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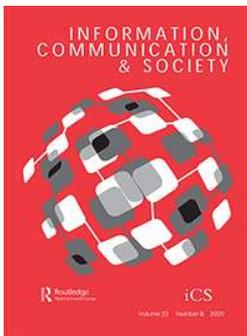
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Published online: 13 Jul 2020.

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Navigating standards, encouraging interconnections: infrastructuring digital health platforms

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ABSTRACT

Apps, websites and networked devices now offer to help consumers produce, access and share health knowledge, precipitating social scientific concern over the consequences of these so-called digital health platforms. This paper makes a novel contribution to this literature, taking up a recent call from Plantin et al. to adopt an infrastructural lens in exploring platforms. It argues, through empirical analysis of digital health platforms of different sizes, ages and nationalities, that this conceptual tool is necessary to surface the work entailed in creating and sustaining digital health platforms. Additionally, we suggest that the social scientific literature on platforms – and initial efforts to explore their infrastructural qualities – frequently focus too strongly on the dominant technology companies. Instead, we emphasise the value of drawing emergent companies' platforms into empirical purview through returning to some of the infrastructures literature that informs Plantin et al. – particularly Susan Leigh Star and colleagues. We demonstrate empirically the importance of looking at standards as part of infrastructure building, and the broader set of interconnections between different actors and materials within an infrastructure. In doing so, we demonstrate the value of an infrastructural lens for understanding the density of interconnections that characterise digital health and propose some orientating questions for further enquiry into the infrastructural qualities of platforms.

Introduction

Apps, websites and networked devices increasingly offer to help consumers produce, access and share health knowledge. In the commercial sector these are often characterised as 'digital health platforms' (DHPs), which promise to connect users engaged in self-care with healthcare providers, collating data from sensors in smart phones or purpose-built hardware (e.g., wearables or networked monitors) and allowing them to be shared and reviewed. In both Europe and the US, policy makers frame these technologies as enabling

a digital health revolution, lengthening lives and reducing strain on secondary care (e.g., NHS, 2019). Social scientists are more pessimistic about new digital health technologies, pointing to their potential as surveillance technologies (e.g., Lupton, 2017). However, both these positions rely on an assumption that DHPs work in fairly similar ways, that they will grow and become more embedded in everyday life, and sometimes that the interests of governments and companies will tend to align. In this paper we apply an 'infrastructural lens' to inform a critical account of DHPs, highlighting underexplored elements of their activities and growth.

Today's digital health landscape is the result of numerous efforts to gather and share health-related data since the 1960s. Technology companies have long provided products to healthcare providers. After several decades of local innovation, in the 1980s the UK's public National Health Service saw policy reforms seeking to embed computer systems across different settings (Gillies, 1998). In 2002, efforts to integrate these systems precipitated software licensing agreements with key players like Microsoft and large healthcare software companies like Phillips, iSoft and Cerner (Brennan, 2005). Over a similar period, efforts in the US encouraged healthcare's 'digitisation', seeing hospitals partnering with technology companies to create computer systems (Wachter, 2015). More recently, the consumer-facing health technology sector emerged in the US. This started with discrete devices, e.g., wearable company Fitbit was established in 2007. In 2009, Fitbit won an award at industry tradeshow Consumer Electronics Show (CES), which also established a Digital Health Summit (CES, 2019). More established companies quickly offered health-related products. In 2008, Google offered to amalgamate one's health records into a 'Google Health' profile, before discontinuing in 2011 because of low take-up (Brown & Weihl, 2011). In 2014, it introduced Google Fit, an app which collates health and fitness data from other apps and devices. It has since announced it will acquire Fitbit (Gartenberg, 2019). In 2014, Apple introduced Apple Health, an iPhone app that collates data from other apps, from an inbuilt pedometer in the iPhone and from Apple Watch and can 'push' these into proprietary patient record systems.

Responding to these developments, a body of social scientific scholarship exploring DHPs has emerged. What Ruckenstein and Dow Schüll (2017) describe as health's datafication has been noted for its potential to support efforts by states, employers and companies to surveil and govern users (Till, 2019), and to allow sale of users' health data between platforms, aggregators, researchers, insurers and healthcare providers (Lupton, 2017). Empirical studies have focused on the dominant digital players above like Apple and Google (e.g., Sharon, 2016), specific apps such as MyFitnessPal (e.g., Didžiokaitė, Saukko, & Greiffenhagen, 2018), activity-tracking platforms like Fitbit (e.g., Fotopoulou & O'Riordan, 2017), and disease-related apps (e.g., Kenner, 2016). Other recent research has also undertaken ethnographic analysis of the Quantified Self community which use DHPs (e.g., Dudhwala, 2018).

In this paper we look beyond well-known players like Apple and Google, or a focus on one specific DHP or movement, to consider a more diverse set of companies offering DHPs in the messy and contested space of digital health. By developing fine-grained empirical accounts of different products and strategies, we follow Plantin et al.'s recent argument, suggesting the platform concept (Gillespie, 2010; Srnicek, 2017a; van Dijck, Poell, & de Waal, 2018) be further developed through an 'infrastructural lens'.

We first provide an overview of the platforms literature, outlining Plantin, Lagoze, Edwards, and Sandvig's (2018) call to draw connections between the platforms and

longer-standing infrastructures literatures. Building on Plantin *et al.*, we focus on scholarship about knowledge infrastructures (e.g., Star & Ruhleder, 1996), further emphasising how standards are part of infrastructure building, including those underpinned by states, and the interconnections between different companies, users, hardware and software. In so doing, we contribute to this special issue's interrogation of contemporary health knowledge landscapes and provide empirical articulation of the value of 'infrastructuring' platforms – i.e., applying an infrastructures lens to platforms, *and* acknowledging the layers of infrastructural 'work' that produce and sustain them.

Theorising platforms

The 'platform', a term invoked by technology companies because of its apparent neutrality as mere facilitator between actors (Gillespie, 2010), has become a central topic in new media scholarship. Many scholars have offered definitions of the term, emphasising that platforms are more than intermediaries, but actively create value from their position (Srnicek, 2017a), most often through finding markets for data generated through use. For example, both Facebook and Google offer specific services – connecting friends or helping users locate information on the internet – but sell data generated to advertisers (Gillespie, 2010). These activities are not secret but may be downplayed in the companies' public accounts.

Data and their potential value are thus central in the world of platforms. According to Srnicek, they are 'the basic resource that drives' the latest iteration of capitalism, *platform capitalism* (2017b, pp. 254–5). As Leaver (2017) notes, DHPs in particular may involve two kinds of profitable commodity: hardware/software (devices like wearables are often sold to consumers), and the data produced by users, but he argues that DHP companies' 'larger long-term commodity is the aggregated big data and related insights, not the individual-level consumer products and apps' (2017, p. 3; also see van Dijck et al., 2018).

Much of the work on 'platforms' also focuses on a few corporate entities: Google (owned by Alphabet), Amazon, Facebook, Apple and Microsoft. These 'Big Five' companies share global reach with interests in consumer and industry hardware and software offering different functions. They also share an apparent expansionary, cross-sectoral ethos, evident in absorbing smaller companies into their portfolios (e.g., when Google bought Youtube), and capitalising on their size and centrality to secure a dominant position in growing fields, like Apple and Google's moves into digital health, described above. While van Dijck and Poell (2016) distinguish between DHPs on the basis of their functionality (e.g., diagnosis platforms, fitness platforms, health monitoring platforms) the efforts of these major players to offer users technology for multiple functions complicate any such characterisations.

The concept of platformization (Helmond, 2015) describes the process of linkages between different actors, as fewer dominant companies are encouraged to become 'interoperable' with these larger companies. One way this happens is through application programming interfaces (APIs), protocols made available by companies to external developers. These encourage linkage between dominant companies and other actors (e.g., companies encouraging users to 'log in' to their website by using their Facebook account, rather than making a new account). APIs are thus important strategic elements of platforms (Bucher, 2013; van Dijck et al., 2018): dominant companies stand to access

new data about consumers' preferences and activities (Nieborg & Poell, 2018), whilst those who connect with them might attract users with an immediately personalised experience (see Facebook, 2019). This literature prompts questions about the interoperabilities promoted within the digital health field particularly. In this paper, we build on Plantin et al.'s (2018) work, expanding upon their conversation with Susan Leigh Star and colleagues. In so doing, we suggest that a 'infrastructural lens' may be useful not only to exploring the growth of specific large technology companies, but also the underlying web of interactions and interdependencies that constitute DHPs.

Infrastructuring digital health platforms

The interrelation between digital platforms and infrastructure has come to prominence in recent years, building partly on scholarship into the materiality of media systems (e.g., Parks & Starosielski, 2015). A particularly useful intervention that explores the broader heuristic richness of 'infrastructuring' platforms comes from Plantin et al. (2018). This conceptual paper, authored by scholars of media and communications, information sciences, and Science and Technology Studies (STS), explores cross-articulations between literatures on platforms and infrastructures. The authors' account of the promise of 'infrastructure' builds on several decades of social scientific work on technology. They identify the concept of infrastructure with widely distributed systems that provide services 'essential to our daily lives' (2018, p. 295), suggesting that the expansion of companies like Google and Facebook into different aspects of life means that they can be analysed as 'infrastructures' as well as platforms.

They elaborate what it might mean to study digital platforms this way by drawing from STS scholars who provide historical analyses of the often difficult emergence of large technical systems like electrification (e.g., Bijker, Hughes, & Pinch, 1987), suggesting these historical comparisons may enrichen the platforms literature by drawing attention back to material structures and the importance of locality. Plantin *et al.* also emphasise the need to consider 'standards' that enable such systems. Though in their historical examples they suggest this results in a view of infrastructures as 'shared, widely accessible systems and services of the type often provided or regulated by governments in the public interest' (Plantin et al., 2018, p. 293), they argue that commercial entities like Google and Facebook also draw on standards that require close analysis.

Work directly building on Plantin et al. (2018) shows how this approach can be useful in drawing attention to important aspects of the dominant digital platforms. In research on WeChat – the social media platform owned by Tencent, a large Chinese conglomerate – Plantin and de Seta (2019) explore its 'infrastructural expansion' to become perhaps the most popular mobile chat platform in China. In their analysis, the government's enabling role is a crucial element of the story. Elsewhere, Mohan and Punathambekar (2019) research the 'infrastructuring impulse' of popular video-sharing platform YouTube (owned by US conglomerate Alphabet). Their focus on southern Indian Youtube content reveals the need to acknowledge the locality of usage as global platforms look to respond to regional specificities and practices.

Van Dijck *et al.* also build on Plantin *et al.*'s arguments. They usefully suggest distinguishing between *infrastructural* platforms – which have taken on Plantin *et al.*'s qualities of infrastructures, and *sectoral* platforms (i.e., between the 'Big Five' companies with

cross-sector interests, and those companies focused on one sector like health). Importantly, however, they note that these distinctions 'best be understood as roles and relationships that particular actors take on, rather than as fixed categories' (2018, p. 19), noting that such roles are highly contingent, shifting with time and context. We exercise a similar reluctance with relying too much on distinctions between single- and multi-sector, or even small and large platforms, suggesting that Plantin *et al.*'s infrastructural approach also has potential value for looking at different platform actors beyond dominant cross-sectoral technology companies, to identify other elements of platforms. For example, Kelkar (2018) draws on Plantin et al.'s (2018) discussion of infrastructures in his account of educational platform Edx, to account for its ability to connect and shape the worlds of different users through an 'assemblage' of software, institutions, knowledge claims, and people (developers and users alike).

In this sense, we see the value of extending the infrastructural lens beyond dominant platforms. We suggest that doing so centralises how standards and interrelations – and the work of navigating these – are central components of other platforms too.

By turning this lens to other platforms, and to DHPs in particular, certain commitments within the infrastructures literature stand to become particularly relevant given the medical world is 'replete' with often-contradictory standards (Bowker & Star, 2000, p. 12). Beyond the large technical systems literature, for example, Plantin *et al.* draw other STS studies of infrastructures into their discussion. In particular, they highlight the relevance of studies focusing on the stability and interoperability enabled by standards grounded in scientific measurement and knowledge claims, as well as regulatory efforts by professional bodies or governments (Star & Ruhleder, 1996). In this paper, we draw particularly on this body of literature as we take up Plantin *et al.*'s invitation to see the infrastructural qualities in platforms.

Star notes how different claims to knowledge may materialise in various standards. Star's account of information infrastructures was based on ethnographic research on scientists, and their relatively early use of computing and the internet to create new networks between researchers working on related topics. This ethnographic work shares with the large technical systems literature a sense of the difficulty of creating infrastructures, though Star and colleagues place more emphasis on the importance of the sometimes arduous, and often never completed efforts to agree upon and work with classifications and standard ways of recording information. In what follows, we pay particular attention these efforts as we unpack the work of navigating the layers of standards in the context of DHPs. Standards can also exclude particular categories/experiences by making them unintelligible within an infrastructure. This informed Bowker and Star's (2000) analysis of the 'sorting' effects created by classification systems in medicine with what Star calls their 'pseudo-inclusive generic' (2002, p. 199) – e.g., 'flesh-coloured' prostheses with a light skin tone – that create socio-material exclusions. Though exclusion is not a primary focus of this paper, we do highlight instances where standards may produce exclusion.

Through ethnography of ongoing infrastructural work, this literature also highlights the risk of missing some of the workers and work that goes into creating infrastructures (Star & Strauss, 1999). Within the social sciences literature on DHPs, as with the literature on platforms in general, key players like Google and Apple are framed as the new facilitators of medical research (e.g., Sharon, 2016) and making 'all individual platforms prisoners of

the larger connective ecosystem' (van Dijck & Poell, 2016, p. 8). Though important, analytic focus on dominant players arguably obfuscates the contingencies, experimentations, and failures of other actors. In this paper we seek to follow Star's commitment to less visible actors in networks, and her argument that by doing so, 'a very different network is discovered' (1990, p. 29).

Plantin et al.'s (2018) focus on standards and material structures, particularly their invocation of the work of Star and colleagues, is also useful for examining contemporary work in the development of DHPs. Engaging this conceptualisation of infrastructures requires attention to the dense set of interconnections between different companies, governments and users in creating DHPs. It also invites us to recognise the critical role of standards in making these infrastructures. Additionally, it emphasises the diverse forms of work that go into maintaining them.

Infrastructure as a concept thus allows us to consider the difficulties of creating knowledge infrastructures in the digital health space, as evidenced by the companies we examine here. In what follows, we explore these issues firstly through a discussion of the layers of standards at play for DHPs and secondly, by interrogating the various connections made by different DHPs as they establish and sustain themselves.

Methods

Data presented here were collected as part of a Leverhulme-funded study exploring, in part, how commercial proponents of health self-monitoring understand the practice and those who undertake it. In doing so, we set out to understand the recent history of a set of companies which had experienced expansion and/or failure/retrenchment within the period of our work. We identified a purposive sample of companies with diverse histories, sizes and geographies, though all operate in the UK market, offering free apps and selling hardware that collect data with clear clinical relevance, e.g., blood pressure (BP), body mass index (BMI). The diversity of this sample of DHPs, some of whom have cross-sectoral interests, highlights the challenge – as noted by van Dijck et al. (2018) of producing stable categories (small/large, cross/sectoral, etc.), even in the context of DHPs.

Withings is a private French company founded in 2008. With an app and suite of consumer devices, its initial funding came from venture capital, before multinational Finnish telecommunications company **Nokia**, bought it in 2016 for USD\$191 million. Nokia rebranded the products and launched an interface for healthcare professionals (HCPs), looking to sell devices in bulk to hospitals for remote patient monitoring. In 2018, it sold the company back to an original Withings founder. **Qardio**, founded in the USA in 2012, is a 'start-up' company funded by venture capital. Its products include an app and a range of consumer health devices. Like Nokia, it offers an HCP interface. **Omron**, a large Japanese company established in 1948, spans various industries. In the 1970s, it began producing automated BP monitors. In 2016, it launched an app that synchronises with its networked devices. These variously sized companies span a range of industries. Whilst Qardio and Withings are smaller companies in the consumer health sector, Nokia and Omron are far larger cross-sectoral companies.

We gathered publicly available accounts of the actors from various sources: to explore companies' public representations of themselves, we collected online content from their

websites, including press releases. For Omron and Nokia, companies who produce annual reports, we also collected reports since 2010, which offer an insight into the way the companies display themselves to shareholders and rationalise their investment choices. We retrieved content discussing any of the four companies from trade press outlets focused on mobile technologies and digital health. This content offers observation (sometimes celebratory, sometimes critical) of these companies and their products, providing material to explore industry expectations and concerns. Additionally, we undertook walkthroughs (Light, Burgess, & Duguay, 2018) of these companies' apps, devices and platforms. This included collecting app store text/imagery, and working through user interfaces ourselves whilst making notes and screenshots. These offer another example of companies' public representation of themselves, as well as elements of their material engagement with users. The app walkthrough method also requires consideration of app terms and conditions and privacy policies, which reveal some of the future intentions of companies, particularly around potential future data sharing with third parties (see Table 1).

During this time, we also undertook interviews with a broader set of commercial and policy actors, including four anonymised companies who have produced self-monitoring devices and apps. It was incredibly difficult to secure interviews with commercial actors. In a highly mobile sector, some key contacts left their roles during our data collection period. Some were reluctant to share material that they considered commercially sensitive. Others agreed to participate on the condition that they could review/redact their accounts. This difficulty demonstrates the challenge of undertaking research in a commercial sector wherein platform companies necessarily provide multiple public versions of themselves to different constituencies (consumers, shareholders, regulators). To analyse data,[1] website material, press releases and annual reports were collated in NVivo and analysed via an abductive approach that views analysis as an 'inferential process' arising out of researchers' social and intellectual position (Timmermans & Tavory, 2012) particularly the authors' familiarity with the various literatures outlined above. App walkthrough data analysis focused on apps' aesthetics and design to consider their anticipated use and governance arrangements, as outlined by Light et al. (2018). The interviews with employees of a different sample of companies were professionally transcribed and read multiple times and analysed in relation to themes emerging both from the broader ongoing research and our analysis of the other data considered here.

Table 1. Sampled companies.

Company	Country	Date app/product suite established	Press releases[a]	Trade press[b]	App walkthrough	Annual reports	Company website text/imagery
					Data sources		
Withings	France	2008–16, 2018-present	20	49	X		X
Nokia	Finland	2016–18	9	31	X	X	X
Qardio	USA	2012-present	32	12	X		X
Omron	Japan	2010-present	14	27	X	X	X

[a] From January 2015 to January 2017. In the case of Nokia, we incorporated online content and press releases from the time they announced their intention to purchase Withings and for the period of their ownership.

[b] Searched websites: MobiHealthNews, ModernHealthcare, digitalhealth.net, mHealthWatch and MobileMarketingWatch were searched for material relating to these companies from January 2015 to January 2018 (inclusive). Items were sifted to include posts related to companies' apps/product suites.

Analysis

In the following sections, we first explore the layers of standards navigated by those working to develop DHPs, and then focus on the ways in which differing companies must cooperate with one another in this landscape to ensure continued profitability. Doing so reveals the challenging work of sustaining platforms in an arena saturated with standards and competitors.

We walk a fine line: navigating layered standards

Star and Bowker highlight the role of standards within infrastructures. Standards are, they argue, essential to the development of working infrastructures, and efforts to navigate them are central in 'how infrastructure happens' (2006, p. 234). We thus explore the layers of standards negotiated to make our sampled apps and devices workable, compliant and useful. These standards range from classificatory schemas that provide clinical measurement thresholds for users to make sense of their data (e.g., what constitutes 'normal' BMI), to medical device regulations that companies must meet to make their hardware saleable (e.g., ensuring devices meet safety and accuracy requirements set by regulators).

Perhaps the most obvious standards here are medical. Blood pressure (BP) and body mass index (BMI) are standards with histories. Whilst BP is generally no longer contested, BMI remains so (Williams, Weiner, Henwood, & Will, 2018). Bowker and Star (2000) note that attending to the standards and classifications texturing a given infrastructure can reveal exclusions at play. As noted in the Nokia and Withings app walkthroughs, when one provides a weight reading in the app, one's BMI is also calculated, and users can click 'What is the body mass index?' Clicking through, this page explains that BMI is a standard adopted by the World Health Organisation, noting 'a BMI between 18–25 defines a weight normality zone in which the risk of nutrition illnesses is minimal'. There is no acknowledgment of contestation around BMI thresholds for differently racialised groups (NICE, 2013). That standard BMI thresholds are treated as a guide for all users suggests a homogenised, white imagined user (Star, 2002) inscribed in a 'purportedly "universal"' technology (Plantin et al., 2018, p. 296)

Enrolling clinical measurement standards is still done carefully, however. In the Withings app walkthrough, measurements from its BP monitor are given a colour (e.g., green for 'optimal') to signify their positions on the European Hypertension Society's BP level classification, through which users can click to a detailed information page. Yet one company representative selling connected devices noted how showing these guidelines to users must be done carefully, as the standard may be useful for a clinical diagnosis, but its use in the consumer sphere does not confer upon users the expertise to diagnose:

> We have to walk a fine line between showing someone a reading and giving a diagnosis. We can never give a diagnosis because that's not our place. Our place is to show them what their reading is. We can show their reading against NHS guidelines, but we don't go any further than that, so we can say … from the band of high/medium and low on BP, where your reading falls. – Interviewee #1

Similarly, as the Omron (2018) terms of service noted during an app walkthrough, the app …

> … is not intended to give or replace … medical advice, or to serve for diagnostic purposes … . OMRON is not a medical care provider and does not provide medical advice. The App is not intended to be relied upon in lieu of medical treatment or advice by a trained medical care provider … Always consult your doctor or other healthcare professional with any questions regarding your medical condition.

The standard of BP's clinical measurement used in the context of these apps and devices to simply 'show [a user] what their reading is' jars with another layer of standards–advertising standards. As the UK's Advertising Standards Authority (ASA) notes, companies selling medical devices 'must not discourage essential treatment for conditions for which medical supervision should be sought … they must not offer … diagnosis of or treatment … unless … conducted under the supervision of a suitably qualified health professional' (ASA, 2010, p. 59).

Nonetheless, regardless of whether they are for use at home or in formal healthcare situations, BP monitors are understood to be medical devices, requiring approval for European sale,[2] or testing for approval by the US Food and Drug Administration (FDA). In this sense, we see the complexity of engaging with clinical measurement standards in a highly regulated environment, and a sense of the work required to do so. Companies must demonstrate their devices' accuracy to provide diagnoses to be able bring them to market, whilst not making claims that might discourage consumers from seeking medical advice.

Across our data, we noted companies highlighting their products' regulatory approvals. Omron's body composition monitor, which synchronises to its Connect app, is noted on its product webpage for its 'Clinically validated accuracy' (Omron, 2019), whilst Qardio's website depicts a man in a white coat and stethoscope to emphasise the BP monitor is 'medically accurate' (Qardio, 2017). Meanwhile, Withings (2016a) invokes regulatory clearances on its sales webpage. Mobilising this language of validation appears to project the clinical value of products, which may be read as an effort of commercial actors to valorise platforms that nonetheless must not be used for consumers' self-diagnosis. Companies thus negotiate borrowing credibility from existing standards whilst acceding to others.

The case of Nokia is instructive of how DHPs actively engage with regulators once products come to market. Nokia's body composition scale, originally launched by Withings, offered Pulse Wave Velocity (PWV) to measure arterial stiffness which, when heightened, is associated with increased stroke and heart attack risk. PWV's inclusion on the device was sold as a revolutionary delegation to consumers of a clinical metric 'that has never been available in a consumer product for home use before' (Withings, 2016b). PWV was available for home use until January 2018, when it was withdrawn in a software update because Nokia was concerned PWV required 'a different level of regulatory approval' (Lovett, 2018). In 2016, the FDA published industry guidance offering clarity on which products required regulation. It explained that whilst high risk health-products would need approval, products promoting general wellness (which could not make any reference to diseases (FDA, 2016, p. 3)) would not. This appeared to create a reprieve from regulation for Nokia's product, but instead produced regulatory ambiguity with practical ramifications.

Once withdrawn, users could now neither calculate PWV nor view historical PWV data through the app, though they could download the raw data, effectively excluding users without technical expertise to make use or meaning out of these raw data. By April 2019, Withings had received assurances from EU regulators that PWV was an acceptable feature on a device with BodyCardio's level of regulatory approval. As such, Withings reinstated PWV for EU users. The feature remains unavailable in the US (Fisher, 2019). This episode demonstrates how the platform comprises not just an app, but also the standards that led to the deletion and then partial reinstatement of PWV, the company's decision to do this, the device itself which could be remotely managed by the company, and the variously excluded users. The story also highlights the exclusions that emerge in infrastructures as different constituencies (in this case, EU and US users) experience the implications of local regulatory standards.

Plantin *et al.* note how large infrastructures have 'complex ecologies whose components must continually adapt' (2018, p. 296) to external change. Here, the same point can be made of the individual DHPs we consider. Standards, necessarily in flux as they adjust to the shifting digital health landscape, produce work for companies who must negotiate a potentially volatile regulatory environment, responsively managing their products. A platform cannot claim to diagnose, yet its creators must still prove its clinical accuracy. It navigates these potentially incompatible imperatives whilst ensuring compliance with medical device regulations, too, opening up possibilities for uneven access. This exemplifies, as Plantin *et al.* note, 'the critical role of infrastructure's human elements, such as work practices' (2018, p. 296). This work undertaken to navigate layers of standards is as critical a part of DHP infrastructures.

Cooperation through interoperability: how to build your infrastructure

In this section, we consider the relationships that go into building DHPs. These relationships between different companies may resemble a more traditional acquisition of one company by another – as in the case of Nokia/Withings – but more often take the shape of strategic cooperation between different players (who may also be competitors). Ultimately, this cooperation, which takes the form of separate companies' software becoming interoperable, appears as an effort to profit from the sale of more physical devices.

Nokia, one of the larger companies in our sample, entered into the DHP market by acquiring Withings. In their 2016 annual report, Nokia explains its rationale to investors. The report notes forecasted digital health market growth to €220billion by 2020. 'Within that market', they write, 'we are focused on the segments fuelling the most significant growth … connected devices that go beyond trackers and smart watches to include scales and blood pressure monitors' (Nokia, 2016). Trade press described the purchase as a 'powerplay' (Essany, 2016), that Nokia was 'interested in devices that had the regulatory clearance and robustness for clinical use but were designed for and marketed to consumers' (Comstock, 2016). The company's rationale for the purchase was, then, specifically Withings' hardware offering.

In 2017, Nokia (2018) announced a review of its digital health enterprise. Internal correspondence leaked to the popular technology press contextualised these decisions, revealing that the 'business has struggled to … meet its growth expectations' (Vincent, 2018). Withings was then sold back to one of its original founders.

Nokia's digital health experience is perhaps a cautionary tale against the traditional route of market entry via acquisition of a smaller business. Qardio, Omron and Withings, however, represent companies that have been building (rather than buying) their infrastructures. In this context, building infrastructure relies partly on making decisions about making one's own products 'interoperable' with others. Indeed, as we will see, in line with Star and Ruhleder's analysis of scientific research infrastructures, 'eventually, not being "hooked up" [with an external platform] may make it impossible to participate effectively within a given community of work' (1996, p. 124).

Star and Bowker argue that emergent infrastructures must be guided by a logic in which integrations with existing, popular programmes 'is key to the success of new infrastructural tools' (2006, p. 235). All companies in this sample precede Apple Health, which emerged in 2014, but Apple Health's status as a default iPhone app rapidly solidified its position as a central data repository from that point on. Whilst the earlier-discussed platforms literature frames this approach of dominant companies in an almost predator-like way, companies in our sample also stood to gain from becoming interoperable with Apple and Google. Interoperabilities can be valuable relationships for different actors, not just the most dominant.

This is demonstrated in a trade press piece that discusses a US hospital buying Withings scales for its patients to connect to the hospital's telecare system via Apple Health: '[t]he popularity of Apple products among [the] hospital's patients made the decision to go live with the connection quite easy' (Tahir, 2015). Similarly, Qardio declares its devices' compatibility with Google Fit and Apple Health on its sales pages and launched a Google Android app shortly after its first Apple iOS app in 2014 (Qardio, 2014). This means data from these other companies' devices can be pushed through into Apple Health or Google Fit. Users can read data from different apps/devices in one central interface.

One can read these companies working with larger players as an effort to secure their own position. One interviewee described the 'marketing benefit' of this decision:

> you can't ignore the Apple and the Android world … they deliberately make it pretty readily accessible for manufacturers and devices to access it, so there's no real reason why you wouldn't. The marketing benefit off the back of that, to say, we're compliant with Apple Health, is quite significant. – Interviewee #1

Highlighting Bowker and Star's point that there is a logic to engaging with existing actors, this interviewee notes the 'marketing benefit' of being compatible. Benefits include putting Apple and Google app store logos on their own hardware and its packaging, and potentially featuring on the Apple Health app as an alternative 'app for tracking weight'. Compatibility thus provides a direct form of marketing for the developers in our sample, highlighting their products to Apple Health and Google Fit users, who may then download apps or click through to the device sales page.

Companies such as the ones sampled here must still tread carefully in working with Apple. Trade press described how Apple Watch's introduction led to other wearables being removed from Apple's online store (Pai, 2015). As of 2019, the Apple store only sells Withings' BP monitors, scales, and thermometer, not its wrist wearables. Companies like Apple and Google play a central role in this landscape. However, Apple and Google's positions do not preclude the existence and profitability of other players like those sampled here, who evidently see much commercial potential from their cooperation.

Demonstrating the importance of hardware devices in the monetisation of the infrastructure, sampled companies use their own apps as further marketing opportunities for their devices. In app walkthroughs, both Qardio and Nokia's apps link customers to hardware in their range. Qardio displays icons for both its BP monitor, scales and ECG, so users are continually reminded of the platform's possible functionalities.

In another example of interoperability, some companies in our sample also look to make their own APIs available to other (sometimes smaller) app developers, again to produce opportunities for potential users to know about and buy their hardware. On the 'Works with Withings' webpage, the company notes 'We believe in sharing – that's why our devices work seamlessly with over 100 friendly compatible apps' (Withings, 2017). These relationships work by the company releasing its API or incorporating a third-party API into its own software. For example, food tracking app MyFitnessPal can take weight data from the Withings app. MyFitnessPal does not sell its own scale, so both Withings and MyFitnessPal stand to benefit from a relationship in which Withings' scales are made useful, and MyFitnessPal can offer automated weight tracking without producing its own hardware.

One interviewee describes the importance of opening up their API so other developers can design apps that link into their DHP, hopefully drawing in new users who buy more devices:

> … anyone now who has a cloud-based service in healthcare … can publish an API … so that somebody else uses the data in a more clever way … it creates new needs around our devices … Anyone developing an app can ask our users to share his data. So, we've seen people develop … running apps, weight loss apps, diabetes apps, electronic health records … Clearly some are encouraging people to order our devices. – Interviewee #3

The push to 'create new needs' exemplifies how APIs invite new developers to exercise imagination and, as Bucher (2013) describes, 'harness the capacity' of external developers. It also demonstrates the work being put into sustaining DHPs' relevance and encouraging the purchase of physical products. Similarly, a different interviewee describes their 'selfish' efforts to open up their software to external developers.

> After we launch the … products … we immediately release our solution, development kit … we want more and more [developers] using this tool and to connect [to our company], either the cloud or the device … [this decision] is very selfish, and actually I can sell more devices then, which is also good for the business. – Interviewee #2

Without this cooperation through interoperability, companies risk their products becoming obsolete, a risk faced by all infrastructural entities that refuse to work with the protocols of other actors in the network in which they are embedded (Star & Ruhleder, 1996). Attempts to make their devices and data channels accessible come out of desire to open up avenues for developers to create new software for the interviewees' platforms to link into, producing 'new needs' around their own hardware.

Plantin *et al.* correctly note that 'platform builders' like Apple and Google 'achieve their success precisely by attracting many independent actors to contribute to their software ecologies' (2018, p. 298). Our focus on these independent actors shows the value in attempting an analysis of this relationship from other sides, acknowledging more explicitly that interoperability has value for less dominant platforms too. The sampled companies appear to make strategic interoperability decisions with bigger players such as Apple

and Google and open up their own APIs to other smaller developers. Within the platforms literature, the value of this kind of interoperability is seen predominantly as a means of opening up data channels between different actors, and of solidifying the centrality of the larger companies (Helmond, 2015). We argue that it is better understood in this context as an attempt to engage users with the aim of them buying physical devices, which are therefore necessarily an intrinsic part of the platform infrastructure. Centralising the issue of interoperability between various DHPs – and not just with dominant actors like Apple – thus makes prominent the diverse, important relationships that comprise and sustain the digital health landscape.

Discussion and conclusions

The dominance of large players like Apple and Google has received much attention in the platforms literature. Less attention is paid to smaller players who constitute a significant part of knowledge landscapes in health. This paper builds critically on the work of media and communications, information sciences and STS scholars Plantin et al. (2018) as well as engaging directly with the important work of Star and colleagues on which Plantin *et al.* partly base their own conceptualisation, applying an infrastructural lens specifically to DHPs. To conclude, we summarise what this lens highlights, focusing on its value for emphasising standards and less central actors as well as proposing directions for empirical enquiry into the infrastructural qualities of platforms.

Firstly, this lens draws out different aspects of DHPs, highlighting standards that affect not just large public infrastructures, but also companies looking to market DHPs: a company must seek regulatory approval for their product, and will use clinical measurement standards. Both of these add legitimacy to DHPs, conveying clinical accuracy and value. However, invoking these standards must be done carefully because other standards delimit marketers' claims about medical products. An app might tell you your reading was above normal, but you are reminded to see your HCP if concerned, reasserting clinical jurisdiction. Navigating standards is important work in the development of any infrastructure, as Star and Bowker (2006) argue. In the case of DHPs, successfully engaging with standards allows companies to further build upon their platforms.

An infrastructural lens also offers insight into the ways companies seek to build upon their DHPs. Through considering interconnections between sampled companies with larger and smaller actors, we see how interoperability between different platforms is beneficial for different players. Plantin *et al.* highlight the centrality of key players. In the case of DHPs, Apple and Google most certainly benefit from accumulating data, though other companies with hardware offerings reap rewards through various relationships. Sampled companies engage with other smaller developers in an effort to create further needs around their devices. For many DHPs, then, the chance to monetise their platforms is not immediately through data but through selling expensive, fashionably designed, and heavily marketed devices (Williams et al., 2018). As Star argues, starting with central figures (here, Apple and Google) can 'screen out the work' (1990, p. 29) of apparently inconsequential actors. By starting with actors like our sampled companies the broader landscape fleshed out above emerges.

Having considered the value of an infrastructural lens in the case of DHPs, we propose routes of enquiry for exploring the infrastructural quality of platforms. Above, we have

highlighted – in line with Plantin *et al.* – that work plays a 'critical role' (2018, p. 296) in developing and maintaining platforms. In the case of the DHPs studied here, this work came in the form of navigating standards, as well as building productive relationships with others beyond one's own platform. We might then ask: what is the nature and distribution of the work in which platform companies engage to build and maintain their platforms, as well as productively engage with other platforms?

Though not an in-depth focus here, this lens is evidently useful for locating exclusions embedded in platforms – as Plantin *et al.* note – following on from Star, 'infrastructure can structurally exclude' (2018, p. 296). In what forms – within and beyond health – might exclusions emerge in different platform contexts? How, and to what effect, are these exclusions entangled with different standards/interoperabilities?

Platforms are more than intermediaries, as existing scholarship notes. They are infrastructures comprising standards, relationships, users, hardware and software, existing in a wider landscape where dominant players are growing (and gathering data, potentially in a longer-term commercial effort) while other actors appear essentially to be developing hardware businesses through strategically opening up their software. This is not to say that sampled companies and other DHPs do not aspire to commercially exploit data – as in any commercial space, DHP companies are guarded about where they make profit. Yet private accounts during interviews suggest that companies find value in creating needs around hardware as well as apps.

We have demonstrated how an infrastructural lens emphasises the dynamics of DHPs – an underexplored area in the platforms literature. It illuminates aspects of digital health missed by studies focussed on health's datafication, particularly connections between different actors – companies, materials, users and standards. Attending to the work of infrastructuring helps us give richer and more nuanced accounts of the digital health landscape than possible if we just focus on the most prominent global brands.

Notes

1. Data collection was ethically approved by Sheffield University.
2. European Medicines Agency regulates medical devices in the EU (EU Regulation, 2017/745).

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

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