SYNCHROS

WORK-PACKAGE 4

Taking stock of emerging and new data collection technologies and their potential impact on the development of future cohort studies and the need to optimise the integration of data

D4.1

Report on the new communication technologies (including social media) used in European and international cohort studies

SYNergies for Cohorts in Health: integrating the Role of all Stakeholders

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Authors	Danielle Derijcke
Contributors	Andreas Weser, Steinar Krokstad, Kinga Polanska, Beatriz Olaya Guzman, Agnieszka Janowska, Wojciech Hanke, Helena Harnik
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ACRONYMS AND ABBREVIATIONS

SYNCHROS	SYNergies for Cohorts in Health: integrating the ROle of all Stakeholders
AI	Artificial Intelligence
SNS	Social network site (social networking site, social networking service)
EHR	Electronic Health Record
IoT	Internet of Things
GNSS	Global Navigation Satellite System
GIS	Geographical Information Systems
RS	remote sensing
GPS	Global Positioning System
NLP	Natural Language Processing
ML	Machine Learning

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EXECUTIVE SUMMARY

Within the scope of this work package we will take stock of the emergence of the use of digital technology for real-time data collection – such as social media, wearables and smartphone sensors – that will be particularly relevant for the design and planning of future cohort studies, including clinical trials, and populations and enhance the potential for integrated data in the future.

The objective of this report is to deliver a landscape analysis mapping potential digital data sources and collection mechanisms (e.g. devices, social media and online behaviours, crowd or cohort participation) that should be considered as part of the strategic recommendation to integrate, develop further and optimize cohort studies. The mapping includes a SWOT analysis (evaluation of Strengths, Weaknesses, Opportunities, Threats) per technology identified. The findings will be an important resource to identify and recommend technologies to be further built into the overall study protocol following Good Practice Guidelines.

The intended readers of this report are all stakeholders of the cohort-community involved in designing and planning new cohort studies/surveys.

The main learning of this mapping exercise is that digital technology is quickly transforming the way we live and work and we will have to keep up with it. Different stakeholders and businesses will have to reinvent their work with technology playing a central role. The same is true for the way we are conducting our studies. Some technology trends to watch in the field of study design are summarised below:

Mobile technology (including smartphones, smart watches and other wearables) is a well-integrated but still fast evolving data collection as well as a communication tool, with 5G being the next generation of wireless connectivity, promising faster connections, lower latency and improved security. Future 3D-sensing lenses in our smartphones will facilitate augmented reality and gesture recognition and, with that, opportunities for collecting new types of data.

Key trends driving sensor technologies include miniaturization of sensors easing integration and facilitating self-monitoring to control health and prevent disease, alleviating the burden on the overall health system.

With the availability of large amounts of multidimensional data, through geospatial technologies and Geographical Information Systems (GIS), new techniques are emerging that apply these data to a wide range of applications, such as holistic systems suitable for complex health studies. The capacity of GIS to link disease information with environmental and spatial data makes it an asset in the progression of worldwide healthcare, including cohort studies.

But whatever technology we consider in the design and planning of our future studies, it will be important to have a close evaluation of the data privacy, ethics, consent and possible legal issues of each technology. This is also the aspect where it becomes more challenging when we talk about social media, crowdsourcing or passive data collection. Equally, the quality of the data collected, whether or not from anonymous users, needs to be monitored closely.

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METHODOLOGY

With this research, we aimed to identify and analyse the new and emerging data and communication technologies in Europe and beyond with the ultimate project goal to evaluate if and how they could play a role in the optimization of cohort studies.

Definitions of the concepts have been established and agreed upon with the partners in order to avoid losing relevant information and to assure consistency and replicability of the search.

Definition of new technology: New technology in the framework of this report is any newly introduced or implemented technology that has an explicit impact on the way products are produced or services are provided.

Definition of emerging technology: Any technology that is not yet fully commercialized but it will become new technology within about five years.

Data collection mechanism: the data collection process, being routes and procedures by which data reach a database (particularly where these may change over time)

Information and Communication Technologies (ICT): devices, networking components, applications and systems that combined allow people and organisations to interact in the digital world. Cloud computing, Software, Hardware, transactions, communications technology, data and Internet access.

Table 1 Inclusion/exclusion criteria for mapping new and emerging data and communication technologies

Inclusion	Exclusion
Existing data collection technologies	Publications/articles/reports with a publication date before 2012
Innovative data collection technologies	Blogs
Data collection technologies from unrelated fields	
Active & passive data collection technologies	
Mobile and smart devices	
Personal monitoring devices	
Disease/public health surveillance technology	
Social media	
Crowdsourcing/crowd seeding	
Geospatial technology	
Technologies that enable storing, managing, and querying data and sharing data among	

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devices and databases	

Search terms and strategy

Different terms emerged from the definitions of the technologies included, the key variables. The exercise included as many terms as possible in order to not miss any relevant findings, while not formulating an impossibly large search. If necessary, new terms can be added or modified.

Search terms that were used for mapping new and emerging data and communication technologies : innovative data collection methods, future technology trends, innovations in data collection methods, new data collection technologies, emerging data collection technologies, synchronising patient data, the impact of technology on healthcare, data collection mechanisms, technology to collect high quality data, big data technologies, digital data revolution, information and communication technology, new technology review.

Search strategy for the mapping of new and emerging data and communication technologies:

- Focused literature review
- Grey literature from trustworthy sources and/or tech expert authors
- Public reliable sources (technology websites, organisations, authorities, professionals)
- Specific projects (from other domains) with a focus on data synchronisation (see below)

Relevant reference projects from other domains:

- The SyncML initiative now consolidated into the Open Mobile Alliance (OMA), composed of nearly 200 companies including the world's leading mobile operators, device and network suppliers, information technology companies and content and service providers [15]. : https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1560702/

Coding Process and Data Collection Format

All findings on new and emerging data collection technologies have been mapped as follows:

1. Name of technology/collection mechanism
2. Subgroup or subcategory
3. Description
4. Used in clinical practice (yes/no)
5. Strengths/opportunities
6. Barriers/threats
7. Example of existing or potential use in healthcare
8. Impact (on business & society)
9. Rate of adoption
10. Future trends
11. References (to website, article)

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All findings on new and emerging data collection technologies have been collected and shared in a Google sheet amongst work package partners.

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1. INTRODUCTION

The healthcare industry is evolving at an incredible pace thanks to advances in modern technology. It has a huge potential that has yet to be fully explored.

Advances in areas such as mobile and wearable sensing devices, video technologies and machine learning, allow researchers to collect and process phenotypic data with greater detail, in more natural settings, over longer periods of time, and with lower cost and participant burden than ever before.

For cohort and longitudinal studies, these technological advances mean it is possible to embed the extended capture of detailed health data into participants' everyday lives.

At the same time needless to say these methods also all have their own challenges and limitations.

In this report, we will zoom in on the different data collection technologies and provide a better understanding of the opportunities and limitations they have in the planning and design of future studies.

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2. A REVIEW OF NEW AND EMERGING DATA AND COMMUNICATION TECHNOLOGIES

Setting the scene: The Internet of Things [1,2,3]

The Internet of Things, or IoT for short, extends the Internet into physical devices, from household objects, cars and machinery to small sensors such as, in healthcare heart rate, oxygen saturation or blood glucose monitors. As components of the IoT, these physical objects are interactive and micro-processor controlled to allow them to communicate and exchange data - or some might say 'talk' to each other - over the Internet. While today the IoT allows us to monitor remote objects more easily, in the near future it will also enable ever smarter objects to work together autonomously, making decisions alone without the need for human intervention.

The term Big Data refers to the extremely large sets of both structured and unstructured data available today. Organizations across all sectors are exploring the best way to analyse this growing volume, velocity and variety of data to deliver insight that will lead to better decision-making. In cohort studies, access to the massive datasets will potentially allow researchers to diversify their studies (along the dimensions of race, ethnicity, gender, sexual orientation, socio-economic status, age, physical abilities, religious beliefs, political beliefs, or other ideologies).

To further explain this potential benefit, one of the apparent advantages of re-analysing existing datasets is their actual existence as recorded information which usually relates to a large group of subjects. Coverage can vary from whole population censuses to specific records on a subgroup who may possess certain characteristics or fall within a certain group. Therefore the considerable research costs associated with questionnaire design, data collection and processing are avoided in being able to access larger datasets. Additionally, they usually provide data on a substantial sample size that is typically very difficult to achieve in most studies due to time and cost considerations.

Existing large datasets provide great advantages to researchers. However, they also require careful consideration and pose a number of challenges to both methods of analysis and in defining and agreeing the research questions considered:

- New security risks
- Privacy challenges and regulations
- Requires an evolution in technology:
    - Costly and sophisticated high-speed data networks
    - Mammoth servers and powerful computers
    - Smaller, more powerful batteries
- Questions over trust of autonomous devices
- Concerns about job losses
- Opportunity/need to build new relationships
- Amplify systematic error
- Features of data-driven epidemiology (such as flexible data analysis and lack of pre-specified hypotheses) also have the potential to lead to research findings that are not true
- Quality of data

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Mobile Data Collection [4]

The term mobile data collection refers to the use of digital devices such as smartphones, tablets, laptops or wearable devices (wearables) for data collection. These devices may have a touchscreen display that allows you to perform actions by tapping or swiping and may also be able to run software apps.

A smartphone is a cellular telephone with an integrated computer and other features not originally associated with telephones, such as web browsing, apps, a touchscreen display and a camera. A smartwatch is a specific type of wearables. This digital watch includes features beyond timekeeping, such as heart rate monitoring, activity tracking and providing alerts and reminders throughout the day.

Mobile technology has been used extensively in public health research and practice and has proven effective for data collection in various settings and locales. Mobile phones, for instance, have been used for data collection via SMS/texting, via a mobile Internet connection and even via pictorial icon-based data collection apps.

SWOT Analysis [4, 6]

General

Strengths	Weaknesses
• Real-time uploads support timely data collection and enable more frequent data collection in insecure or remote areas. • Icon-based apps enable people with no digital experience or unable to read or write to participate. • Optimize the steps of data organization and processing. • Opportunity to passively collect large-scale human behavioural data. • Less time consuming. • Cost-effective way of collecting data.	• Maturity and quality of devices vary. • Technical or connectivity problems could potentially lead to delays and potential gaps in monitoring data. • If participation is limited to people with specific devices, data might not be representative. • Compared with traditional ways of data collection, data quality depends even more on the design of the survey/study due to error-prone technology, selection bias, participant's compliance with study protocols, etc. • Special international and national regulations are needed to ensure data security and privacy. • Vulnerability of the mobile network data to malicious attacks. • It is difficult for users to remove their data from the aggregated datasets.
Opportunities	Threats

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• Have the potential to become an integral part of the future of healthcare and biopharmaceutical development. • 5G, the next generation of wireless connectivity, promises faster connections, lower latency and improved security.	• Data privacy and consent will continue to be a significant barrier. • Potential WiFi, Bluetooth and cellular network security threats. • 5G requires a paradigm shift in network architecture.

Smartphones

Strengths	Weaknesses
• An already familiar technology. • Extensive use between users. • A wide range of formats for quantitative and qualitative data collection: videos photo, satellite images, geospatial mapping and more. • Facilitate remote interactive communications: voice, SMS text, email, video chats and more. • Help reduce the variability and enhance the understandability of a complex process. • Can include passive monitoring (might be perceived as not intrusive).	• The use of smartphones is not so extensive in some geographical areas (i.e., developing countries). Thus, these people who do not own a smartphone could be at risk of being excluded.
Opportunities	**Threats**
• Vendors are adding features to turn devices into hubs for storing and interpreting health and medical data. • In low-income and developing countries, smartphones could become a cost-effective way of collecting public health data. • Possibility of analysing mobile data in real-time. • Aggregated data can minimize privacy concerns while still being of great value for public health. • Useful for public health surveillance Useful for monitoring behaviours. outside clinical settings and without depending on self-report (thus overcoming potential	• Information could be used to identify individuals.

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issues such as recall bias, measurement errors)	

Smartwatches and wearables

Strengths	Weaknesses
• A newer technology that's increasing in popularity. • Can touch the user's skin continuously to collect data on heart rate, oxygen saturation, temperature and skin conductance 24/7. • Wrist accelerometry can identify activities such as smoking, eating, walking and running and estimate energy expenditure.	• An intense workout or loose band can mess with the smartwatch sensors, impacting data reliability. • The short battery lifespan of some devices may hinder acceptance.
Opportunities	**Threats**
• Regulatory approval is also making it easier for people to continuously monitor their hearts with wearable devices. • Health insurance companies are experimenting with using smartwatches to encourage customers to measure their fitness and exercise.	• Some insurance policies are demanding policyholder use, risking a patient backlash and heightened regulatory scrutiny. • Biopharmaceutical R&D scientists may not be familiar, creating a barrier for adoption in trials.

Adoption and impact [7, 8, 9]

A 2017 study showed five billion people connected to mobile networks, or two-thirds of the world's population, but slowing growth. More than half of mobile connections are smartphones. Nevertheless, smartphone ownership can vary widely by country and within a country based on socio-economic status, even across advanced economies where the age gap has been closing since 2015. In emerging economies, the age gap in ownership has been growing in recent years with faster adoption among younger groups.

Smartphone technology has transformed many aspects of our lives; healthcare is no exception. A 2012 survey showed almost half of smartphone users use their device to access health-related services.

Mobile apps are increasing in popularity with end users and becoming mission critical for businesses. Globally, 197 billion mobile apps were downloaded in 2017 with that number

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expected to reach 352 billion by 2021. Mobile apps are convenient tools on personal smartphones and also serve as a gateway to help companies better understand, connect with and continuously engage their users.

Growth in wearables is around 12% a year with smartwatches accounting for more than half of all sales. User penetration is expected to rise from 5.6% in 2019 and to 5.9% by 2023.

Future trends [5, 10]

4G is forecast to account for half of the global mobile connections by 2025 (up from around a quarter today). 5G smartphones will make their appearance in 2019, but the technology is not expected to take off until 2021 or 2022. 5G adoption is likely to be slower than 4G and expected to reach around 14% by 2025.

Smartphone technology is evolving constantly. Future developments include not only foldable smartphones but the addition of camera sensors. Future 3D-sensing lenses will facilitate augmented reality and gesture recognition and, with that, opportunities for collecting new types of data.

Wearable technology is developing constantly, with tremendous improvements. Security is increasing, devices are consuming less memory and file space, batteries are advancing and devices are becoming ever easier to use.

In the near future, mobile devices may eliminate the need for bulky files and documents for each patient. Instead, wearables would make important information easily accessible.

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Social Media [11, 12, 14]

Social network sites (SNS) and social media include all types of online social platforms that allow participants to share interests, opinions and many other social interactions. Well-known examples are Twitter, Facebook, Google+ and so on. The importance of SNS is reflected by increasing efforts within health sectors and organizations to embrace SNS. Facebook, for instance, has been utilized successfully for recruiting online survey participants (Nolte et al., 2015).

Social media monitoring (harvesting) extracts information from social media networks is the fourth primary method of data collection in social sciences. In some instances, the users generating the information are known, while in others they are not.

SWOT Analysis [11, 12]

Strengths	Weaknesses
• An environment where sharing information, knowledge, interest and opinion is not only meaningful and fun. • Data is usually fine-grained, real-time and on a global scale. • Data can be collected automatically and unobtrusively, and without affecting social behaviour. • Increasing use has generated rich information online (useful for recruiting and follow up cohort participants).	• The demographic and psychological variables of users may not be known, impacting the quality of the data collected. • Users generating the information are often anonymous or use avatars. • Self-reported data may introduce self-selection bias, sampling bias or other generalizability/reliability issues. • Data is analysed by researchers with very different backgrounds. • Collecting Big Data requires a new set of methods, as well as careful preparation with regard to compliance to GDPR. • Bias related to users' socio-demographic or socioeconomic characteristics (parts of societies don´t use SNS at all).
Opportunities	**Threats**
• A great way to reach hidden and hard-to-reach groups. • Can help share or receive public messages ubiquitously and at low cost. • An effective way of helping patients with chronic diseases manage their health conditions.	• Platform designs dictate how users can behave and, therefore, what behaviour can be measured. • Large numbers of spammers and bots masquerading as normal users may mistakenly be incorporated into measurements and predictions of human behaviour.

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Adoption and impact [13]

The number of social media users worldwide in 2019 is 3.484 billion, up 9% year-on-year. Almost a quarter of the world's population is now on Facebook.

Social media sites have transformed the way people communicate and socialize on the web, becoming more powerful as they grow since they feed off interactions among people. By increasing the visibility of issues, social networking has shifted the balance of power from the hands of a few to the masses. At the same time, we could say that the power has shifted to those who are active on social media, i.e. predominantly younger people and organisations, lobbyists, parties ... Social Media are a platform for activists and campaigners of any couleur.

Future trends [11]

As information technology evolves, sharing medical scientific information is moving from print and on-site presentations to digital online publication (webinars, etc.). Social media is the ideal platform for this, enabling everything from hosting and sharing information to interaction.

SNS has a niche role in health research. We need to ascertain how to use it effectively without affecting the quality of research.

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Geospatial Technology [15, 16, 18, 23, 24, 27, 28]

Geospatial technology collectively refers to Global Navigation Satellite Systems (GNSS), Geographical Information Systems (GIS) and Remote Sensing (RS). A GIS is the mapping of geographical coordinates with other, mostly location-based information. GPS, GIS and accelerometry in combination can provide a detailed picture of study participants' interaction with their environment.

Positioning technologies, such as the Global Navigation Satellite System (GNSS), are a satellite constellation that transmits signals from space to users with a compatible device to determine that person's position, velocity and time. Researchers have made use of positioning systems to, for instance, investigate the link between location and engagement in physical activity. The widely used GPS - Global Positioning System - is the US-American global navigation system and GALILEO the European pendent, to name just the most relevant systems for Europe and America. Common to all is that receiving the GNSS-signals through a mobile device is a passive process, i.e. the device receives geospatial coordinates that are mapped on other information like maps (which might be available offline or online. A device using GNSS only does not send out own location data. This only happens if the user allows apps to use the data (using the location-data without authorisation of users is illegal). This is worth mentioning because many people hesitate to use GNSS because they believe their position is being tracked.

GIS or spatial analytics capture, store, manipulate, analyse and interpret relationships, patterns and trends in digital spatial (geographic) and related data. Researchers might use them to track child immunizations or analyse, visualize and map diseases, for instance.

Vital for updating GIS data, remote sensing gathers information about an object without any physical contact, most commonly using airplanes, satellites and drones. Microwave remote sensing techniques are being explored for detecting minute vibrations on the body surface induced by heartbeat and respiration. Examples of remote sensing use cases include surveillance of a patient's movements, monitoring cardiac and respiratory parameters, screening of patients with infections and analysis of environmental factors in air-borne, vector-borne, soil-borne, and water-borne diseases.

SWOT Analysis [19, 21, 24, 25, 26]

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Geospatial and positioning technologies and analytics

Strengths	Weaknesses
• One-time investment that enables rapid data collection. • As these technologies require effective planning and strict monitoring, it enhances more transparency. • High accuracy, leading to better predictions and analysis. • Integrates a wide range of data sources. • Make complex data easier to understand. • Reveals relationships, trends and patterns in maps, charts and more.	• Expensive. • Free publicly available resources often lack basic information. • Results only as accurate as the data. • GIS needs a signal in remote areas. • Issues with data ownership/licencing with the growing data volume and variety.
Opportunities	**Threats**
• Link to EHR data to evaluate how the environment contributes to health. • Provides knowledge about the proximity to resources for treatment. • Huge investments in gathering and disseminating geospatial resources for public use. • Volunteered geographic information (VGI) groups popularizing collection of geospatial data.	• Lack of awareness impeding adoption. • Lack of the required specialised skill set, knowledge and understanding. • Privacy and data protection concerns. • Gap in adoption between developed and emerging economies. • Rapid technology evolution means GIS systems quickly becoming obsolete.

Remote sensing

Strengths	Weaknesses
• Cost-effective for quickly assessing trends across large areas. • Allows for the easy collection of data over a variety of scales and resolutions. • Not burdensome to patients. • Can reduce the risk of secondary infection. • Works practically anywhere, monitoring of remote areas possible.	• Fairly expensive, especially when measuring small areas. • Needs manual interpretation that requires specialised expertise. • Instruments may be uncalibrated, leading to uncalibrated data.

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Opportunities	Threats
• Remote monitoring systems (RMS) provide many opportunities for interactivity.	• Risk of human error with selection and interpretation of data and also with calibration of sensors.

Adoption and impact [15, 20, 22, 29, 30, 31]

While user adoption in developed economies is very advanced, the same is not true for the developing and emerging economies. The silos of research, policy and funding for public health, environmental health and personal medicine must be broken to halt the slowdown in adoption.

The GPS market size was estimated at USD 37.9 billion in 2017 and is anticipated to progress at a CAGR of 18.4%. Increasing penetration of smartphones, surging social media use and rising GPS-enabled vehicles is projected to bolster market growth. Early adopters include private healthcare.

The tremendous potential of GIS to benefit is beginning to be realized in the healthcare industry with both public and private sectors developing innovative ways to harness the data integration and spatial visualization power of GIS.

Technology advancements and demand for high-tech sensing systems are driving growth in the remote sensing technology market, with the global market expected to grow at a CAGR of 15.14% between 2017 and 2022 and to reach USD 21.6 billion in 2022.

New diseases and epidemics spread through the world's population every year. The discipline of medical geographic information systems (GIS) provides a strong framework for our increasing ability to monitor these diseases and identify their causes. It is an invaluable approach, which identifies and maps medically vulnerable populations, health outcomes, risk factors and the relationships between them.

The evolution of medical GIS from early disease maps to digital maps is a journey long in the making, and continues to evolve. These maps have enabled us to gain insight about diseases ranging from cholera to cancer, all while increasing the knowledge of worldwide health issues. As modern technology continues to thrive, medical GIS will remain a lasting approach for understanding populations and the world we live in.

Future trends [17]

The future will see sensor data processed more effectively and automatically, location-based applications developed and high volumes of unstructured data integrated. Improvements in accuracy will be driven by an increased dependency on location information and consumer demand for geographical accuracy.

Collaboration between different sources is likely to increase over the next five to ten years, with GIS having a greater importance in tomorrow's increasingly information-intensive healthcare environment. With the availability of large amounts of multidimensional data, new techniques are emerging that apply these data to a wide range of applications, such as holistic systems suitable for complex health studies.

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Smart Sensors [32, 33, 34, 37, 38, 39]

Smart sensors are pill-sized ingestible electronic devices that include a power supply, microprocessor, controller, sensors, etc. Composed of biocompatible materials and roughly the size of a medicine capsule, their ability to light up, buzz and send text and voice messages makes them ideal for disease diagnostics and monitoring. Ingestible sensors might commonly measure temperature, pressure, pH or images. They could also, for instance, detect signs of excessive bleeding in the gut and then transmit the results to a smartphone, alerting the user of signs of an impending issue.

Bio-sensors use a living organism or biological molecules, especially enzymes or antibodies, to detect the presence of chemicals. They range from consumer products, such as blood pressure monitors, through specialised measurements, such as spectroscopy for non-invasive blood glucose monitoring for blood-withdrawal-free diabetes screening.

SWOT Analysis [33, 35, 39, 40]

Smart sensors

Strengths	Weaknesses
• Simpler diagnosis and management of a range of diseases. • Reduces the need for invasive procedures.	• Some people may not like putting devices into their bodies. • Harvesting huge amounts of data and putting them to work requires extremely costly and sophisticated network infrastructure: high-speed data networks, mammoth servers and powerful computers. • Still in development; need refinement.
Opportunities	**Threats**
• As more intelligent objects become ubiquitous and interlinked, a new world of opportunities will arise from the larger and richer data sets these devices produce. • Researchers across a number of industries can potentially provide more accurate predictions and insights tied to the world around us—but only if they're able to successfully gather and understand the information flowing in.	• Raises numerous scientific, legal and ethical questions as people can be monitored without knowing.

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Bio-sensors

Strengths (internal)	Weaknesses (internal)
• Allows continuous monitoring of vital signs. • Suitable for both long-term monitoring and single shot analysis. • Can be used in resource-limited settings and sophisticated medical set-ups. • Can use a range of transduction techniques, including electrochemical, optical and acoustic. • Suitable for everyone from premature infants to athletes.	• Issues with stability, costs and ease of manufacturing of each component. • Can be powered by acids in our stomachs, no longer having to rely on batteries to lower costs.
Opportunities	**Threats**
• Government agencies bolstering research activities. • High levels of investments into translational research worldwide. • Facilitating self-monitoring to control health and prevent disease, alleviating the burden on the health system.	• Difficulties translating research into commercially viable prototypes. • Complex regulatory issues in clinical applications. • Specialist skill set, knowledge and understanding is lacking. • Requires different disciplines to work together.

Adoption and impact [34, 36, 39]

The ingestible sensor market is growing because of the need for real-time patient monitoring and medication adherence as well as an increase in chronic diseases and improved accuracy in invasive diagnostic tests. It is expected to grow from USD 198.2 Million in 2015 to USD 678.2 Million by 2022, at a CAGR of 20.2% between 2016 and 2022.

In emerging economies, sensor-driven technology can foster socioeconomic development and increase the country’s ability to compete on the world stage. A new world of opportunities will arise from the larger and richer data sets as more intelligent objects become ubiquitous and interlinked. Researchers across industries could potentially provide more accurate predictions and insights if they’re able to successfully gather and understand the information.

The rapid development of biosensors is due mainly to developments in nanotechnology, miniaturisation and microfabrication technologies; the use of novel bio-recognition molecules; novel nanomaterials and nanostructured devices; and better interaction between life scientists and engineering/physical scientists.

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The global biosensor market is expected to grow at a 12% CAGR between 2018 and 2023, from revenues of USD 17.7 billion in 2018 to USD 31.2 billion by the end of 2023.

Future trends [40]

Nano-sensors and other smart pill technologies could change the game when it comes to wireless health. Image, speech, and voice recognition will advance to near 100% accuracy by 2025 while the speed of analytics will grow thirty-fold by 2030, with 95% of queries answered in milliseconds.

Key trends driving sensor technologies include miniaturization of sensors easing integration; increase in aging population; high demand for enhanced safety; and growth in real-time, and remote monitoring that reduces healthcare expenses offer opportunities for growth.

Theranostics (portmanteau of therapy and diagnostics) offers an important new financial model to drive further development of biosensors. The expanding biosensor market generated will stimulate the development of new, inexpensive sensor platforms with implantable biosensor for long-term usability one key R&D focus area.

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Crowdsourcing and Crowdseeding [42, 45]

Crowdsourcing and crowdseeding are real-time data collection methods. While with crowdsourcing, information is obtained directly from technology users who volunteer their own data; with crowdseeding, information is obtained from trained informants in the field. They may make use of mobile health (m-health) technologies but this is not a requirement.

Crowdsourced data collection is when researchers turn to internet communities to answer research-, survey- or feedback-questions.

Crowdsourcing is used in health-surveillance, both in the context of research and in emergency situations for planning of operations. A physical crowdsourcing exercise conducted in a mall, for instance, recruited 500 participants for skin self-examination for melanoma. The researchers implemented various thresholds to improve crowd results.

SWOT Analysis [41, 45]

Strengths	Weaknesses
• Can collect a huge amount of information from a large number of people. • At least as accurate as traditional research methods. • Can cover unpredictable events, produce novel discoveries • Can also be used to raise public awareness. • Innovative and adaptable. • Has already been widely used.	• Difficult to assure quality outputs with scale up. • Anonymous and compensated participation may provide unsatisfactory quality data. • Often undertaken by a small set of crowd workers, many with low income, who spend long hours on the website. • Description of crowdsourcing logistics and crowd workers' characteristics frequently missing in study reports.
Opportunities	**Threats**
• Provide more accessible health care to more communities and individuals rapidly and to lower costs of care. • Great potential in global health where resources are lacking. • Can cover a variety of research, including quickly evolving epidemiological research and traditional behavioural research.	• Potential for fraud and manipulation through monetary means, administrative privileges and malicious attacks.

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Adoption and impact [44]

The application of IT-mediated platforms such as crowdsourcing is undeniably increasing in both developed and developing countries in private and public sectors.

The future is human-centric, about participation and the ability to co-create via an increasingly connected world. New ways of doing things - including crowdsourcing, crowdfunding, co-creation, collaboration and open innovation - are challenging established business models, offering an immense opportunity to rethink and reinvent conventional processes.

Future trends [43]

Crowdsourcing is rapidly evolving. It is expected that some of the current limitations of crowdsourcing platforms, such as the inability to use different forms of crowdsourcing simultaneously, will be addressed by the development of new hybrid crowdsourcing platforms.

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Artificial Intelligence [46]

Artificial intelligence (AI) is described as “The theory and development of computer systems able to perform tasks normally requiring human intelligence, such as visual perception, speech recognition, decision-making, and translation between languages.” It is often divided into two major categories: Natural Language Processing (NLP) and Machine Learning (ML). NLP refers to the elements of AI relating to speech. ML refers to intelligent machines using sophisticated algorithms to learn to perform specific tasks autonomously.

Before AI systems can be deployed, they need to be ‘trained’ through data so they can learn about similar groups of subjects, associations between subject features and outcomes of interest. In healthcare settings that may be data generated from clinical activities, such as screening, diagnosis and treatment assignment. These clinical data often exist in medical notes, electronic recordings from medical devices, physical examinations and clinical laboratory and images.

Arterys’ medical imaging platform became the first FDA-approved AI-based platform for helping cardiologists diagnose cardiac diseases. It uses AI to provide automated, editable ventricle segmentations based on conventional cardiac MRI images. Somashekhar et al. demonstrated that the IBM Watson for oncology would be a reliable AI system for assisting the diagnosis of cancer through a double-blinded validation study.

SWOT Analysis [46, 48]

Strengths	Weaknesses
• Learning and self-correcting abilities to improve its accuracy based on feedback. • Extracts useful information from a large patient population to assist in making real-time inferences for health risk alert and health outcome prediction. • Reduces diagnostic and therapeutic errors inevitable in human clinical practice. • Informs proper patient care by providing up-to-date medical information from journals, textbooks and clinical practices.	• Need to be continuously trained by data from clinical studies. • Continuous data supply is critical for further development and improvement. • The current healthcare environment does not provide incentives for sharing data on the system. • Real-life implementation is still facing obstacles.
Opportunities	Threats

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• Could use insights obtained in cohort studies.	• Current regulations lack the standards needed to assess their safety and efficacy. • Widespread fear that robotics and AI are going to take away people's jobs.

Adoption and impact [46, 48, 49, 50]

A 2018 McKinsey Global Survey focused on the adoption of AI found 47% of companies had embedded at least one AI capability in their business processes and another 30% piloting AI – a sizable leap from just 20% using AI in a core part of their business or at scale in 2017.

Respondents to the survey from the pharma and medical products industries revealed where they had adopted AI: 31% of them in service operations, 31% in product/service development, 28% in manufacturing and 27% in sales and marketing.

Research from the McKinsey Global Institute estimates that the disruption of society caused by AI is happening ten times faster and at 300 times the scale than the Industrial Revolution, having roughly 3,000 times the impact.

Particularly when combined with robotics, AI is helping to improve workplace productivity and, as such, the economies of many developed countries. Gartner estimates that 30% of data centers failing to apply AI effectively will cease to be operational and economically viable by 2020.

AI is bringing a paradigm shift to healthcare, powered by the increasing availability of healthcare data and rapid progress of analytics techniques. Technologies could help more quickly and accurately diagnose heart disease, cancer, strokes and more.

Future trends [47]

AI will have a dramatic impact on many industries, including healthcare. As the technology becomes more developed and widespread, it could help diagnose strokes, eye disease, heart disease, skin cancer and other conditions. Research, however, mainly concentrates around a few disease types: cancer, nervous system disease and cardiovascular disease.

Integrating AI with geospatial technologies will pave the way for better workflow automation, process and project management.

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Passive Data Collection [51, 52]

Passive data collection occurs without any overt consumer interaction and generally includes capturing user preferences and usage behaviour, including location data, from personal mobile devices. A well-known example is the use of cookies on a user's computer to capture Internet browsing history. It is traditionally used for market or political research.

SWOT Analysis

Strengths	Weaknesses
• A better representation of preferences and future behaviours than with expressed opinions. • Objective measure of user experience, duration and frequency of activities, preferences and habits. • Can provide incomparably more samples over a shorter period of time.	• Informed users can control cookies. • The various types of data and file types that are collected can be quite complex. • Every transaction from server to client results in the creation of a log file. On any site with heavy traffic, the volume of information collected and interpreted is immense, especially when transactions involve embedded files like graphics that take up space. Processing log files can take substantial time and system resources.
Opportunities	**Threats**
• Passive data collection is naturally easier to recruit for as there is no opt in, or one which requires minimal effort. • The sample you select can be huge, much bigger than for any survey or equal research project.	• Fears of misuse of data growing as users become more aware. • Fears of discrimination and invasion of privacy, specifically with techniques becoming increasingly sophisticated.

Adoption and impact

Passive data collection is the automatic gathering of consumer data through their behaviour and interaction without actively notifying or asking the consumer's permission. This means, most consumers don't even realize how much data is actually being captured, nor how it's being used or shared.

Examples of passive data collection are a browser or mobile device recording your location. Even though you may have clicked okay when first asked if the resource could monitor you, the device passively records your position from there on out.

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Future trends

There have been questions about passive data collection and the role that it will have in the future of market research – however, as long as people are looking for large samples in short timescales, passive data collection will be around.

Many of the leading thinkers in policy for the Internet, specifically the W3 consortium, are addressing the "Open Personalization Standard." This standard will serve to blur the lines of active and passive data collection allowing a user to actively define the information they are willing to provide and to whom.

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3. CONCLUSIONS [53]

We are moving toward the fourth industrial revolution, in which mobile communications, social media and sensors are blurring the boundaries between people, the internet and the physical world. Data is increasingly building up on who we are, who we know, where we are, where we have been and where we plan to go.

MOBILE is a Fait Accompli. 5G, the next generation of wireless connectivity, promises faster connections, lower latency and improved security. Smartphones and wearable technology are evolving constantly, with tremendous improvements: analysing mobile data in real-time, aggregating data that minimize privacy concerns and vendors adding features to turn devices into hubs for storing and interpreting health and medical data. Future 3D-sensing lenses in our smartphones will facilitate augmented reality and gesture recognition and, with that, opportunities for collecting new types of data.

Other stakeholders such as regulatory authorities and health insurances are starting to embrace mobile technologies, and encourage their use to monitor behaviours outside the clinical settings and measure customers' fitness and exercise.

Social media, on the other hand, offer great solutions to reach hidden and hard-to-reach groups and can be an effective way of helping patients with chronic diseases manage their health conditions. We need to stay vigilant though as social media platform designs can dictate how users can behave and, therefore, what behaviour can be measured, impacting the quality of data.

Collaboration between different sources is most likely to increase over the next five to ten years, with GIS having a greater importance in tomorrow's increasingly information-intensive healthcare environment. With the availability of large amounts of multidimensional data, new techniques are emerging that apply these data to a wide range of applications, such as holistic systems suitable for complex health studies. The capacity of GIS to link disease information with environmental and spatial data makes it an asset in the progression of worldwide healthcare.

Additionally, health organizations can now visualize, analyse, interpret and display multifaceted geo-location data through the use of GIS tools, mapping applications and Big Data. These new tools have unleashed new modelling techniques previously thought impossible. Continuing innovations in GIS and Big Data make this an exciting time for medical GIS, and it will be interesting to witness how new technologies, analytical techniques, and data sources will shape the future of the discipline and impact the way we are conducting trials.

Nano-sensors and other smart pill technologies could change the game when it comes to wireless health. Key trends driving sensor technologies include miniaturization of sensors easing integration and facilitating self-monitoring to control health and prevent disease, alleviating the burden on the overall health system.

Crowdsourcing and crowdseeding provide more accessible health care to more communities and individuals rapidly and to lower costs of care and has great potential in global health where resources are lacking. This technology can cover a variety of research, including quickly evolving epidemiological research and traditional behavioural research. The threats with this collection tool is the potential for fraud and manipulation through monetary means, administrative privileges and malicious attacks, as well as the quality of data.

It was discussed whether or not Artificial Intelligence should be included in this review of new and emerging data collection tools. Although most current AI applications are within the field of engagement, recruitment and matchmaking, the tool holds a promising future in identifying new

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paths, and therefore new data, within large datasets. It is a domain to be watched closely as it is just the beginning of an exciting and promising journey.

As a final conclusion, all of these advances in new technologies allow researchers to collect and process phenotypic data with greater detail and precision, in more natural settings, over longer periods of time and with lower cost and participant burden than ever before.

Speed and accuracy of data collection, as well as continuous monitoring, offers great opportunities for future development and optimization of patient and population cohorts.

Continuous monitoring is an important contributor to realizing the vision of personalized medicine, allowing health care providers to precisely predict an individual's risk of getting certain diseases as well as his or her response to specific therapies based on his or her genotype (genetic information) and phenotype (human traits and behaviours). By linking information about an individual's genotype and the phenotype, continuomics can lead to individualized diagnoses and therapies on a scale previously unimaginable.

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