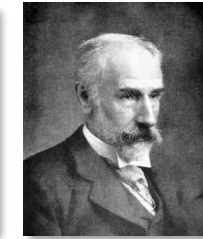
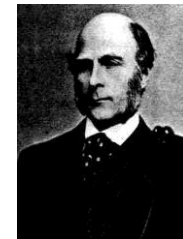
Scheutjian calculation engine used for long-division in producing life tables for the 1841 Census informing subsequent **public health reforms**

Health Data Science / Action Industrialisation



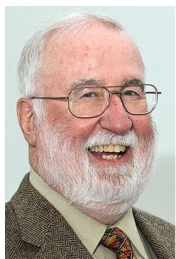
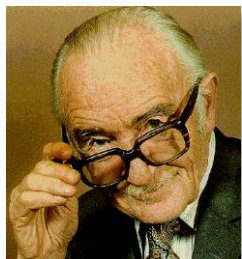
Mid-late 1800s: Lister uses **statistical arguments** and Pasteur's germ theory to **revolutionise surgery** with carbolic spray

Early 1900s: **Statistical Movement**, strong in Agriculture and emerging in Medicine

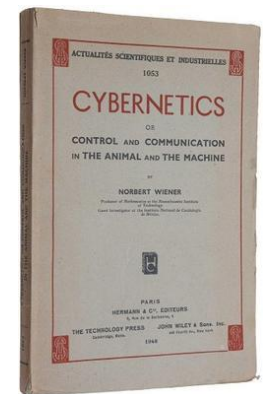


Mid 1900s: **Experimental (statistical) discipline into Medicine and NHS founded (1948)**

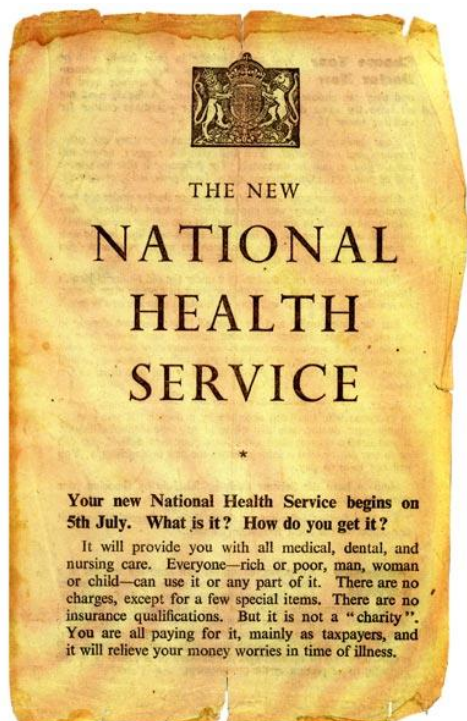
1960s-70s Cybernetic Medicine, Medical Informatics, knowledge representation basics, primitive, rule-based AIs:
Quest for automation



1970-80s onward: Disciplined implementation of **evidence into practice**



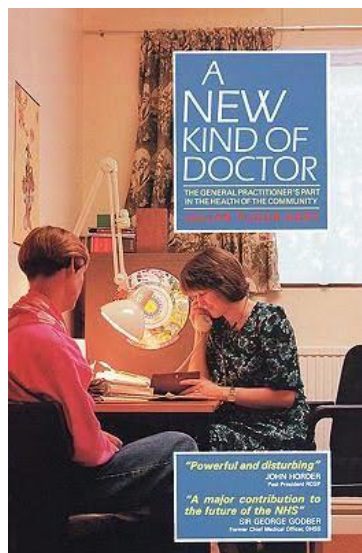
UK Spawns Coded Care Record Capture / Use



The Inverse Care Law

- The availability of good medical care tends to vary inversely with the need for the population served.

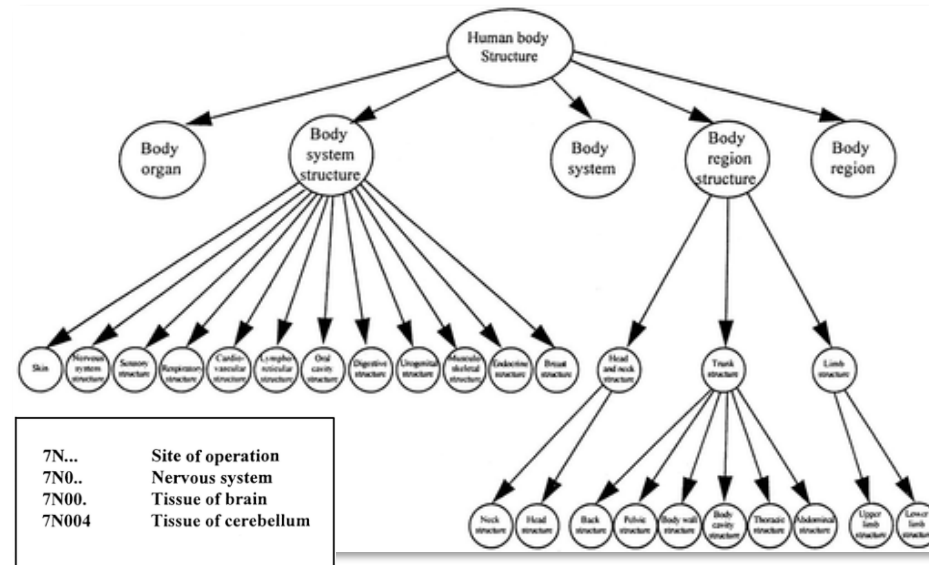
Julian Tudor Hart. The Lancet: Saturday 27 February 1971



Measure care vs need:

Constitutional duty of NHS since 1948

Four decades of GPs capturing ontologically-based codes



Schulz EB, Price C, Brown PJ. Symbolic anatomic knowledge representation in the Read Codes version 3: structure and application. J Am Med Inform Assoc. 1997 Jan-Feb;4(1):38-48.

Data to drive NHS decision-making

- Körner review 1980: standard data to compare hospitals underpinning the International Classification of Diseases
- Computers for GPs in exchange for research data in 1980s/90s
- Quality management and decision-support from 2000s...

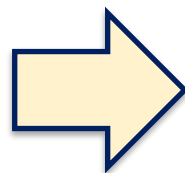
Engineering for Alert-fatigued Prescribers

4.1% NHS prescriptions contain an **error**

US estimate: **staff cost** of responding to medication **alerts 80x less** than cost of healthcare for **adverse drug effects** *

Most GPs ignore popup-alerts about drug safety: so called **alert fatigue**

GP gets an email and clicks to identify their patients



Data scientist does not see patients' identities

- [Slight SP, Seger DL, Franz C, Wong A, Bates DW. The national cost of adverse drug events resulting from inappropriate medication-related alert overrides in the United States. J Am Med Inform Assoc. 2018 Sep 1;25\(9\):1183-1188.](#)
- [Tsang JY, Peek N, Buchan I, van der Veer SN, Brown B. Systematic review and narrative synthesis of computerized audit and feedback systems in healthcare. J Am Med Inform Assoc. 2022 May 11;29\(6\):1106-1119. doi: 10.1093/jamia/ocac031](#)

Patient Safety Dashboard | Dashboard | Users | Richard Williams

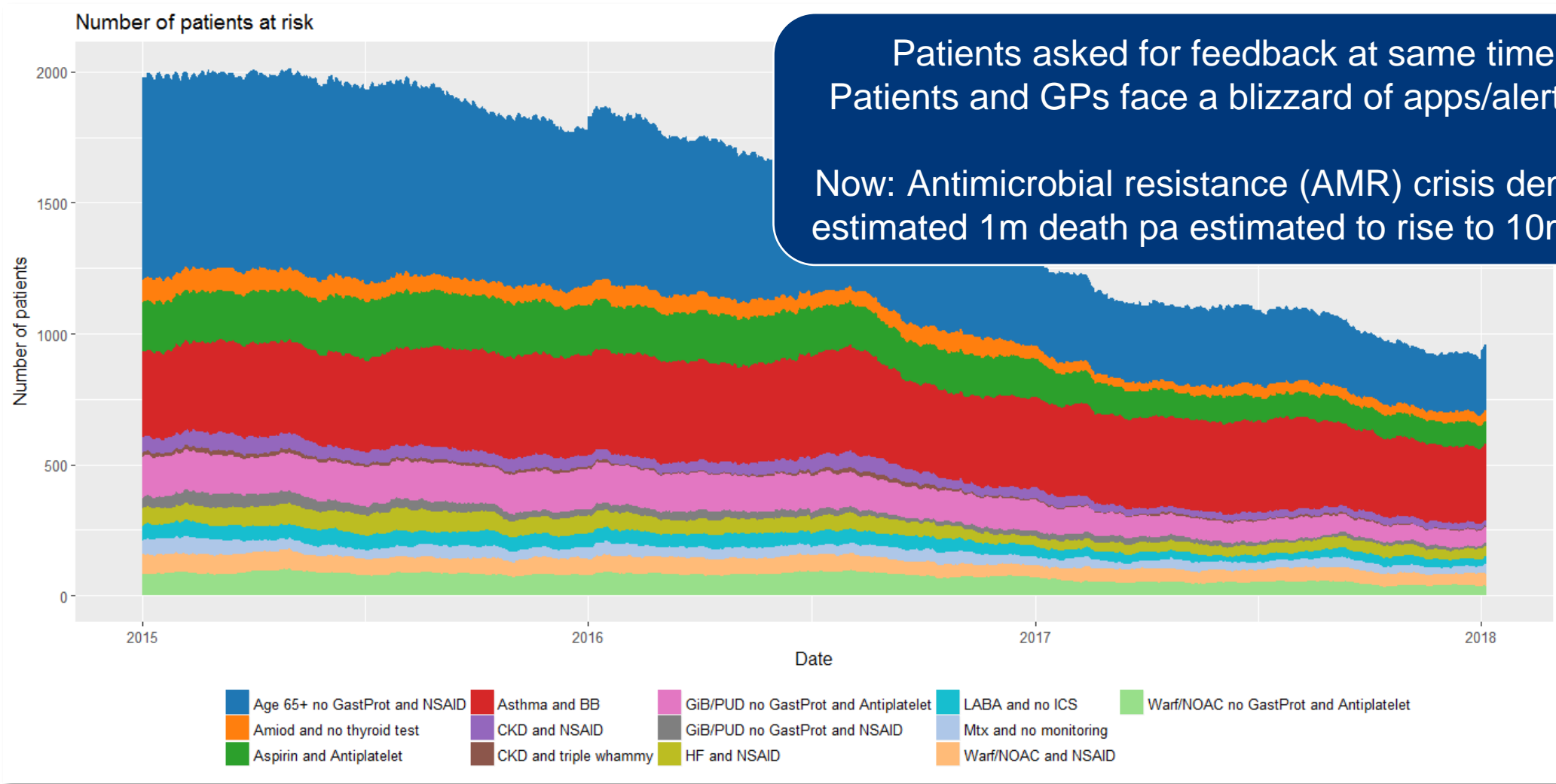
Single Practice / Glendale Medical Centre

Glendale Medical Centre | Report date: 15 Nov (Latest) | Comparison date: 16 Oct (30 days ago) | Sort by: Affected patients

Practice summary | Table | Charts | Export

Indicator	Affected patients	% of eligible patients affected	CCG Avg (%)	New cases	Trend	Show on top
Age≥65 no GastProt and NSAID	19	2.04	0.32	3	1	<input type="checkbox"/>
Mtx and no monitoring	12	11.01	2.67	2	-3	<input type="checkbox"/>
GiB/PUD no GastProt and Antiplatelet	8	6.61	2.49	1	-1	<input type="checkbox"/>
Asthma and BB	8 Click to view patients...	3.67	1.51	2	0	<input type="checkbox"/>
Aspirin and Antiplatelet	7	3.47	1.11	7	7	<input type="checkbox"/>
CKD and triple whammy	5	2.86	1.30	5	5	<input type="checkbox"/>
Warf/NOAC and NSAID	4	19.05	9.05	1	0	<input type="checkbox"/>
HF and NSAID	3	2.94	2.11	2	-2	<input type="checkbox"/>
LABA and no ICS	2	0.85	1.07	0	2	<input type="checkbox"/>
Amiod and no throid test	2	9.09	11.54	4	-3	<input type="checkbox"/>

Targeted Feedback Halved Medication Safety Issues



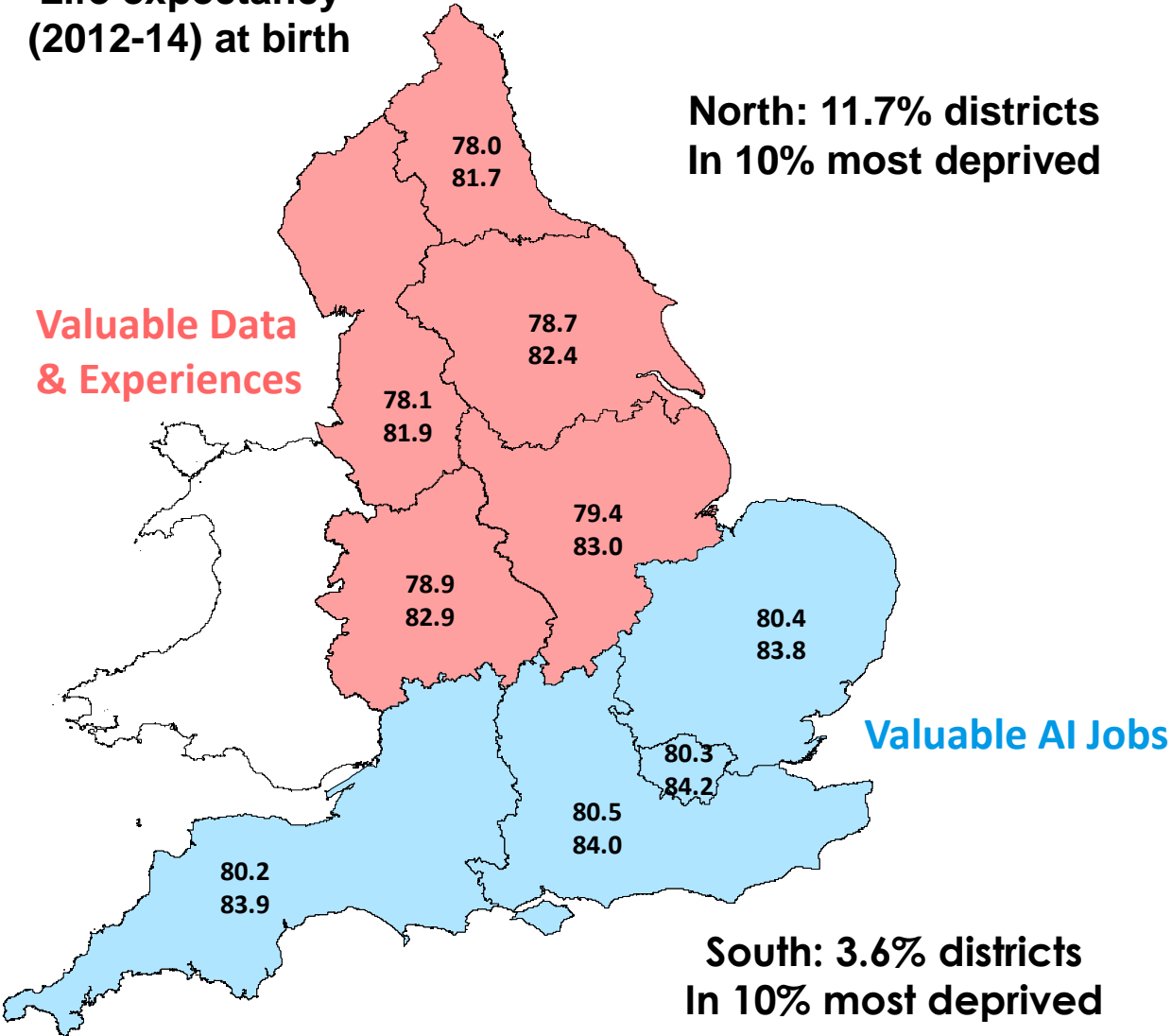
Patients asked for feedback at same time as GPs
Patients and GPs face a blizzard of apps/alerts/interfaces

Now: Antimicrobial resistance (AMR) crisis demands action
estimated 1m death pa estimated to rise to 10m pa by 2050

Pharmacist led dashboard feedback reduced harmful prescribing: <https://pubmed.ncbi.nlm.nih.gov/33048923/>
Consider GP alert fatigue and AMR: <https://pubmed.ncbi.nlm.nih.gov/36448824/>

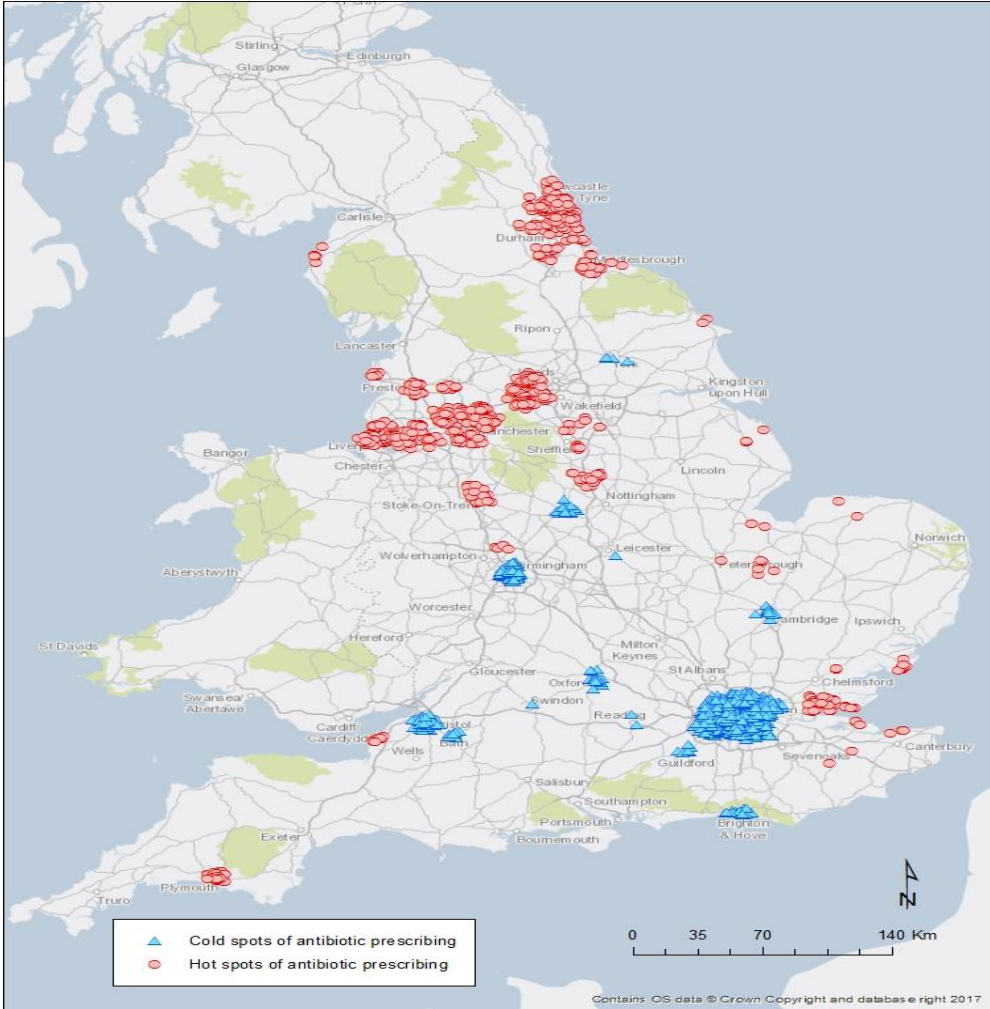
Inequalities in Mortality, Care Quality and AI Jobs

Life expectancy
(2012-14) at birth



<https://doi.org/10.1136/jech-2017-209195>

Antibiotic prescribing
hotspots (red) and cold spots (blue)



<https://doi.org/10.1016/j.healthplace.2018.07.004>

Engineering Antimicrobial Stewardship with Patients & GPs

The screenshot shows the BRIT2 Knowledge Support System interface. The title bar reads "BRIT2: KSS - Diagnosis selection". The main header is "BRIT2 Knowledge Support System" with the sub-header "Diagnosis selection". On the left, a sidebar lists navigation options: "Diagnosis selection" (highlighted), "Symptom Survey", "Summary and Risk", "Treatments", "Patient Summary", and "Patient communication". The main content area displays patient information for "Mr Edward Pugh" (DOB: 13/09/1948, 73 y/o) and a red instruction: "Select your patient diagnosis and click 'Next'". Below this, there are fields for "Infection type:", "Last KS use for patient:", "Infection type:", and "Treatment:". A dropdown menu is open, showing options: "Lower respiratory tract infection (disorder)", "Bronchitis (disorder)", "Acute bronchitis (disorder)", "Cough (finding)" (highlighted), and "Community acquired pneumonia (disorder)". At the bottom, there is a button labeled "Down to Symptom Survey" with a downward arrow icon.

- **10m deaths/year** worldwide by **2050** if do nothing
- Too **few new** antibiotics, antivirals, antifungals
- **Bugs** become **resistant** to these drugs **naturally**
- More resistant bugs are **killing more people**
- **Careless use** of antimicrobials **breeds resistance**

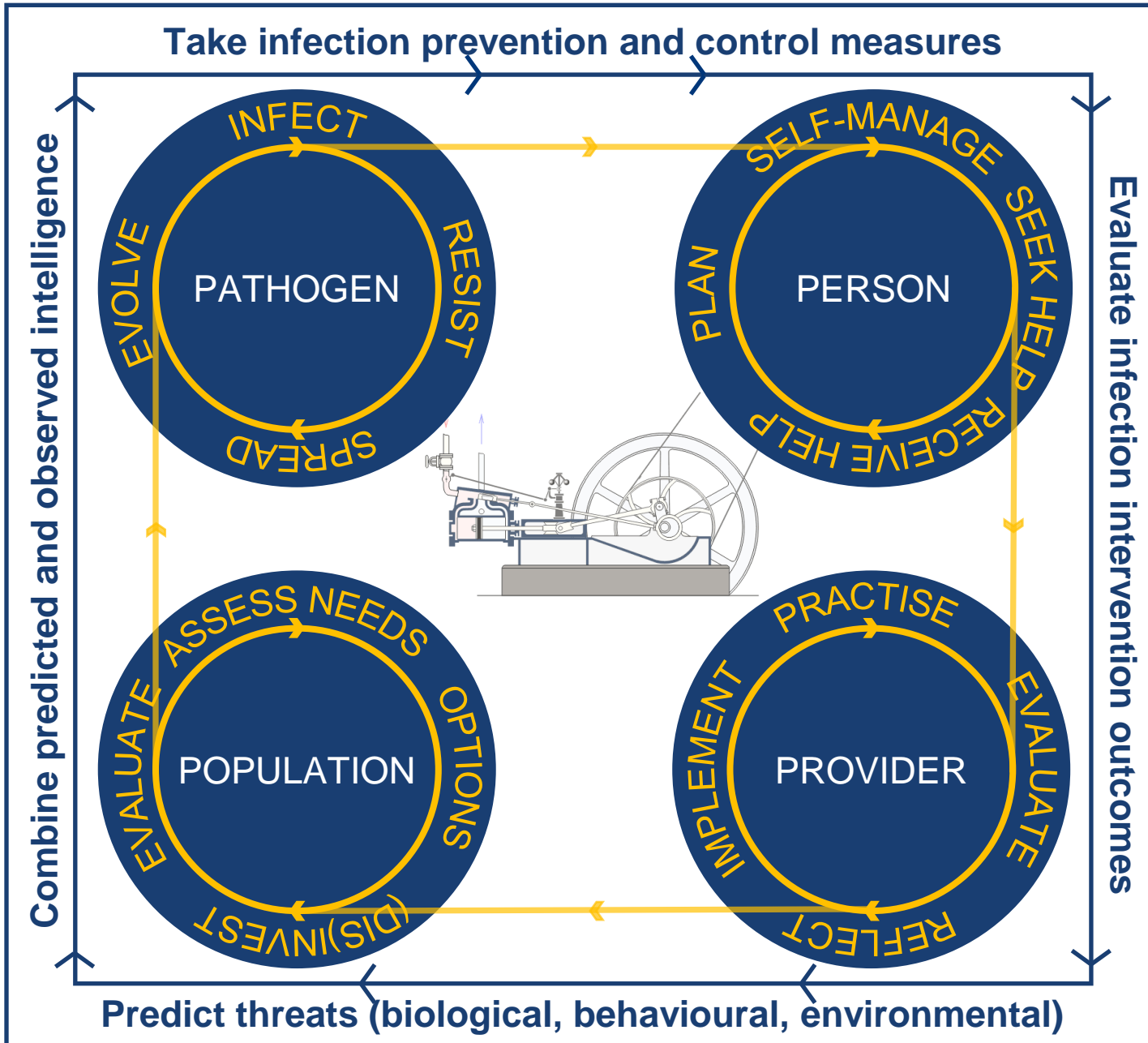
The dashboard displays information for "Infection: Sore Throat" with the note "Last antibiotic prescription: 22/08/2022". It features four risk assessment gauges:

- Risk of severe infection Complications:** A gauge with a needle pointing to the left, indicating a low risk. Below it, text reads: "Patient's risk of hospital admission for infection-related complications: XX%".
- Risk of antibiotic resistance:** A gauge with a needle pointing towards the right, indicating a higher risk. Below it, text reads: "Antibiotics received by patient in year before: XX".
- Risk of antibiotic failure:** A gauge with a needle pointing towards the right, indicating a higher risk. Below it, text reads: "Patient's risk of getting another antibiotic in next 30 days".
- Risk of severe antibiotic side-effects:** A gauge with a needle pointing towards the right, indicating a higher risk. Below it, text reads: "Patient's risk of hospital admission for antibiotic side-effect: XX%".

Navigation icons for home, refresh, and medication are visible at the top right of the dashboard.

Four large, rounded rectangular buttons are arranged in a 2x2 grid:

- Top-left: **Risk Score** (purple button)
- Top-right: **Patient Summary** (light blue button)
- Bottom-left: **Record Assist** (purple button)
- Bottom-right: **Patient Interaction** (light blue button)



Engineering better antimicrobial stewardship needs to work with nature's pathogen 'learning system'

And join up...

Population-level actions on antimicrobial restrictions and tracking resistance

Provider-level actions on rational prescribing

Person-level actions on demand for, and uses of, antimicrobials

'Civic' Public Support to Bridge the Data-Action Gap

2016 & 2022: Regional citizens' juries asked, "should the NHS be allowed to create anonymised copies of patient records for secondary use?" saw major shifts from opt-in to **opt-out consent**



“ Having listened to a number of presentations from esteemed professionals, we have collaborated as a 'Jury' to express our views on proposals to use and share personal data for the purposes of addressing this important area of public health. Put simply, it is to try and find solutions to the fact that antibiotics are becoming less effective and we need to research, fund and find new treatments and drugs for the benefit of us all. Our findings will help shape policy to address these issues. ”

Quote from Jury member

<https://civicdatacooperative.com>

2016 & 2022: Public **discontent** with **national** data-sharing initiatives, which is seldom seen locally; and **patients** now **expect data-driven services**



Controversial £360m NHS England data platform 'lined up' for Trump backer's firm

Patients will have no say over records going to Palantir, the software giant run by billionaire Republican backer





GP, Social Care Sources



Hospital Sources



Community, Public Health Sources




Patient Sources

CIVIC DATA COOPERATIVE


TRUSTWORTHY LINKAGE, PSEUDONYMISATION, CODE EXECUTION

Health system 1...

Provider Data Processing



Integrated Care System Data Processing
Linked
Pseudonymised
Part-curated data




National Data Service
Trusted Third Party

- ❖ Key management
- ❖ Deidentification
- ❖ Reidentification

Approved Tools for Dataset production
Data curation
Analysis & Simulation

Actionable Analytic/Trustworthy Research/Secure Data Environment (TRE/SDE) in national grid / federation

Dataset Extraction and Curation Pipeline
Audited Execution of Code on Data
Population Health Management Linked to Care Workflow



API

SDE Network

COMMONS
Data Catalogue
Analytic Code Books
Algorithm Library
Terminology Services
Metadata Resources
Federated Analytics

APPROACH
Open Standards
Open Development
Open Assurance
Open Maintenance
Open Innovation

COMMUNITY
Dashboard exchange
Analytic load-balancing
Shared learning resources
Predictive cooperative

Three key components for closing the data-action gap:

Spring 2019

People-to-data:

Liverpool City Region
Civic Data Cooperative

civicdatacooperative.com

Summer 2020

Data-to-analysis:

NHS/social care/public health longitudinal record for 2.6m stood up in 90 days "Combined Intelligence for Population Health Action"

cipha.nhs.uk

Autumn 2020

Analysis-to-action:

World's first universal voluntary Covid-19 rapid antigen testing



OVERSIGHT

Strategic Data Insights
Steering Group

Role-based Access



GOVERNED EXECUTION



OPEN DISCOVERY
OPEN IMPACT



CIVIC GOVERNANCE

Efficiently considering data access requests, processing agreements and monitoring data quality, curation and transferable value from innovative data processing – while driving patient, practitioner and public involvement within a region health system 'diameter of trust & actionability'

- [Ainsworth J, Buchan I. Combining Health Data Uses to Ignite Health System Learning. Methods Inf Med. 2015;54\(6\):479-87](#)
- [Buchan I, National Grid of Civic Data Cooperatives for Health in The Health of the Nation February 2020](#)
- www.liverpool.ac.uk/coronavirus/research-and-analysis/covid-smart-pilot/



Liverpool City Region
COMBINED AUTHORITY



Covid-19 Wakeup Call for Action Ready Data

Tests & Cases

All Cheshire & Merseyside (C&M) residents tested at any Pillar 2 test site and non-C&M residents tested at a C&M test site

Note: this report does not include Pillar 1 data.

Note: positivity rate calculations do not follow PHE methodology

Show Filters

Clear Filters

Filters Applied



18,274,586

Tests Completed (LFT+PCR)

2,439,026

Individuals Tested (LFT+PCR)

803,196

Individuals Tested Positive (LFT+PCR)

3.22%

LFT Case Positivity Rate (Asymptomatic)

15.04%

PCR Case Positivity Rate (Symptomatic)

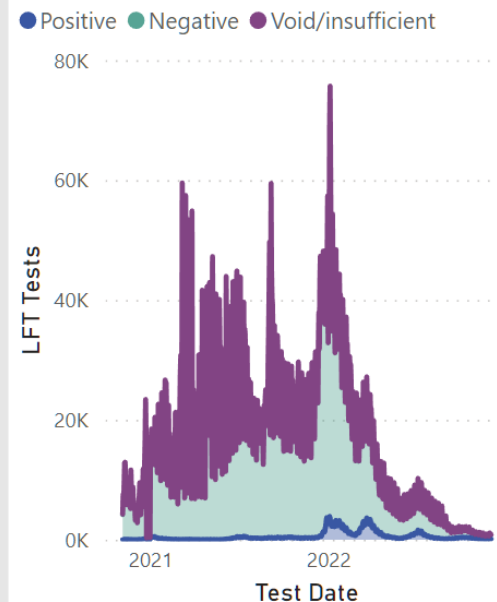
TEST COUNTS

Test Kit	Tests Completed	Positive Tests	Negative Tests	Void / Insufficient Tests
▲	406,360	21,834	369,056	15,470
LFT	13,394,612	430,575	12,948,537	15,500
PCR	4,473,614	659,790	3,726,918	86,906
Total	18,274,586	1,112,199	17,044,511	117,876

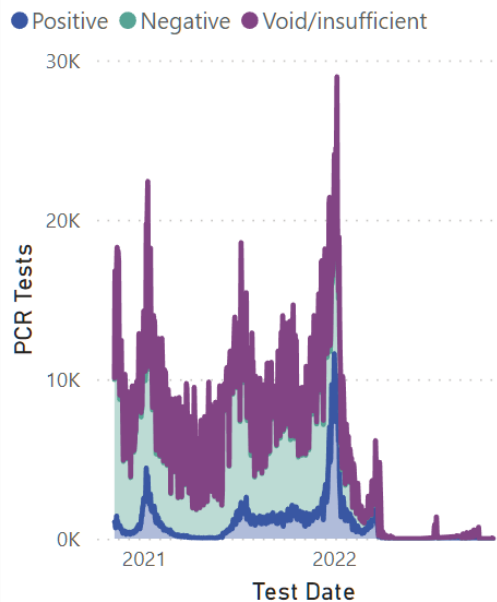
INDIVIDUALS TESTED POSITIVE

Test Kit	Individuals Tested	Individuals Tested Positive	Case Positivity Rate (Individuals)
▲	115,833	21,137	5.59%
LFT	1,666,102	315,295	3.22%
PCR	1,585,738	610,445	15.04%
Total	2,439,026	803,196	6.13%

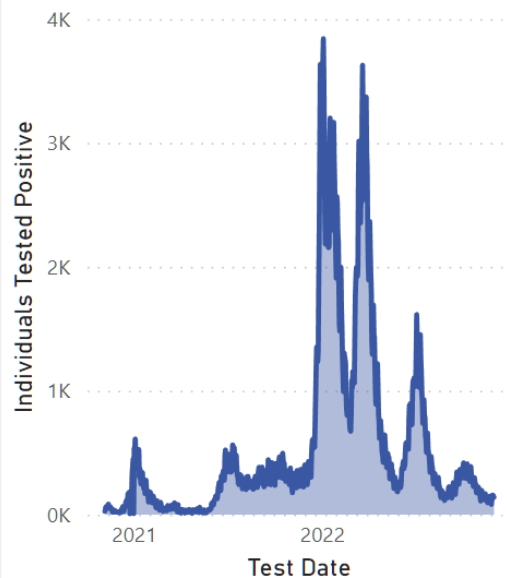
TESTS OVER TIME: LFT



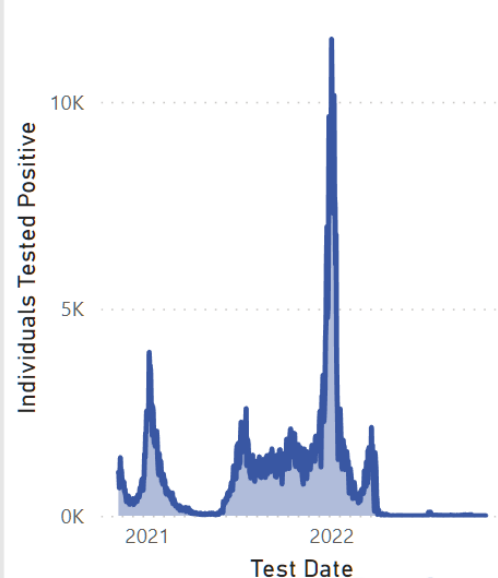
TESTS OVER TIME: PCR



INDIVIDUALS TESTED POSITIVE OVER TIME: LFT



INDIVIDUALS TESTED POSITIVE OVER TIME: PCR



Near real-time covid testing data for 2.7m people of Cheshire & Merseyside

Linked to GP and partial hospital and social care records

Dashboards for care, planning and research

Liverpool October 2020

- COVID-19 **deaths** surge
- One of most **deprived** parts of UK
Third of children born in poverty
- **Job-losses** surge from
COVID-19 restrictions
- Visitors, hospitality and events
form **half** of Liverpool's **economy**
- **Lockdowns** a public health hazard
as well as SARS-CoV-2



The screenshot shows the ECHO Liverpool website. The header is red with the ECHO logo and a swan icon. Navigation links include NEWS, IN YOUR AREA, LIVERPOOL FC, EVERTON FC, WHAT'S ON, CELEBS, SPORT, and SPECIAL FEATURES. The main article headline is "Liverpool NHS Trust has highest number of coronavirus patients in the whole of England". The sub-headline reads: "Admissions of people with coronavirus are approaching the peak levels of last spring, city hospitals boss has warned". The article is by Luke Traynor (Chief Reporter) and Liam Thorp, dated 10:41, 10 OCT 2020. Social sharing icons for Facebook, Twitter, and LinkedIn are visible, along with a comment count of 9.

ECHO 

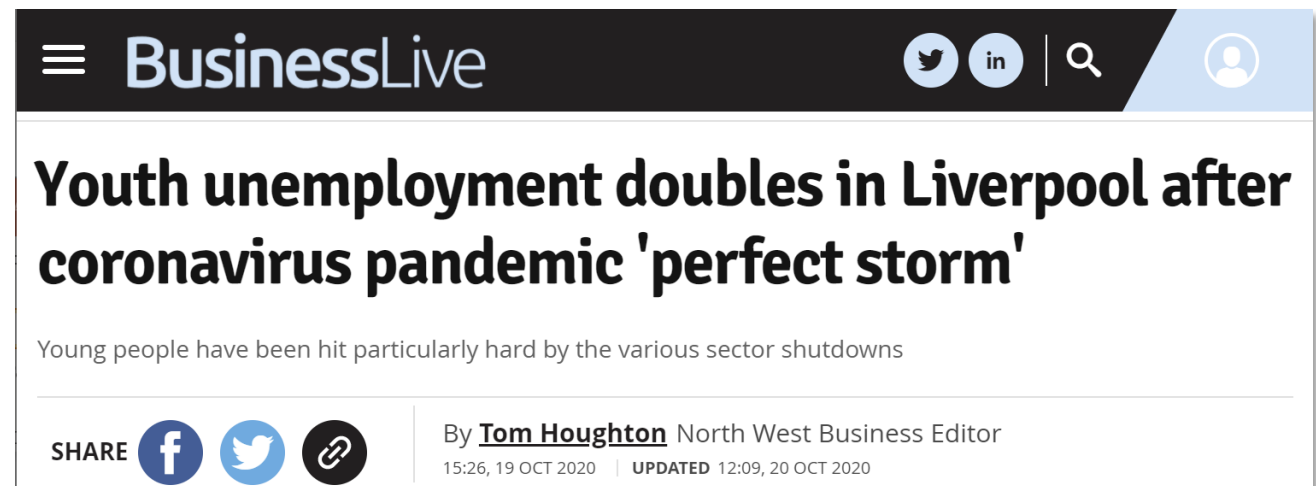
SIGN UP TO RECEIVE LIVERPOOL OR EVERTON EMAILS AND GET A FREE PRE SEASON GUIDE **ECHO** 

NEWS IN YOUR AREA LIVERPOOL FC EVERTON FC WHAT'S ON CELEBS SPORT SPECIAL FEATURES

Liverpool NHS Trust has highest number of coronavirus patients in the whole of England

Admissions of people with coronavirus are approaching the peak levels of last spring, city hospitals boss has warned

SHARE    |  9 COMMENTS By [Luke Traynor](#) Chief Reporter & [Liam Thorp](#)
10:41, 10 OCT 2020






The screenshot shows the BusinessLive website. The header is dark grey with the BusinessLive logo. Navigation links include a search icon and a user profile icon. The main article headline is "Youth unemployment doubles in Liverpool after coronavirus pandemic 'perfect storm'". The sub-headline reads: "Young people have been hit particularly hard by the various sector shutdowns". The article is by Tom Houghton (North West Business Editor), dated 15:26, 19 OCT 2020, and updated at 12:09, 20 OCT 2020. Social sharing icons for Facebook, Twitter, and LinkedIn are visible.

BusinessLive

Youth unemployment doubles in Liverpool after coronavirus pandemic 'perfect storm'

Young people have been hit particularly hard by the various sector shutdowns

SHARE    By [Tom Houghton](#) North West Business Editor
15:26, 19 OCT 2020 | UPDATED 12:09, 20 OCT 2020

Liverpool November 2020: Rapid Testing Pilot Impactful

- World's **first city-wide pilot** of testing for people without COVID symptoms to save lives and livelihoods
- **Quarter** of population **volunteered** in a month despite external media negativity
- **Case detection increased** by a fifth
- **Known case rate fell** by a fifth
- **Hospitalisation fell** by a quarter

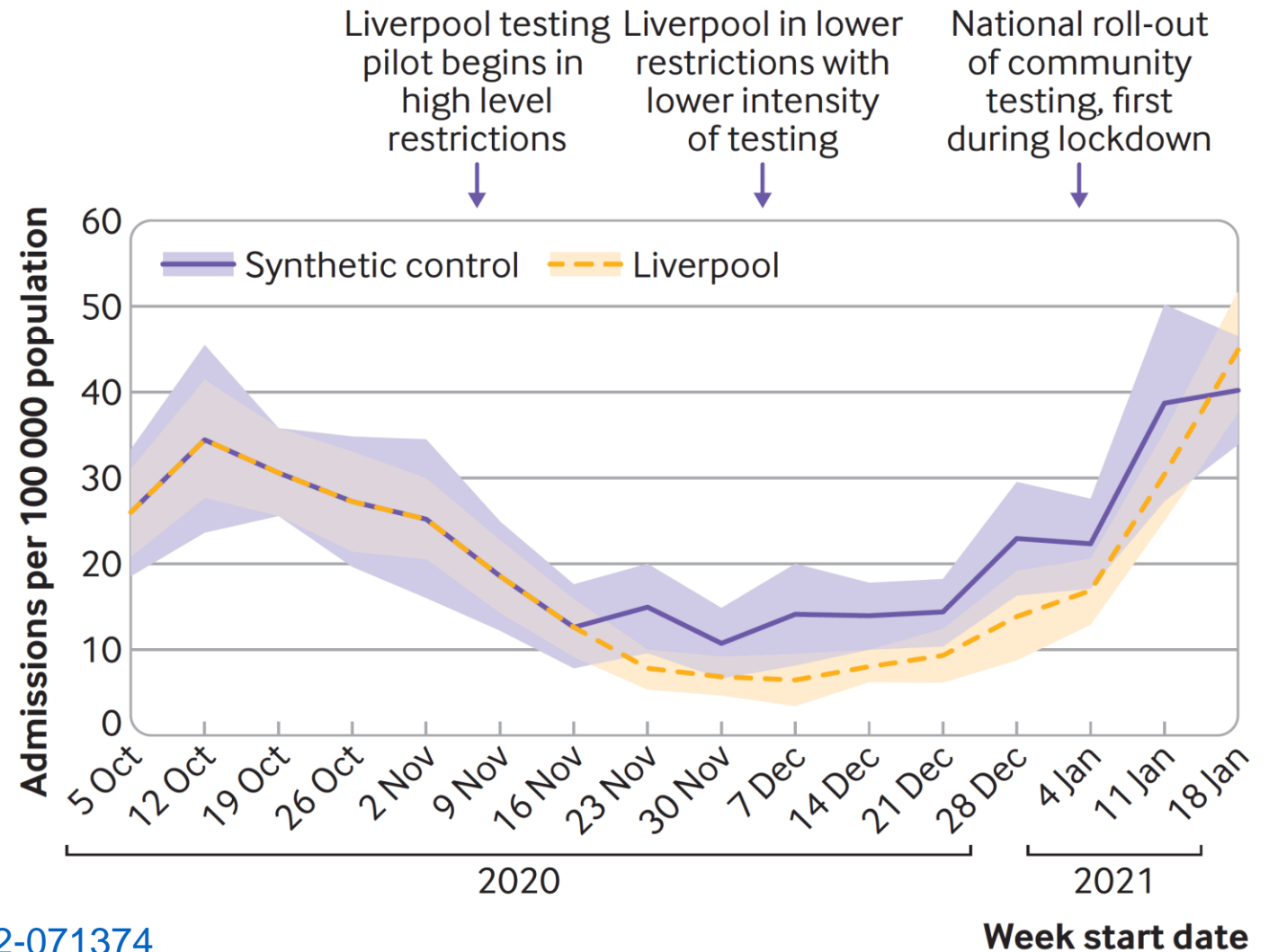
www.bmj.com/content/379/bmj-2022-071374

www.liverpool.ac.uk/coronavirus/research-and-analysis/covid-smart-pilot/



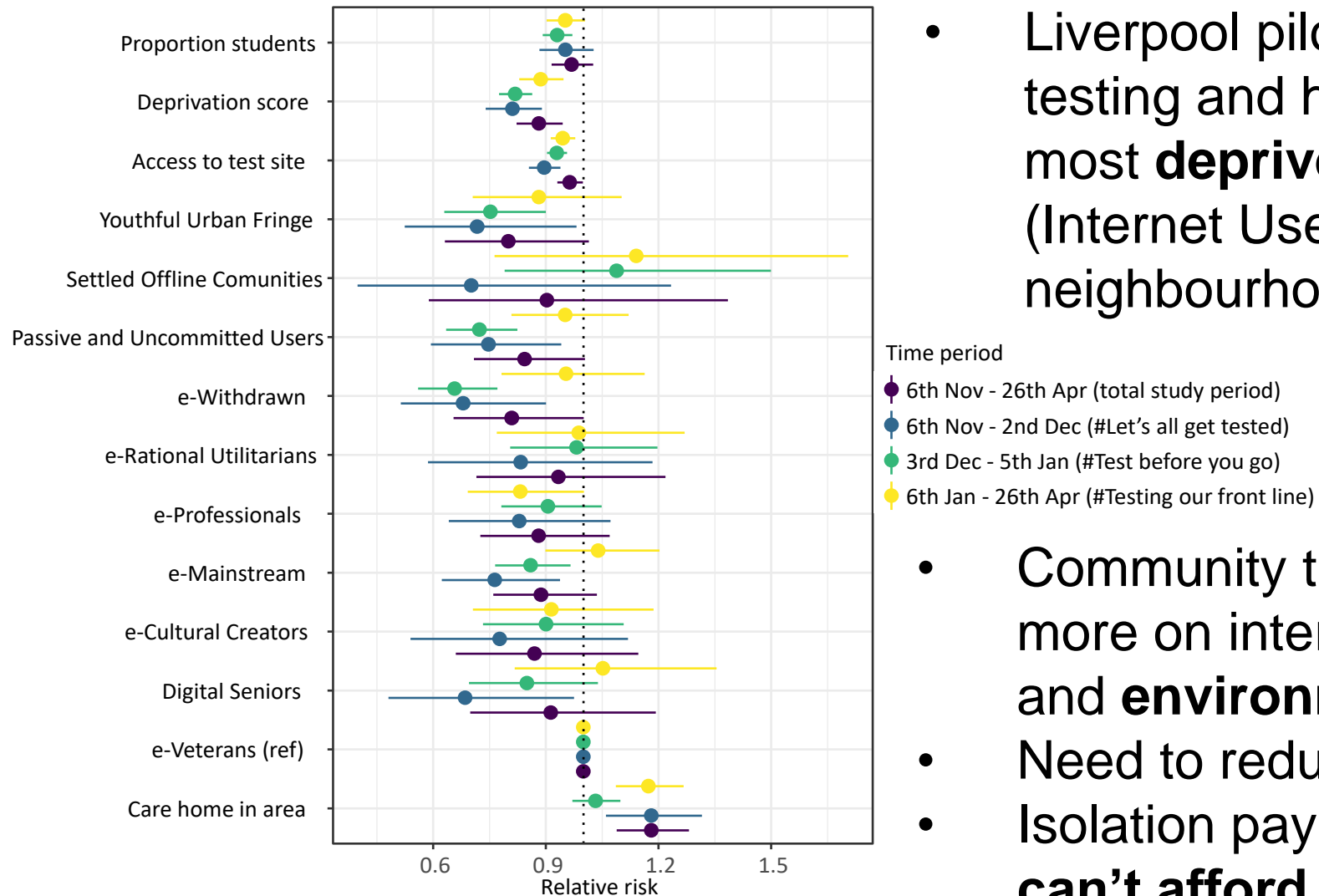
Impact of 'Mass Testing' Pilot on Covid-19 Hospitalisations

- **Synthetic control** analysis making neighbourhoods similar in terms of background risks, epidemic and control measures
- Initial mass testing with military: **43%** (29% to 57%) **reduction** in COVID-19 hospital admissions
- Overall community testing pilot with handover to local services **25%** (11% to 35%) **reduction**



- Results: <https://www.bmj.com/content/379/bmj-2022-071374>
- Methodology: <https://www.bmj.com/content/379/bmj.o2712>
- Policy impacts: www.liverpool.ac.uk/coronavirus/research-and-analysis/covid-smart-pilot/

Digital Poverty → Low Test Uptake: Need Universal Access



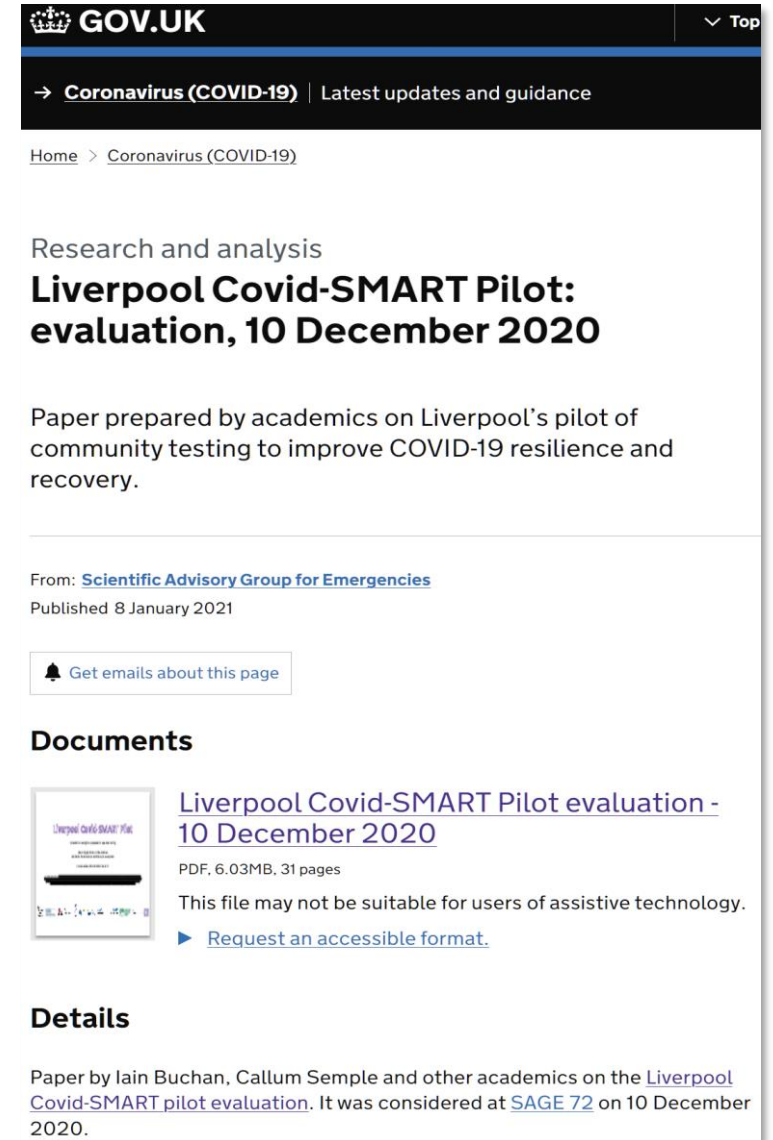
- Liverpool pilot demonstrated **lower uptake** of testing and higher infection rates among the most **deprived** and the **digitally excluded** (Internet User Classification of neighbourhoods)

- Community testing roll-out advised to focus more on interactions of **biology, behaviour** and **environment** (end-to-end testing)
- Need to reduce **digital complexity**
- Isolation payments needed for those who **can't afford to isolate**

London December 2020: Community Testing Policy Made

- End-to-end testing **evaluation** considered by UK Scientific Advisory Group for Emergencies and Universal Access Community Testing **policy** made
- Media **debate** over 40% lateral flow sensitivity vs PCR, confusing clinical test of having been infected with public health test of being ~infectious
- Public health utility function to optimise:
1/time to % appropriate action (e.g., isolation)
30 min lateral flow vs 48h PCR
consider '**actionable accuracy**'

[Mina MJ, Peto TE, García-Fiñana M, Semple MG, Buchan IE. Clarifying the evidence on SARS-CoV-2 antigen rapid tests in public health responses to COVID-19. Lancet. 2021 Apr 17;397\(10283\):1425-1427](#)



The screenshot shows a GOV.UK webpage. At the top, there is a navigation bar with the GOV.UK logo and a 'Top' link. Below this is a breadcrumb trail: 'Home > Coronavirus (COVID-19) | Latest updates and guidance'. The main heading is 'Research and analysis' followed by 'Liverpool Covid-SMART Pilot: evaluation, 10 December 2020'. A sub-heading reads: 'Paper prepared by academics on Liverpool's pilot of community testing to improve COVID-19 resilience and recovery.' Below this, it says 'From: Scientific Advisory Group for Emergencies' and 'Published 8 January 2021'. There is a button that says 'Get emails about this page'. Under the heading 'Documents', there is a PDF icon and the title 'Liverpool Covid-SMART Pilot evaluation - 10 December 2020'. The document is described as a PDF, 6.03MB, 31 pages. A note states: 'This file may not be suitable for users of assistive technology.' and there is a link to 'Request an accessible format.'. Under the heading 'Details', it says: 'Paper by Iain Buchan, Callum Semple and other academics on the Liverpool Covid-SMART pilot evaluation. It was considered at SAGE 72 on 10 December 2020.'

Digital Twin from Records or Self-experiment Avatar?



Sparse NHS records of clinical 'pit-stops'
Digital by-products of health, habits and self-care experiments
Rhythms of life to tap for discovery, engagement and intervention

Complex Person-driven Health Data Force Better AIs

Which came first, self-weighing or weight-loss?



- Recently lost 1kg ~ twice as likely to reweigh as someone who remained same weight

[J Med Internet Res](#). 2016 Jan; 18(1): e17.

Published online 2016 Jan 21. doi: [10.2196/jmir.4767](#)

PMCID: PMC4742620

PMID: [26794900](#)

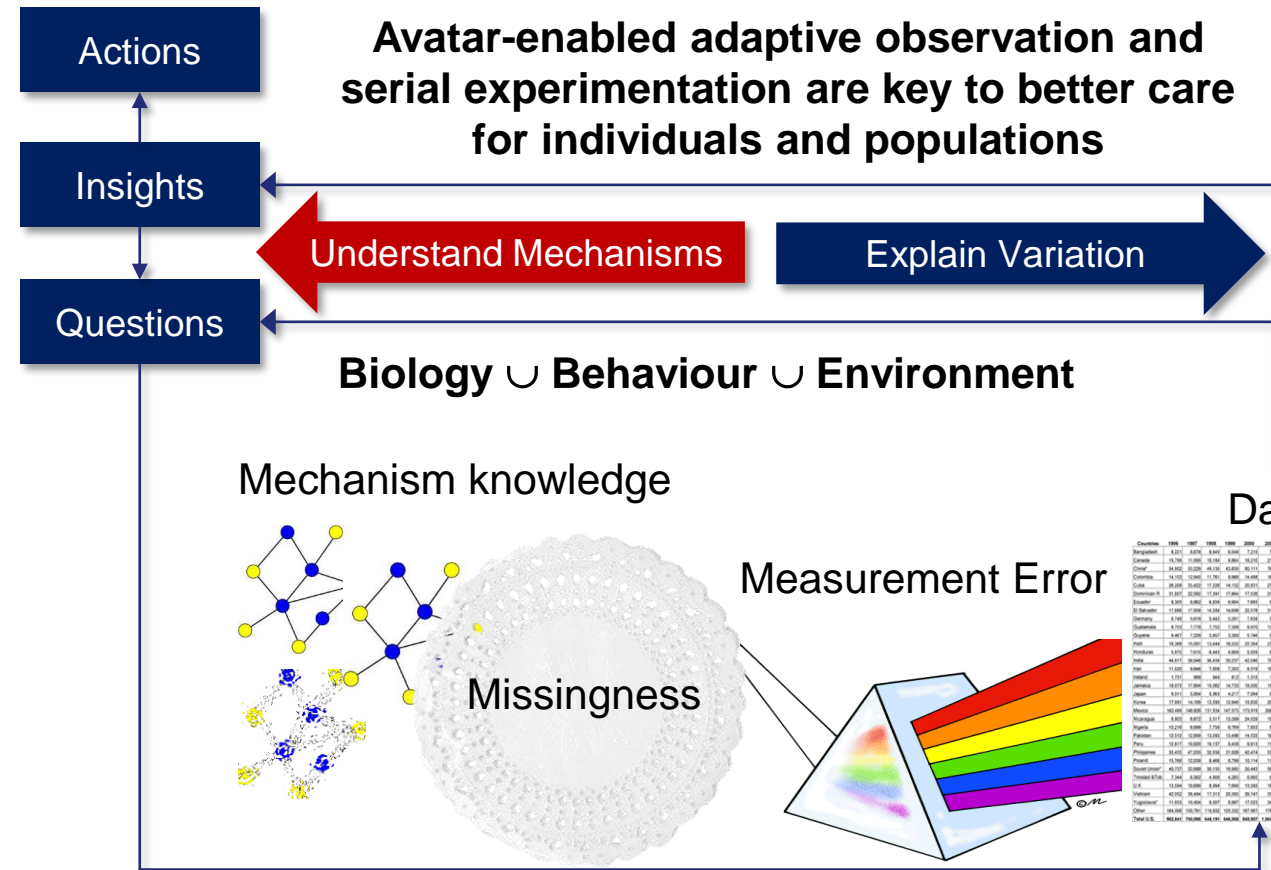
Who Self-Weighs and What Do They Gain From It? A Retrospective Comparison Between Smart Scale Users and the General Population in England

- Reinforcement learning based AI starting to approximate coaching

Can the artificial intelligence technique of reinforcement learning use continuously-monitored digital data to optimize treatment for weight loss?

[Evan M. Forman](#), [Stephanie G. Kerrigan](#), [Meghan L. Butryn](#), [Adrienne S. Juarascio](#), [Stephanie M. Manasse](#), [Santiago Ontañón](#), [Diane H. Dallal](#), [Rebecca J. Crochiere](#) & [Danielle Moskow](#)

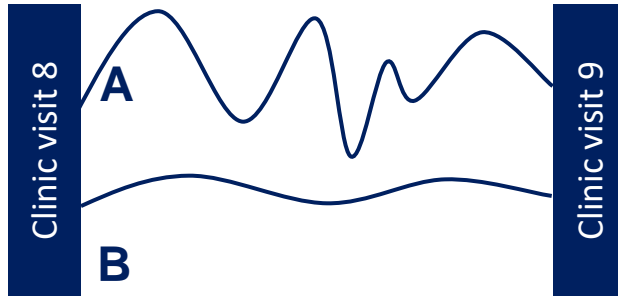
[Journal of Behavioral Medicine](#) 42, 276–290 (2019) | [Cite this article](#)



[Causal inference and counterfactual prediction in machine learning for actionable healthcare | Nature Machine Intelligence](#)

Millions of health avatars training and testing AIs in better care would advance global causal machine learning for health

Apps → Avatar Skills and Measurement Based Care

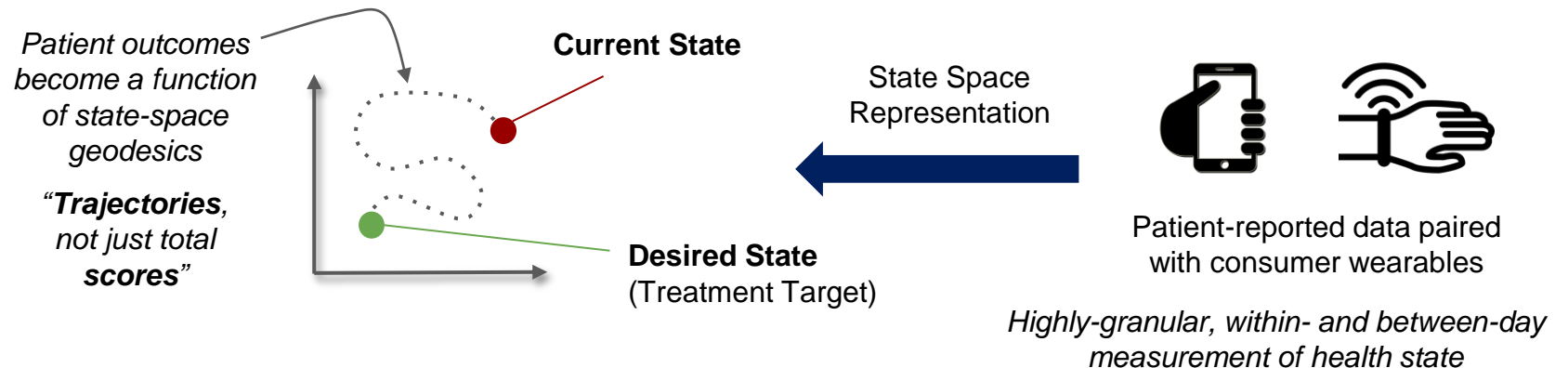
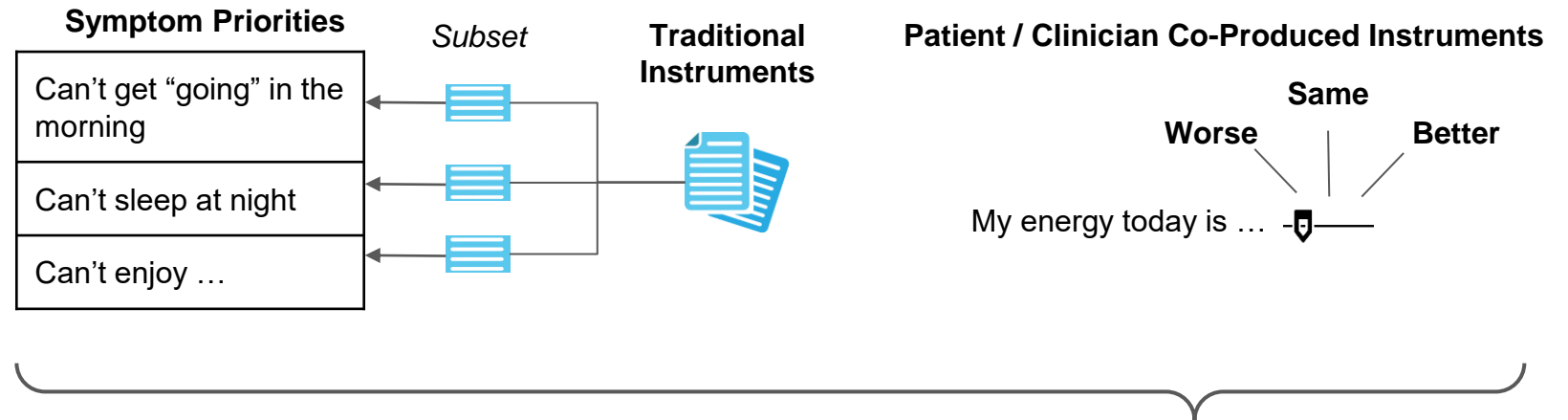


Two patients:

- Same diagnosis / treatment
- Different conditions / needs
- Key rhythms invisible to clinic

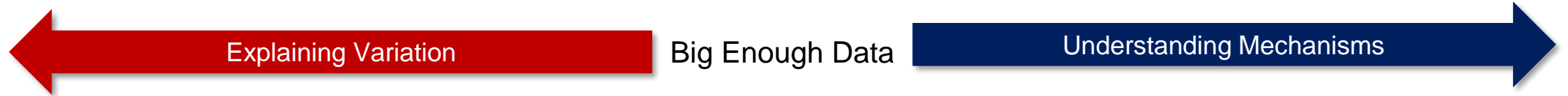
App market failure:

- Blizzard of apps for drugs, devices, clinics etc.
- Patient burden too high
- More people living longer with more than one condition
- Combinatorial explosion of complexity and confusion
- Lack of transparency & trust



**TREAT THE PATIENT NOT THE DIAGNOSIS
AND MANAGE THE JOURNEY NOT THE VISIT**

Paradox of Computable Healthcare



[Causal inference and counterfactual prediction in machine learning for actionable healthcare](#) | [Nature Machine Intelligence](#)

PLoS Med. 2005 Aug; 2(8): e124.

PMCID: PMC1182327

Published online 2005 Aug 30. doi: [10.1371/journal.pmed.0020124](https://doi.org/10.1371/journal.pmed.0020124)

PMID: [16060722](https://pubmed.ncbi.nlm.nih.gov/16060722/)

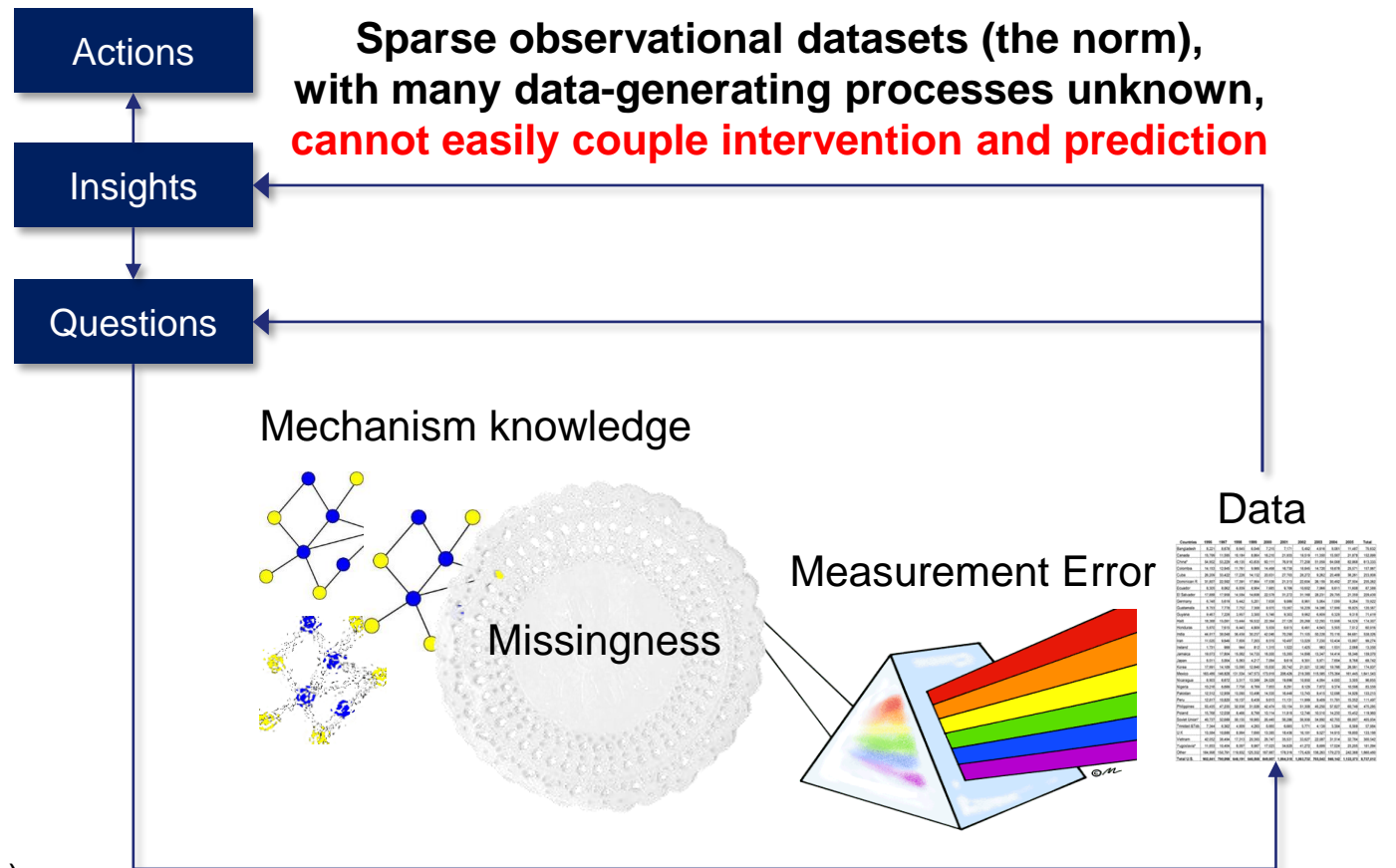
Why Most Published Research Findings Are False

[John P. A. Ioannidis](#)

Big data * small research → noise
Biology ∪ Behaviour ∪ Environment

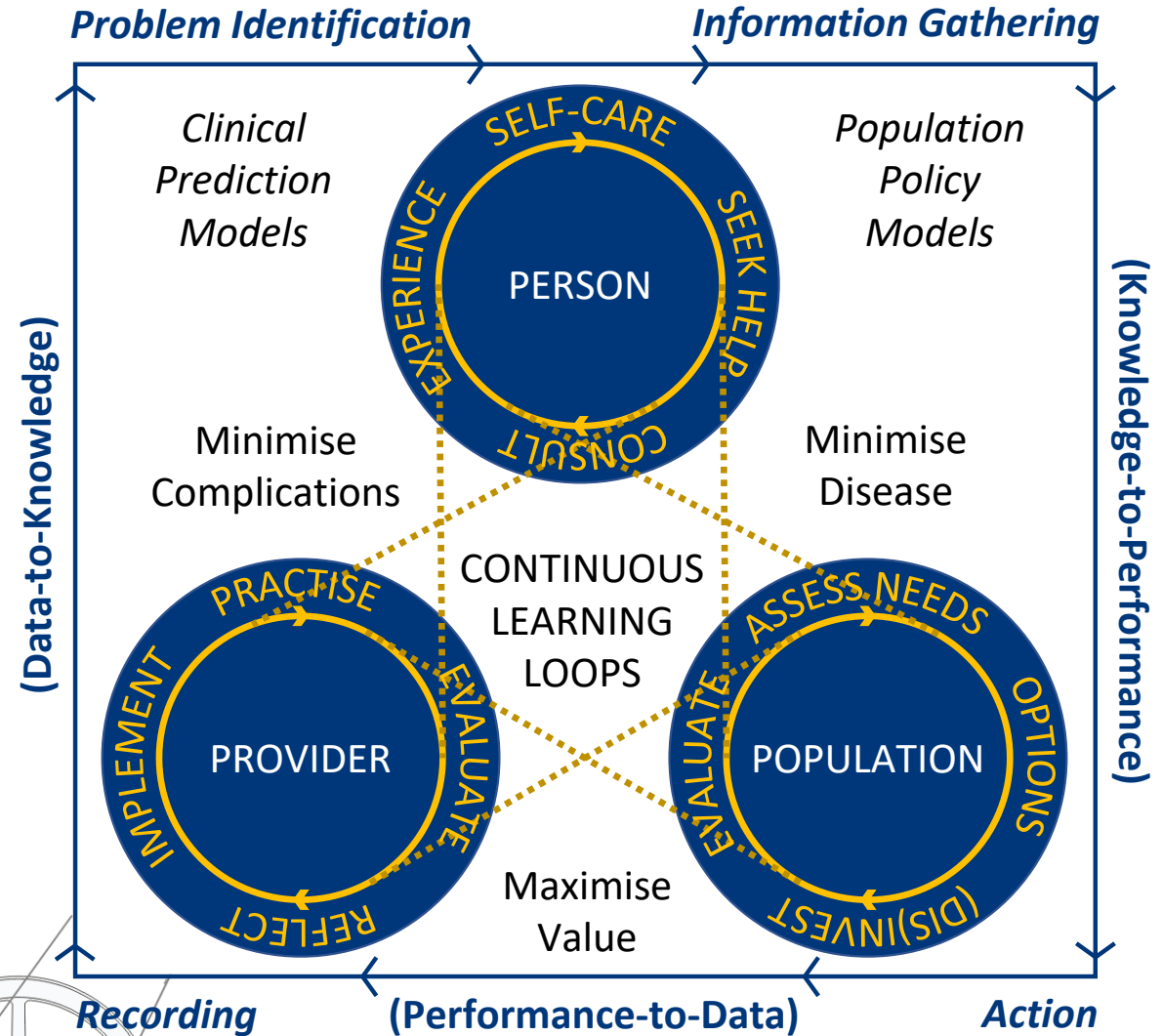
Begs better (serial) interventional studies,
 and for squeezing more out of observational data,
 some causal machine learning is becoming useful:

- [TARNET \(estimating individual treatment effects\)](#)
- [CEVAE \(autoencoders with causal structure\)](#)
- [Dragonnet \(doubly robust\)](#)
- [PSSAM-GAN \(synthetically balanced case-control\)](#)
- [DCN-PD \(based on propensity scores\)](#)
- Treatment effects with [dynamic regimens](#) (~ g-estimation)



Health Systems Need an OS

- Future ‘health **avatars**’ / ‘useful digital twins’, using **records, predictions and preferences**, could broker better (personalised, precise, preventive) care for the patient while generating richer data for clinical decision making, population health management and research
- Train-test cycles of **AI**s for better care need to be **grounded in population health management**
- A **global grid** of civic **data and AI cooperatives** could crowd-source radically better technologies and societal value



Thank you

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[@profbuchan](https://twitter.com/profbuchan)

