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Kharkiv International Medical University

Digital technologies for healthcare: from apps and wearables to AI

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Outline of lecture

- Digital technologies developed in last two decades
- Smartphone apps in UK National Health Service (NHS)
- Using digital health platforms for remote management of chronic conditions
- Virtual wards : using wearables for patient monitoring
- Moving from the hospital into the community: "Hospital at Home"
- AI for healthcare
- Conclusions

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Digital technologies in last two decades

In **2007**, the **first-generation iPhone** hit the U.S. market. This new "smartphone" had an in-built webcam but could not record video. It also made it possible to design bespoke software applications for the smartphone ("apps"), although there was no App Store.

In September **2009**, the **Fitbit** (a "**health wearable**" as a **consumer device**) was launched.

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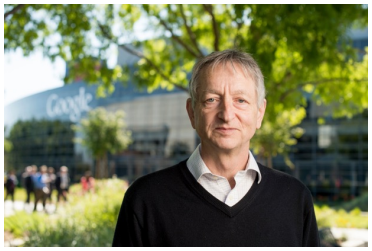
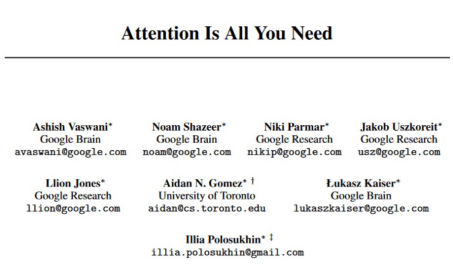
Digital technologies in last two decades

In **2006**, a paper by Geoff Hinton showed how a many-layered feedforward neural network could be effectively pre-trained one layer at a time. In 2009, **deep-learning neural networks** were first trained with Nvidia graphics processing units (GPUs).



In **2017**, a paper from 8 scientists working at Google introduced the **transformer architecture**, based on the attention mechanism. In **November 2022**, ChatGPT was publicly released by OpenAI.



Attention Is All You Need

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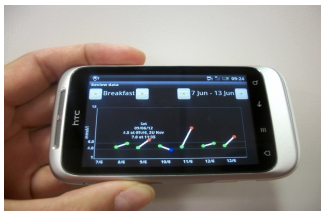
Apps for the NHS: gestational diabetes management

BRC1



Prototype of gestational diabetes app

BRC2

Observational study and randomised clinical trial

BRC3

One of first apps in the NHS Digital library of apps

Technology exclusively licensed to Sensyne Health

Sensyne Health

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Mackillop, L. et al. "Development of a real-time smartphone solution for the management of women with or at high risk of gestational diabetes". *J Diabetes Sci Technol.* 2014 Nov;8(6):1105-14. doi: 10.1177/1932296814542271

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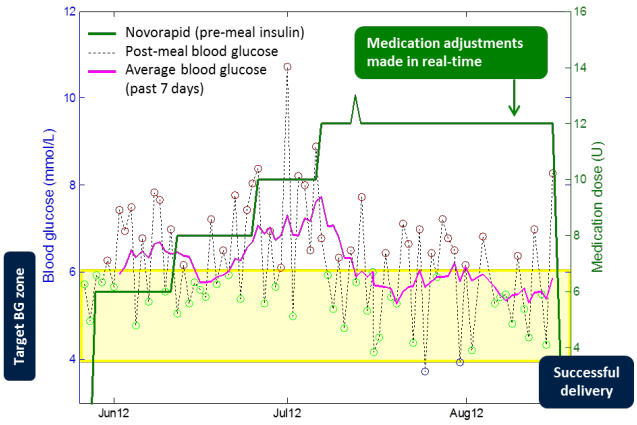
Apps for the NHS: gestational diabetes management

Real-time medication adjustments



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Smartphone app: gestational diabetes management

Independent 6-month evaluation at the Royal Berkshire Hospital:

- 26% reduction in clinic visits for women using the GDm-health app (in comparison to those receiving usual care)
- 50% reduction in time spent by diabetes midwives on clerical and administrative tasks

Randomised controlled trial of GDm-Health:

- Significant improvement in compliance with self-monitoring (80% v 61%)
- Preterm birth less common in the intervention group (5/101, 5.0% vs 13/102, 12.7%; OR 0.36, 95% CI 0.12-1.01)
- Fewer caesarean deliveries in the intervention group (27/101, 26.7% *vs* 47/102, 46.1%, P = 0.005)

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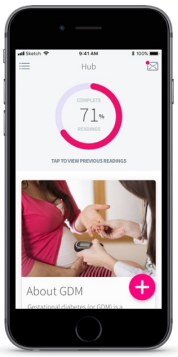
Mackillop, L. et al. "Comparing the efficacy of a mobile phone-based blood glucose management system with standard clinic care in women with gestational diabetes: Randomized controlled trial." *JMIR mHealth and uHealth* 6.3 (2018): e71

8

Apps for the NHS: gestational diabetes management

- Patients using the GDm-Health app have faster treatment optimisation and are less likely to require medication.
- They require **47% fewer appointments** with diabetes specialists.
- GDm-Health™ is now deployed in **64 NHS Trusts** (50% of Trusts with maternity services).
- **180,000 patients** with gestational diabetes have used the GDm-Health app since August 2018.



Sensyne Health

HUMA

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Mackillop, L. et al. "Comparing the efficacy of a mobile phone-based blood glucose management system with standard clinic care in women with gestational diabetes: Randomized controlled trial." *JMIR mHealth and uHealth* 6.3 (2018): e71

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Remote monitoring of patients with chronic diseases

Chronic disease management accounts for 80% of the growth in healthcare spending in the developed world in the last 50 years.

- Chronic diseases are health problems that require on-going management for years or decades (e.g. diabetes, hypertension, heart failure or Chronic Obstructive Pulmonary Disease – COPD) .
- In the US, chronic diseases affect 133 million people, generating healthcare costs of approximately $2 trillion a year overall.
- There are 15 million people in the UK with a chronic disease, accounting for 50% of all GP appointments and 70% of all bed days. Two-thirds of these patients are aged 75 or above.

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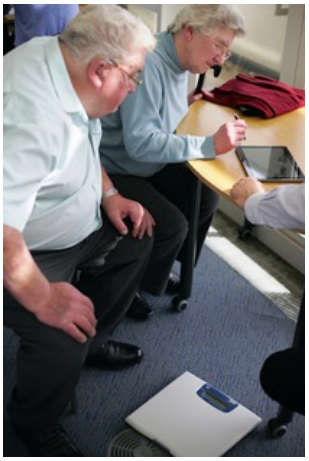
Designing digital health platforms for chronic disease patients



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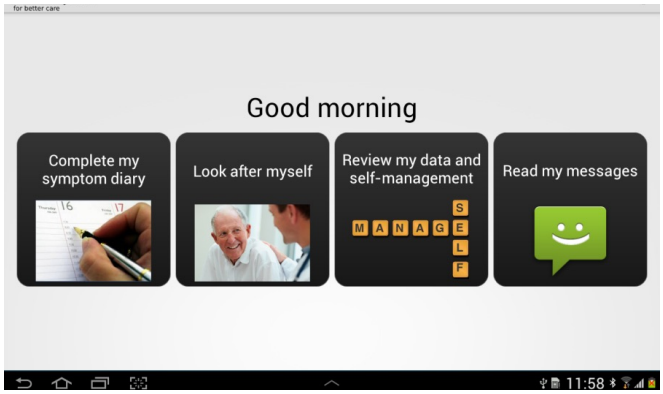
Designing digital health platforms for remote monitoring



1. Use state-of-the-art, multi-purpose tablet technology, with Bluetooth-enabled sensors
2. No keyboard: Use large icons with bright colours for selecting menu options or answers to symptom diary questions

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Velardo C, Shah SA, Gibson O, Clifford G, Heneghan C, Rutter H, Farmer A, Tarassenko L. Digital health system for personalised COPD long-term management. BMC medical informatics and decision making. 2017 Dec;17(1):1-13.

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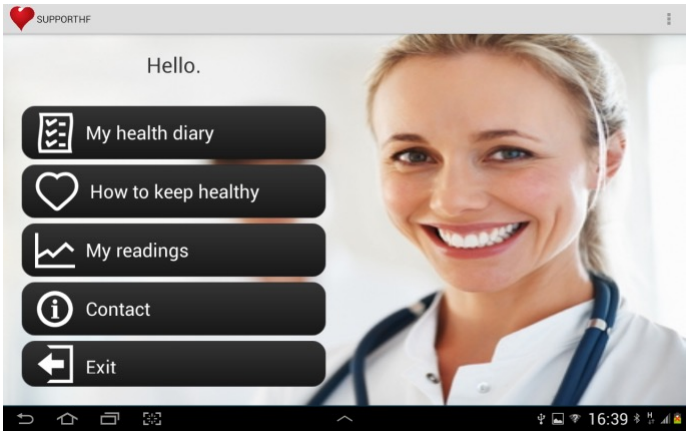
Designing digital health platforms for remote monitoring



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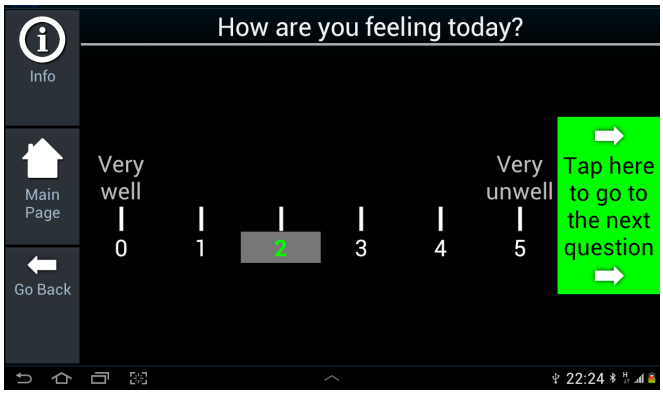
Triantafyllidis A, Velardo C, Chantler T, Shah SA, Paton C, Khorshidi R, Tarassenko L, Rahimi K, SUPPORT-HF Investigators. A personalised mobile-based home monitoring system for heart failure: the SUPPORT-HF study. International journal of medical informatics. 2015 Oct 1;84(10):743-53.

14

Designing digital health platforms for remote monitoring



3. Allow time for choice of answers to symptom diary questions

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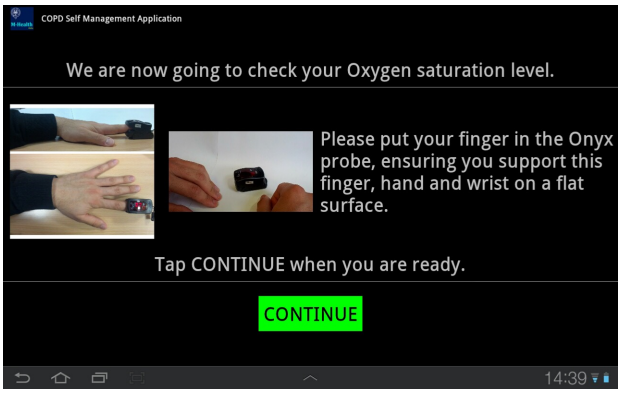
Designing digital health platforms for remote monitoring



4. Use signal quality algorithms to ensure artefact-free measurements of vital-sign values

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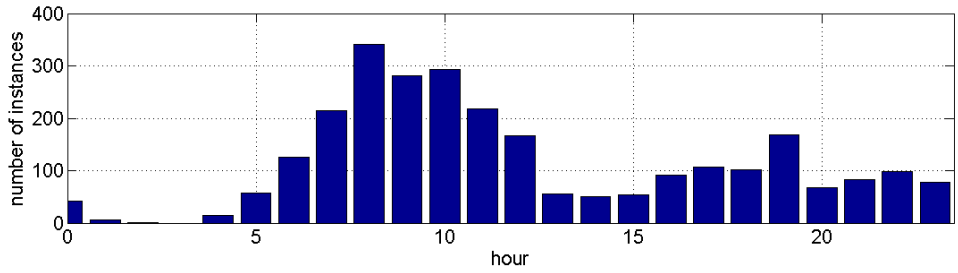
Designing digital health platforms for remote monitoring

5. Allow patients to complete diary at a time of their choosing



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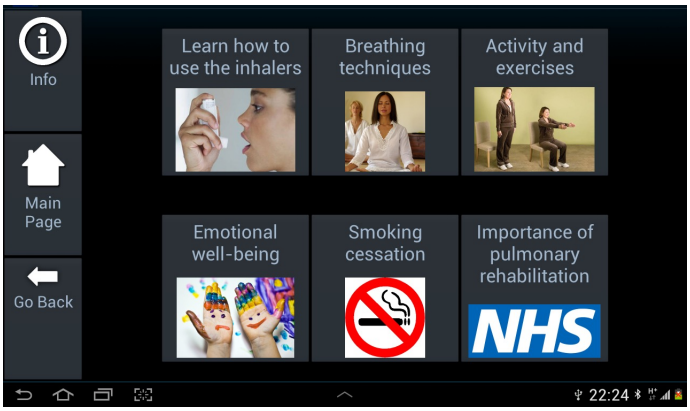
6. Support self-management (where possible)



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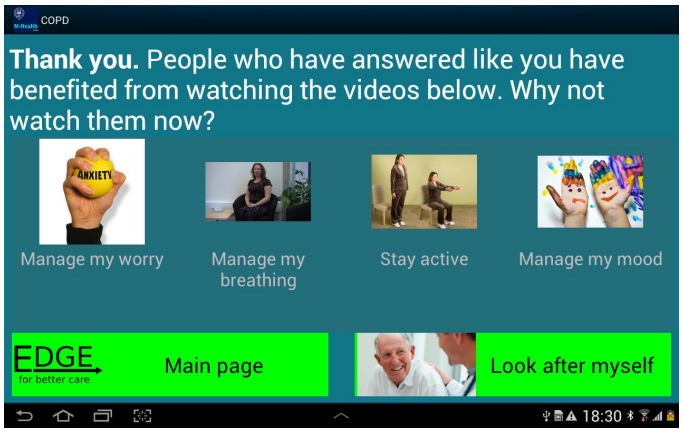
Designing digital health platforms for remote monitoring

7. Self-management using multi-media resources



Selection of videos available after completion of "Emotional well-being" diary

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Designing digital health platforms for remote monitoring

8. Patient-specific alerting

- Remote monitoring also requires alerting to detect patient deterioration (e.g. untreated exacerbation or fluid build-up).
- Global thresholds (e.g. 92% oxygen saturation for COPD patients) generate many false alerts.
- Alerting algorithms need to learn individual patient variability.

Learn patient physiology in an open-loop phase (typically six weeks) before switching patient-specific alerting on

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Designing digital health platforms for remote monitoring

Patient-specific alerting

- Collect vital sign data and symptom diaries for training set (first six weeks).
- Use machine learning to analyse the variations in heart rate, breathing rate, oxygen saturation (vital signs) and total symptom score in the training set for that individual.
- Personalised alerting thresholds are then created for each patient.

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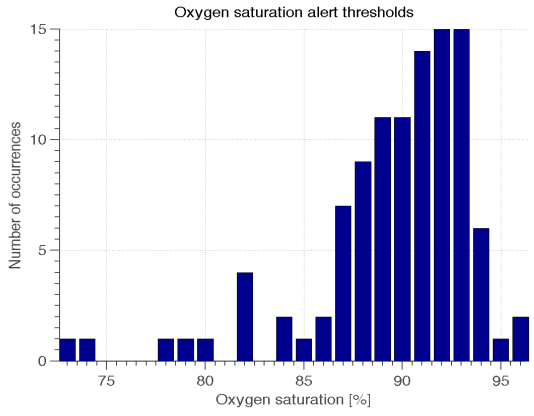
Designing digital health platforms for remote monitoring

Patient-specific alerting



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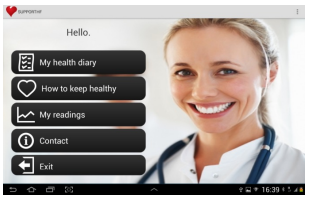
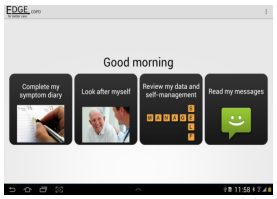
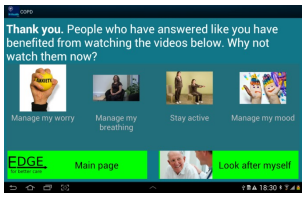
Using digital health platforms for remote monitoring







- **Wireless-enabled tablets with large icons (no keyboard)**
- Smart Bluetooth sensors for *reliable* physiological data
- Patients given help to interpret their data
- Tailored *self-management* component
- **Machine learning for personalised alerting**

- High levels of adherence (>85%) in all studies
- Overwhelming acceptance of technology (ease of use, perceived relevance and usefulness of feedback)

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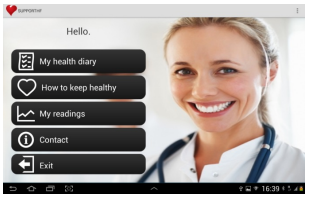
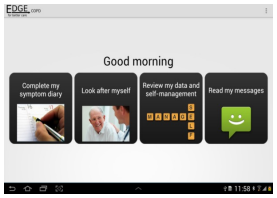
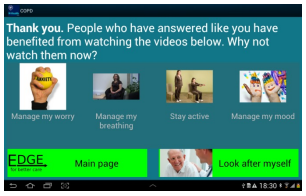
Using digital health platforms for remote monitoring







- **Wireless-enabled tablets with large icons (no keyboard)**
- Smart Bluetooth sensors for *reliable* physiological data
- Patients given help to interpret their data
- Tailored *self-management* component
- **Machine learning for personalised alerting**

- 170-patient Randomized Controlled Trial with COPD patients
- Fewer contacts with GPs (4 vs 5.5, p = 0.06) and Practice Nurses (1.5 vs 2.5, p = 0.03)
- 20% reduction in numbers of hospital admissions

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Farmer, A., Williams, V., Velardo, C., Shah, S. A., Yu, L. M., Rutter, H., ... & Tarassenko, L. (2017). Self-management support using a digital health system compared with usual care for chronic obstructive pulmonary disease: randomized controlled trial. *Journal of medical Internet research*, *19*(5), e144.

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Outline of lecture

- Digital technologies developed in last two decades
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Virtual Wards – a solution to the NHS bed crisis?

- "Virtual wards" is a concept first pioneered in the UK in 2006. They are a hospital-led and managed alternative to in-patient hospital care, enabled by technology.
- NHS England Transformation Directorate: Virtual wards support people who would otherwise be in hospital, to receive the care and treatment they need in their own home (or care home). They are suitable for a range of conditions that can be safely and effectively monitored at home, including COPD and heart failure.
- Virtual wards use a variable combination of remote monitoring and face-to-face care, and usually incorporate remote monitoring, for example, through apps, technology platforms, wearables and devices such as pulse oximeters.

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Wearable technology for virtual wards

- Fitbits and Apple watches have remained consumer devices and do not have regulatory approval for healthcare applications.
- We have been evaluating **clinical-grade wearables** (for monitoring heart rate, respiratory rate and oxygen saturation) in the context of a Virtual High-Dependency Unit (vHDU) at the John Radcliffe Hospital in Oxford.
- The aim of the vHDU project is to demonstrate how **high-risk patients can be monitored and managed on a general ward using wearables and smart alerting algorithms,** with full integration of the periodic nurse observations**.**

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Wearable monitoring of in-hospital patients

The wearable devices (a chest patch and finger-worn pulse oximeter) are linked via Bluetooth to a computer tablet by the bedside of ambulatory patients on the ward.

- Android Tablet
- Pulse Oximeter (WristOx2® 3150 BLE, Nonin)
- Chest Patch (VitalPatch®, VitalConnect)

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Wearable monitoring of COVID-19 patients

- It became clear at the end of February 2020 that the technology and software developed for the vHDU project could be adapted for the COVID-19 isolation ward in the John Radcliffe Hospital.
- The patients were **remotely monitored within the hospital:** they were in individual rooms on the COVID-19 Ward, with the nursing staff caring for them situated in another location nearby.
- The amount of contact between the infected patients and the nursing staff was to be minimised, with the frequency of nurse observations, which required the use of PPE, decreased.
- The system went live with its first ambulatory patients on Monday 23rd March 2020, rapidly becoming part of usual care for the patients on the isolation ward (not ill enough to go to Intensive Care or stepping down from it).

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Santos, MD, et al. A real-time wearable system for monitoring vital signs of COVID-19 patients in a hospital setting. *Frontiers in Digital Health* **3** (2021), 630273. doi: 10.3389/fdgth.2021.630273

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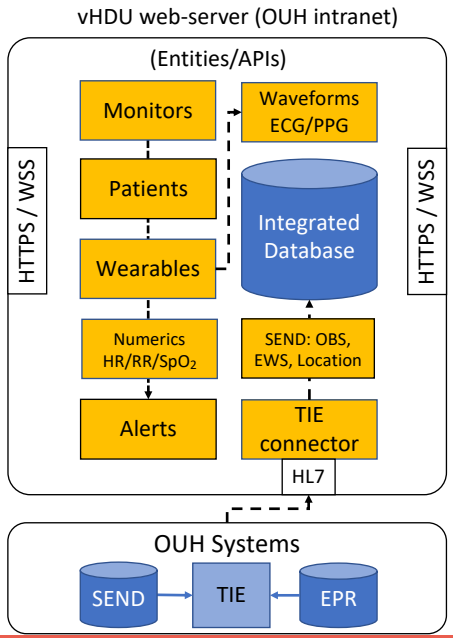
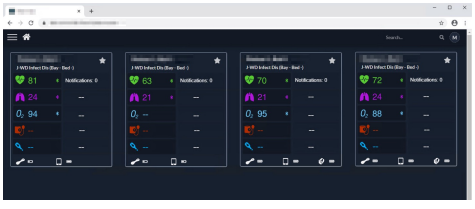


Patient dashboard

The processed vital-sign data was made available to the nursing staff outside the isolation rooms using the hospital wi-fi, and displayed on a dashboard which allowed the physiological status of the patients to be tracked in real-time.



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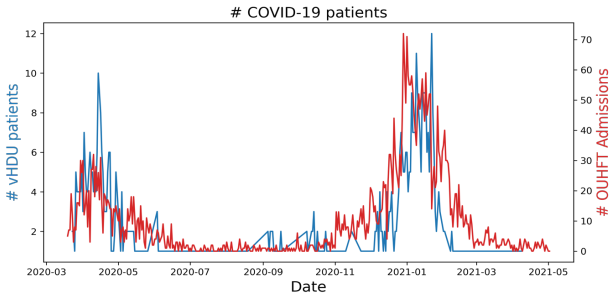
Wearable monitoring of COVID-19 patients



Over half the patients on the isolation ward were monitored with the wearable system during the peaks of hospital admissions in the first two waves of COVID-19.

- Median time between nurse observations on the isolation ward **increased by 51 minutes** for those patients monitored with the wearable system.
- There is some evidence that **early deterioration** (nurse returning to patient well before next observation was due) was detected by the vHDU system in **25 out of 144 patients** (whose data was available for analysis).

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Roman C, Vollam S, et al. Clinical evaluation of a real-time wearable system for monitoring in-hospital ambulatory COVID-19 patients: A retrospective data study. In press (JMIR).

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Moving from the hospital into the community: "Hospital at Home"

- Hospital at Home is described in the NHS England specifications as the '*most intense*' form of virtual wards, as it relies on face-to-face physical delivery of diagnostics and intra-venous treatments.
- Hospital-at-Home services provide face-to-face care at home through a multi-disciplinary team (MDT) based in the community, as an alternative to in-patient care.
- These services manage a variety of acute illnesses and exacerbations of chronic conditions in adults including COPD, heart failure, COVID-19, pneumonia and urinary tract infections.

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Hospital at Home in Oxfordshire

- Remote vital-sign monitoring has the potential to reduce the number of visits by nurses to carry out face-to-face vital-sign observations.
- The aim of our current study is to **embed the use of the wearable technologies** developed in the Virtual HDU project and allow remote vital-sign monitoring for those with acute illness being treated at home.
- Our study is testing whether using remote monitoring reduces the number of home visits required, improves the scheduling of home visits when they are needed, and reduces the need for further hospital assessments, when compared to current care protocols.

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AI for healthcare

Over the last two decades, the number of medical imaging scanners in the developed world has seen a substantial increase not matched by an equivalent increase in the number of radiologists available to read and interpret the images.

- 700,000 women across the UK are taking part in a world-leading trial to test how cutting-edge machine learning (ML) tools can be used to catch breast cancer cases earlier,
- Currently, 2 specialists are needed per mammogram screening. The ML tool enables just one to complete the same mammogram screening process efficiently (with a safety feature built in).

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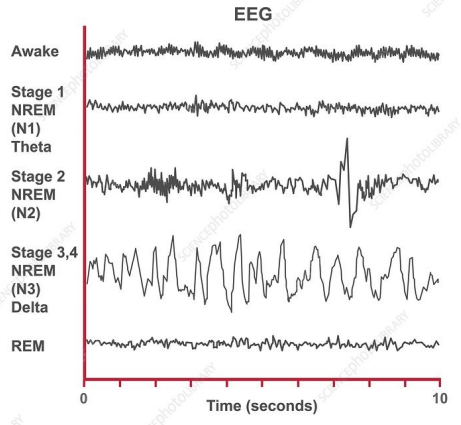
AI for healthcare - sleep staging

Sleep staging is performed by trained technicians who review the 4-channel EEG, EOG, and chin EMG acquired overnight **in a sleep lab**.

Sleep is classified, or "scored", into the following five classes: wakefulness (W), light sleep (N1), intermediate sleep (N2), deep sleep (N3) and Rapid Eye Movement (REM) sleep (R).

Deep sleep (N3) is sometimes known as **Slow Wave Sleep** (SWS), the main functions of which are to **support memory**, **boost immune function**, and facilitate growth and repair of tissues.



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Sleep and neurodegenerative diseases

- New research at the University of Berkeley (May 2023) has shown that SWS (N3 sleep) can act as a **protective factor against memory decline** in those with existing high amounts of Alzheimer's disease pathology.
- Those patients with high amounts of beta-amyloid deposits in their brain who also experienced higher levels of performed better on memory tests than those with the same amount of beta-amyloid deposits but with less N3 sleep.
- In October 2023, a Monash University team reported that a **1% reduction in N3 sleep per year for people above the age of 60 translates into a 27% increased risk of dementia**, and that N3 sleep loss could be a modifiable dementia risk factor.
- **Manipulations of N3 sleep could enhance cognitive function in older adults, and in those with mild cognitive impairment**.

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Sleep and neurodegenerative diseases

- Heart rate and respiratory rate vary according to sleep stage; for example, heart rate is variable but highest during REM and decreases as an individual enters deeper stages of sleep.
- With generative AI, we can map any input sequence (e.g. successive epochs of heart rate and breathing rate) to any output sequence (e.g. the sleep state during that epoch).

With the 7-day wearable chest patch providing both heart rate and breathing rate signals as inputs to a transformer, we derive the sequence of sleep states for each night and track how sleep varies over a week.

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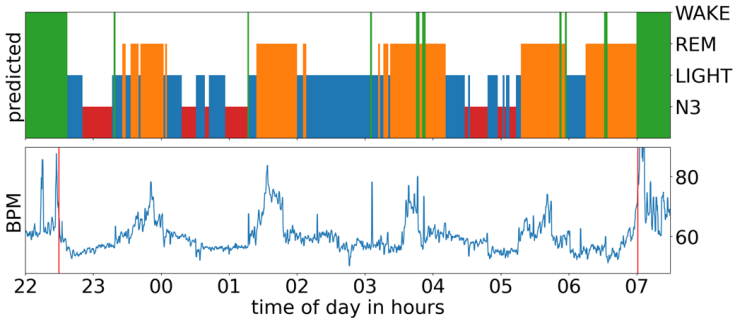
Generative AI – moving the sleep lab into the home

Latest results using transformer model with respiratory waveform and ECG as inputs give an accuracy of 83% for 4-class sleep staging (N1-N2 as a single class).



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Davidson S. Roman C, Carter J, Harford M & Tarassenko L. Sleep staging using wearables and deep neural networks. *Proc. 2023 IEEE-EMBS International Conference on Biomedical and Health Informatics.*

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Generative AI – moving the sleep lab into the home

- We can track how sleep varies over one (or more) weeks and monitor the impact of interventional strategies for improving sleep.
- Even if the relationship between N3 sleep and extent of dementia is not causal, longitudinal monitoring of N3 sleep will provide a useful **biomarker for assessing the effectiveness of new treatments for dementia and other neurodegenerative diseases**, as repeated CT or MRI scans are not feasible.

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Davidson S. Roman C, Carter J, Harford M & Tarassenko L. Sleep staging using wearables and deep neural networks. *Proc. 2023 IEEE-EMBS International Conference on Biomedical and Health Informatics.*

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- Digital technologies developed in last two decades
- Smartphone apps in UK National Health Service (NHS)
- Using digital health platforms for remote management of chronic conditions
- Virtual wards : using wearables for patient monitoring
- Moving from the hospital into the community: "Hospital at Home"
- Generative AI for neurodegenerative diseases
- Conclusions

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The UK NHS needs a successful Virtual Wards programme

- Number of NHS hospital beds has declined from 299,400 in 1987 to 141,000 in 2019. The total number of beds/1,000 inhabitants is: 7.9 in Germany, 5.8 in France, 2.5 in UK (2.52 in UK).
- NHS England: "Virtual wards will provide round-the-clock monitoring for up to 50,000 people a month, with patients given wearable devices that track vital signs such as heart rate, temperature, and oxygen levels and alert medical teams to any changes."
- A strategic programme is needed to transition from pilot studies to national deployment at scale.

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Digital technologies, including AI, for the NHS

- Short-term: the in-hospital Virtual HDU technology (wearables) and algorithms (AI for alerting) is likely to be adopted, because high-risk patients can now be on 4-hourly observations, rather than on hourly observations. This will deliver a saving in the number of nurses needed on the ward.
- Long-term: longitudinal monitoring of N3 sleep using wearables and generative AI will provide a useful biomarker for assessing the effectiveness of treatments for dementia and other neurodegenerative diseases, as repeated CT or MRI scans are not feasible.
- "AI will never replace physicians – but physicians who use AI will replace those who don't" (President, American Medical Association, July 2023)

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