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Fertility apps, datafication and knowledge production in reproductive health

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Abstract

Despite being the target of much criticism, commercialised digital technologies have proliferated in reproductive health arenas. Fertility applications (apps) are now some of the most popular and ubiquitous digital health tracking technologies, with millions of downloads. Previous scholarship has already underlined the problematic nature of their design and surveillance features. However, less attention has been paid to the wider effects of datafied knowledge availability. This research specifically asks: How does the proliferation of fertility apps shape knowledge (and associated practices) in reproductive health? Drawing on an analysis of key document sources, I here argue that fertility apps act as mediators between stakeholders, data and datafied outputs, thus facilitating: (1) the datafication of fertility awareness knowledge and the production of new datafied knowledge, (2) legitimation discourses and practices and (3) the remaking of private/public expertise and knowledge production networks in reproductive health. To effectively analyse the effects of commercialised reproductive health apps, this work argues for an understanding of data technologies that is informed by critical data studies.

KEYWORDS
critical data studies, digital health, fertility apps, knowledge, reproduction

INTRODUCTION

In recent years, a significant amount of attention has been paid in the social science literature to reproductive health apps (Algera, 2023; Grenfell et al., 2021; Hamper, 2022; Kressbach, 2021; Levy & Romo-Avilés, 2019; Lupton, 2020; Wilkinson, 2020). Feminist scholars have critiqued how such devices reproduce problematic assumptions about gender (Kressbach, 2021) and reinforce neoliberal subjectivities in health care by placing the burden on individuals to engage in data work to manage their health (Lupton, 2017, 2020). In addition, the highly commercialised nature of reproductive health apps raises concerns about misuse of intimate data by private companies (Ford et al., 2021; Mishra & Suresh, 2021). Such perspectives have focused on power relationships borne out of dangers associated with commercialisation and the quantification and further objectification of the reproductive body. While this article does not seek to downplay such concerns, it aims to expand our conceptualisation of reproductive health apps by using critical data perspectives to analyse how such technologies shape broader datafied knowledge production patterns. In doing so, it shifts attention from the interplay between individuals and apps which has dominated the literature on digital reproductive health to the apps' ability to influence knowledge practices more widely. Datafication and datafied technologies are inextricably linked to the deployment of data as an object of knowledge (Ruppert et al., 2017). The increased use of digital health technologies in reproductive health, I argue, bridges data, stakeholders and datafied infrastructures in ways that shape who knowledge producers are, how knowledge is disseminated and the types of knowledge produced. By focusing on an analysis of fertility apps, the findings in this article show how such devices draw on existing reproductive health knowledge, while at the same time facilitating the production of new types of expertise, scientific knowledge and legitimacy discourses. Attention to such processes is needed to enable an effective analysis of datafication in reproductive health and, implicitly, a critique of apps and the consequences of their widespread use.

In this article, I use the term 'reproductive health apps' broadly to encompass period apps, fertility apps as well as other apps that involve user data input and tracking related to reproductive health issues/needs. Fertility apps usually include tracking one's menstrual cycles, but also have the added feature of providing users with an indication of which days they are likely to be fertile. This fertility prediction is what I define here as their key feature. Fertility apps can be used for contraceptive, conception or general wellness purposes and their features can vary depending on companies' stated and/or user purpose of use.

DIGITAL HEALTH AND DATAFICATION THROUGH REPRODUCTIVE HEALTH APPS

This section details scholarly work on digital developments in reproductive health, while the next section engages with critical data studies perspectives that have been applied to a lesser extent in the digital reproductive health literature, but which this article uses to advance its

argument about the knowledge production effects of fertility apps. Most research on reproductive health apps has focused on the nexus of user/technology interactions and how data are produced and understood by individuals. The experiences of users tracking menstrual cycles and fertility-related health information has been examined by several scholars (Costa Figueiredo et al., 2018, Costa Figueiredo, 2020; Della Bianca, 2022; Epstein et al., 2017; Gambier-Ross et al., 2018; Hamper, 2022; Levy, 2018; Starling et al., 2018). Those who use reproductive health apps have various reasons, including contraception, facilitating conception or simply tracking general health (Epstein et al., 2017; Gambier-Ross et al., 2018). Existing studies, however, report overall mixed feelings from app users. While women perceive period tracking apps as helpful, digital methods can sometimes be ineffective and give inaccurate predictions of future menstrual cycles (Gambier-Ross et al., 2018). In addition, app design can "create feelings of exclusion for gender and sexual minorities," while many apps also "fail to consider life stages that women experience, including young adulthood, pregnancy and menopause" (Epstein et al., 2017, p. 6876). Although the experience of fertility tracking can be empowering and lead to sensory self-knowledge (Algera, 2023), it can also be frustrating given the onus it places on the user to input data daily (Costa Figueiredo et al., 2018). Infertility patients may have limited knowledge about what symptom data to input (Costa Figueiredo et al., 2018, 2020). For those using reproductive health apps when trying to conceive, the apps highlight the reproductive potential of the user through the configuration of the pre-pregnant reproductive body (Hamper, 2020). This potential is also highlighted when users track for contraceptive purposes: women report knowing/understanding their body as reproductive, natural and regular (Chen, 2017). Users do place value on self-knowledge and the feeling of control that tracking can facilitate (Epstein et al., 2017), but also want reproductive health apps to be science-based (Starling et al., 2018). Thus, while some of the literature points to the importance of knowledge, self-knowledge and the perceived accuracy of knowledge, we know very little about wider knowledge production patterns including how accurate knowledge is produced and incorporated into apps.

Critiques of app design have focused on gendered interfaces and the surveillance features of reproductive health apps. Although there is potential for subversive practices in the use of self-tracking the reproductive body (Fox, 2017), apps often reinforce normative ideas about the digital reproductive citizen (Hamper, 2020) or the pregnant body as a site of risk (Thomas & Lupton, 2018). Many period and fertility apps are known to have a problematic design (Levy, 2018) that reinforces gendered embodiment and the desirability of white middle-class privileged femininity (Kressbach, 2021). Users can struggle with the ideals conveyed by apps and often want technologies that can better capture the diversity of their experiences and embodiment (Epstein et al., 2017). Apps need more holistic design and careful consideration of user fertility needs (Costa Figueiredo, 2020). In addition, the data collection practices and tailoring of such technologies could be much improved (Epstein et al., 2017). Thus, studies of knowledge disseminated through apps have mainly focused on what is conveyed to users through platforms as opposed to knowledge produced beyond the platform.

Another pressing concern among researchers has been the rise of surveillance practices brought on by new digital technologies (Haggerty & Ericson, 2017). The data security of health apps has been found lacking by computing scholars (Dehling et al., 2015; Grundy et al., 2019). Sharing user data is routine, but this process is far from transparent (Grundy et al., 2019). Scholars advise that both clinicians and patients should become more conscious of privacy risks embedded in the use of digital health apps (Grundy et al., 2019; Rosas, 2019). Technology can widen the scope of company and state surveillance; this is especially dangerous when it enters

intimate areas of life, as is the present case of reproductive health tracking—an arena rife with manifestations of biopower and biometric surveillance (Sanders, 2017). Despite concerns about data misuse, there has been little attention to other systemic issues relating to the data used and produced by reproductive health apps. In the next section, I outline what a critical data studies approach is and what it can offer to expanding our understanding of reproductive health apps.

TOWARDS A CRITICAL DATA STUDIES APPROACH TO FERTILITY APPS

Critical data studies see big data as "always-already constituted within wider data assemblages" (Iliadis & Russo, 2016). It is these assemblages that I argue have received limited attention in the reproductive health app literature. Kitchin and Lauriault (2014, p 6) define a data assemblage as a socio-technical system that "consists of more than the data system/infrastructure itself [...] to include all of the technological, political, social and economic apparatuses that frames their nature, operation and work." Data assemblages and the structures they enable have a significant impact on social processes through the changes and organisation modes they facilitate (Iliadis & Russo, 2016). They include forms of knowledge, systems of thought and practices that maintain the data assemblage (Kitchin & Lauriault, 2014). The analysis presented here thus pays attention not only to datafied forms of knowledge but also the forms of knowledge that maintain/legitimate the data assemblages of fertility apps. We know that the development and use of technologies is intertwined with practices of legitimation (Feenberg, 2017). Previous work on legitimation in health care (Foley & Faircloth, 2003; Lambert, 2012; Perrotta & Geampana, 2020) showcases narratives of legitimation whereby professionals justify the use of novel treatments and technologies through discursive means that highlight their benefits.

Scholars who have looked at the dynamics of digitalisation in health have considered how power operates at macro-levels and how technical objects create data–human mediations (Ruckenstein and Dow Schull, 2017). While the former perspective has been somewhat emphasised in critiques of commercialisation in women's health (Ford et al., 2021; Mishra & Suresh, 2021), fertility apps and the constitution of their data assemblages have seldom been looked at in relation to their effects on the organisation of reproductive health networks and knowledge. This article contends that technoscience concepts are particularly useful in illuminating the workings of reproductive health (Van de Wiel, 2019) and health practices more widely (Shim, 2002). It draws on Science and Technology Studies conceptualisations of socio-technical data assemblages (Iliadis & Russo, 2016; Kitchin & Lauriault, 2014), where a technology can be conceptualised as a link/mediator in data–human interactions and between data infrastructures and the wider assemblages they are part of. Thus, the technology (in this case, fertility apps) facilitates knowledge flows embedded in particular networks of stakeholders or knowledge creators. Because data have become an object of power, to look at knowledge production in relation to data is an inherently political exercise. In a context where increased knowledge of reproductive health and conditions is touted as desirable (Dahlman et al., 2023), yet the benefits of increased datafication are unclear, it is important to understand the role of apps in producing knowledges and knowledge networks in the context of developing data assemblages. To answer the central question of this research study, namely how does the proliferation of fertility apps shape knowledge practices in reproductive health, this article makes use of a case study approach outlined in the section below.

METHODOLOGY

Delineating the research case

This research involved an analysis of online sources pertaining to fertility apps only (as opposed to an analysis of all reproductive health apps). In the first part of this section, I outline the study case and why the research focuses on fertility apps specifically, while in the second part I detail the document sample and analysis.

To empirically study fertility apps, I make use of an in-depth case study method. Gerring (2006, p. 19) defines a case as "a spatially delimited phenomenon (a unit) observed at a single point in time or over some period of time. It comprises the type of phenomenon that an inference attempts to explain." Guided by questions about network-building and knowledge production in reproductive health, the present case consists of an in-depth analysis of the datafied knowledges that fertility apps enable. I focus specifically on fertility apps that may or may not be paired with wearable technologies (measurement devices such as bracelets or rings that connect to and send data points to a digital fertility app). As mentioned in the introduction, the defining feature of such apps is the provision of a fertility prediction to users. Some fertility apps can simply be used as period apps if the user limits the data points they enter to menstrual cycles only. Such apps were still defined as 'fertility apps' for the purpose of this study because they do have the in-built fertility prediction feature should an individual wish to use it. There are now more than 200 fertility apps on the market; they vary significantly, drawing on different approaches to determining fertile days/windows (Ali et al., 2021). However, some are more popular and widely used than others. Fertility apps (as opposed to all period tracking apps or all reproductive health apps) were chosen as a focus here due to their visibility in the media and their claims about reliability as well as the scientific/medical nature of such claims tying them to other actors in the reproductive health landscape (e.g. regulatory bodies and medical professionals).

Methods and analysis

Case studies often rely on multiple data sources (Feagin et al., 2016). Data that inform this study were collected over an extended period (May 2020–March 2023) in multiple stages that allowed familiarisation with and in-depth analysis of information about fertility apps as defined above. Over the course of the study, the author followed news about popular fertility app companies both by following popular fertility apps with a notable presence on social media (e.g. Ava, Clue, Daisy, Flo, Glow, Kindara, Natural Cycles and Ovia) and 2) and by subscribing to weekly newsletters from two popular femtech networking groups (FemTech Insider and Women-OfWearables (WOW)) that provide links to media articles with news related to innovation in women's health (FemTech Insider provides a weekly newsletter while WOW provides periodical updates, fortnightly or monthly). Social media fertility app presence and the regular newsletters from Femtech groups can be perceived as online community groups looking to grow the influence of new innovations and, implicitly, fertility apps. As such, they did tend to present more positive perspectives on fertility apps. Nonetheless, these sources were helpful for keeping up with updates on development of fertility apps, acquisitions and regulatory updates, coming from a wide variety of English-language Internet sources (these were mostly online sites varying from developments discussed in *The Conversation* or *STAT News* to *The Cut* as opposed to

traditional daily news media). Over the course of the study, links that pertained to fertility apps were followed and notes were taken about any mentions of data, scientific publications using data or the use of fertility app data in any other context. I made use of Venturini's (2010) controversy mapping approach to map elements of the data assemblages. Mapping data assemblages also involved collecting information from public company websites of fertility apps mentioned in news articles. This included information on research activities and references to the use of data collected through fertility apps. The case notes were complemented by a closer analysis of relevant documents ($N = 81$) found through these links or though web searches, including: 1) the data policies of popular fertility apps mentioned in the news, 2) published medical and scientific literature on fertility apps, 3) regulatory approval/recommendation documents (FDA and National Institute for Health and Care Excellence (NICE)) related to apps that have sought approval for their products and 4) online media commentary/op-ed pieces about fertility apps. This latter source was chosen due to its more critical review of fertility apps to balance the optimism of tech media sources. The analysis process was guided by grounded theory principles whereby analysis and data collection occurred in parallel (Morse et al., 2016). Notes were taken and documents were collected until they yielded no new information on the fertility app landscape (e.g. stakeholder involvement, critiques, data practices). The data (documents and notes) that support the findings of this study are available from the corresponding author, upon reasonable request.

Coding was guided by an inductive strategy to the generation of codes for the dataset consisting of notes and the documents mentioned above. Given the focus on data and knowledge, specific attention was paid throughout the analysis to references to data uses and datafied, scientific and/or legitimation knowledge. Thus, I aimed to trace wide patterns of datafied knowledge production and interactions. The main limitation of the approach taken is that it can only give a macro-level overview of the processes studied. As such, no claims about localised practices can be made (e.g. how public/private research partnerships develop on the ground). The aim of the research study, however, is to highlight and call attention to large shifts in reproductive health knowledge-making. To argue that fertility apps act as mediators between data, datafied outputs, practices and networks, I detail below how they facilitate: (1) the datafication of fertility awareness knowledge and the production of new datafied fertility knowledge, (2) legitimation discourses and practices and (3) the remaking of private/public knowledge production networks and forms of expertise in reproductive health.

FINDINGS

The datafication of fertility awareness and the production of new datafied knowledge

Fertility apps are often presented as an entirely new technology. However, apps do draw on previous medical knowledge of the reproduction process in many ways, while facilitating the production of new research. Knowledge about menstrual cycles and tracking fertile times of the month has developed at a more accelerated pace in the past six to 7 decades (Flynn, 1984). At the beginning of the 20th century, doctors still believed that the point when ovulation occurred coincided with the onset of a woman's period (Tone, 2002). We now know that ovulation usually occurs around the mid-cycle point (although significant variation exists) and that there are bodily markers that correlate with different cycle phases. Such markers can be measured,

for example, through the use of ovulation tests or by measuring one's temperature regularly to observe a rise in basal body temperature during the latter phase of a menstrual cycle. Although developers rarely make a patented algorithm available due to commercial reasons, a review of data points users need to input in popular fertility apps reveals connections to fertility awareness methods (FAM) that rely on temperature and cervical mucus observations. For example, a rise in basal body temperature is considered an indicator of the body entering the luteal cycle phase that follows ovulation (Pallone & Bergus, 2009). This is a key data point that many digital fertility solutions rely on. For digital contraception/conception tools, then, what is novel is not what is measured but rather the platforms' ability to digitise and automate this knowledge as well as offer personalised predictions that rely on tools with increased measurement accuracy. Through wearable devices, developers seek to provide additional precision in the measurement of data points and minimise user uncertainty. For example, popular fertility app Natural Cycles was initially released in conjunction with a digital thermometer that individuals could use to measure basal body temperature themselves. The device would then send these data to the app. Now, users have the option of using the app in conjunction with a wearable ring which records temperature data points continuously during sleep, thus minimising onerous measurement tasks as well as potential errors. The ring is described on the company website as follows:

> The Oura Ring [...] can measure heart rate, heart rate variability, temperature trends, activity, and sleep quality [...] Using the Oura Ring with Natural Cycles unlocks insights into your cycle, body, and fertility. The Oura Ring collects 'temperature trend' data instead of one single measurement. The Natural Cycles algorithm then creates an 'absolute value' based on that temperature trend data, which is the measurement you'll see in the NC App. This is the temperature value that will be used to calculate your fertility status.
>
> (Natural Cycles, 2023)

The wearable device is presented not only as convenient and accurate, but also as an opportunity for users to engage in further tracking of other data points to get broader health insights, thus linking menstrual cycle patterns to knowledge about other body patterns. This linkage between fertility and broader health information would be difficult to achieve with traditional pen-and-paper tracking. Thus, fertility apps facilitate the integration of reproductive health data into wider health data assemblages. Similarly, the Ava fertility bracelet, cleared by the FDA for fertility tracking for conception, measures signs of fertility through a wearable device worn continuously at night. However, while some apps make use of wearable devices and rely on input of specific body markers, many others that market themselves as fertility solutions, rely only on menstrual cycle information (Ali et al., 2021). As such, they can only give an approximation of one's fertility window based on the calendar method which simply relies on counting days from the start of a period; medical professionals consider this a highly inaccurate method. Notably, the purpose of use (conception vs. contraception) shapes whether an approximate prediction of fertile days is risky. For those trying to avoid getting pregnant, an inaccurate fertility window prediction, could result in an unwanted pregnancy, with potentially devastating results. Apps used for conception, on the other hand, cannot assess the nature of existing infertility issues and can thus make users feel they are tracking incorrectly if they do not get pregnant (Grenfell et al., 2021). Thus, not all fertility apps are equal in the data precision they aim for and the data work they ask users to perform. Such factors can affect the reach and constitution of an app's data assemblage.

Data collected is then used to produce new knowledge. The usefulness of commercially-collected data for gaining further insights into reproductive health conditions is often highlighted by app developers. For example, Flo, a fertility app used for conception, published a study looking at polycystic ovary syndrome (PCOS) in collaboration with researchers at Northwestern University (Jain et al., 2021). The importance of such collaborations is discussed more in-depth in the third section of the findings. What is notable here, however, is the size and the novelty of the data available: the app facilitates the collection of millions of data points related to a particular reproductive health condition like PCOS. This would have been a difficult task without the aid of digital technologies. The Flo PCOS study analysed reported symptoms and concluded that they are broader and more complex than previously thought; the study also touts the dataset as 'the largest known PCOS dataset' (Jain et al., 2021). This highlights how fertility app data is deployed increasingly as an object of knowledge in data assemblages pertaining to reproductive health. The new datafied knowledge produced is facilitated through multiple stakeholders' engagement with the same app, thus highlighting the technology as a key mediator in this wide data assemblage. Although fertility app companies highlight research benefits, the scientific merits of their technologies are still debated. As such, legitimation practices are integral to maintaining the relevance of these datafied technologies and, implicitly, the increasingly wide reach of their data assemblages. It is these practices of legitimation that I turn to next.

Legitimation discourses and practices

Because the practice of FAM has historically been associated with a high failure rate, Christian religious views and refusal to engage with modern contraceptive methods (LeMaire, 2016), fertility apps have met with criticism. Specifically, their trustworthiness has been questioned repeatedly due to the wildly different approaches they offer in their measurement approach and precision. Consequently, app companies and sometimes the apps' user base engage in legitimation practices. Here I detail how narratives of legitimacy are an integral part of the data assemblage of fertility apps. As Kitchin and Lauriault's (2014) suggest, data assemblages include 'maintenance' practices.

Data gathered through fertility apps, often referred to as 'real-world evidence' can be used to aid regulatory approval for contraceptive use, thus legitimating the technology as a contraceptive method. For example, both Clue and Natural Cycles apps have FDA clearance to market themselves as contraceptive technologies based on evidence submissions that included data collected through their platforms from users who consented to be included in effectiveness studies. Thus, user data allowed companies to obtain sufficient evidence to prove effectiveness for contraception purposes (FDA, 2018). As such, data flows between users and companies contribute to legitimacy practices in fertility app data assemblages. In addition, Ava has become the first digital fertility wearable device used for conception to get accuracy certification from the FDA. Thus, it is not only fertility apps used for contraceptive purposes that are looking to gain increased legitimacy. Approvals have occurred in a regulatory context of increased focus on approving digital innovations that are perceived to benefit users. However, there is little consensus on what the approval should be based on, especially for reproductive health apps. Uncertainty exists around how regulatory bodies should evaluate digital health innovations (Cortez, 2019). Nonetheless, recent years have seen increased enthusiasm around making digital solutions available to consumers (Lievevrouw et al., 2022). As digital technologies are

categorised as 'medical devices,' they are subject to evaluations that take into account similar devices already approved (Cortez, 2019). Natural Cycles was the first contraceptive app cleared to market itself as such in the US and in Europe. Thus, the approval of such a technology created a precedent upon which similar devices can be evaluated. Shortly thereafter, another fertility app, Clue, also got contraceptive approval from the FDA. The makers of Natural Cycles took issue with the rigorousness of data submitted by Clue when compared to their submission, thus seeking to legitimise their app at the expense of the other:

> Elina Berglund, the CEO of Natural Cycles, said in a statement that the company will be doing its own analysis of Clue. "Our initial findings based on the FDA filing indicate a significant difference between Natural Cycles and this other product — including that this product is solely based on menstrual data and no other biomarker such as temperature," she said.
>
> (Wetsman, 2021)

It is evident that there is limited regulatory consensus on what data need to be included in an algorithm that gives users fertility predictions. Even though FAM knowledge is adapted by digital apps, how this is done, what constitutes a baseline standard in tracking and which method is most effective remains an open question, thus leading to continued practices of legitimation. Emerging legal scholarship, nonetheless, argues for a more forceful and robust regulation of such devices (McMillan, 2023).

By updating, or rather, upgrading FAM to a method that can be perceived as science-based, precise and backed by advanced technology, fertility apps discursively 'technologise' and secularise FAM by datafying it, thus seeking to legitimise methods traditionally perceived as natural and non-invasive yet high risk due to their potential failure. Arguably, digital health devices seek to make FAM more accessible for those who would not have had the required dedication to use such methods without the aid of digital tracking technologies. In a popular media piece, Magray (2019) suggest that 'comprehensive cycle-tracking' that makes use of digital apps is different from what people perceive as 'woo-woo, unscientific' practices:

> When most people think of fertility awareness, they imagine woo-woo, unscientific, or religiously fuelled practices like the rhythm method, a mistake that both conflates comprehensive cycle-tracking with far less effective practices and stigmatises users in the same breath. This assumption pits responsible, intelligent birth control users who take their birth control pills against the classist cliché of reckless, uneducated future mothers or abortion patients.
>
> (Magray, 2019)

Here, the author legitimises her use of fertility apps and argues that we should not be creating hierarchies and divides when it comes to assumptions about the quality of contraceptive methods used. Problematic app cases, however, show that digitalisation in and of itself does not provide legitimacy assurance. In 2019, press sources (Glenza, 2019) revealed that a popular fertility app, Femm, has backers and close ties to anti-abortion organisations; the app 'sows doubt' about the safety of birth control, a Guardian investigation found. Thus, what it means for an app to be 'backed by science' remains unclear at times. As a result, continued legitimation practices become necessary for apps that do not want to have their secular science-

backed credentials questioned. It is usually the apps that are willing to engage more extensively with regulatory processes and professional stakeholders that also engage in knowledge-making practices that rely on their digital datasets.

Remaking private/public knowledge production networks and forms of expertise in reproductive health

In this section, I detail how fertility apps bring together private and public actors in particular data assemblage configurations that include some forms of established expertise but not others. Such data assemblages facilitate new types of knowledge exchanges and networks in reproductive health arenas.

Fertility apps link public and private actors that access and use app data sets. Apps collect unprecedented amounts of data on users' fertility symptoms, periods and reproductive health more generally. Traditionally, the collection of such systematic data would be done by researchers, medical practitioners and/or through clinical trials conducted by pharmaceutical companies. With the proliferation of digital apps, however, digital health companies have become key stakeholders in the dissemination of information and research on reproductive health. There are now tens of publications using app data to answer questions about menstruation, cycle length, infertility and other reproductive health conditions (Schantz et al., 2021). Studies often rely on public/private partnerships where app companies allow researchers to make use of their user data. As such, they have a high degree of control over who, when and how these data are used.

App companies co-opt as well as exclude certain experts and forms of expertise in the data assemblages they maintain. Specifically, they highlight medical and scientific expertise in how they present themselves. Most company websites list affiliated advisors, often with medical degrees. Moreover, companies discursively showcase scientific expertise in other domains as well. Due to the data-intensive nature of such technologies, data analytics and precision in fertility algorithms are also touted as essential. For example, Elina Berglund, one of the founders of the Natural Cycles fertility app emphasises her PhD in physics and associated complex data expertise credentials in media appearances and on the app's website. This introduces a new type of data analytics expertise in addition to the medical expertise that would generally be associated with health innovations. Consequently, the datafied nature of fertility apps results in increasing expertise heterogeneity in data assemblages of new digital health technologies.

On the other hand, the commercialisation of women's health through digital innovation does not always allow for meaningful stakeholder engagement and/or challenges to the growing datafied socio-technical systems of fertility apps. Expertise might only be co-opted to the extent that it gives technologies scientific credibility and, implicitly, legitimacy. An extreme case of a digital fertility company trying to undermine established expertise and scrutiny from reproductive health experts is the lawsuit filed by Valley Electronics, the maker of the Daysy fertility monitoring system, against Dr Chelsea Polis, a reproductive health epidemiologist. Dr Polis published a peer-reviewed commentary (Polis, 2018) critiquing a study that allowed the fertility app to claim a high efficacy rate in preventing pregnancy:

> Unfortunately, the published Koch et al., 2018 estimates are fatally flawed and inaccurate, and are likely to be substantially higher than the actual contraceptive effectiveness of the device and app. By using marketing language based on inaccurate analyses, Valley Electronics falsely increases consumer confidence in the

> effectiveness of the Daysy device and the DaysyView app, which could endanger the well-being of their customers [...] to protect public health, scientific integrity, and potential consumers, these concerns should be documented in the published literature, the Koch et al., 2018 analysis should be retracted, and marketing materials on contraceptive effectiveness should be subjected to appropriate oversight.

The publication referenced here by Dr Polis was eventually retracted by the journal. The lawsuit claiming defamation was eventually dropped after 2 years in 2022. However, it raised questions about independent experts' ability to critique digital health companies and their data practices.

Medical professionals' decisions not to engage with or endorse fertility apps further shows that public/private knowledge production networks co-opt those who see datafication as valuable but not necessarily those who are sceptical about the value of fertility apps for patients. Professionals have engaged in criticism of fertility apps both in the medical literature (Zwingerman et al., 2020) and in the media (Bateson, 2019). Some go as far as to warn users against using any kind of reproductive tracking app (McQuillan, 2022). Professionals worry about data being sold to third parties and, for fertility tracking, worry about inaccuracies in the fertility predictions provided by fertility app algorithms. For those who use fertility apps for conception, the medical concern is with technologies overpromising results in cases where tracking cannot fix infertility problems. When used for contraception, fertility apps are a type of method that does not call for the involvement of a clinical practitioner. The technologies bypass the need for a clinical prescription, thus diminishing the importance of clinical expertise in the knowledge production networks and adjacent data assemblages that fertility apps facilitate. In the UK, The NICE has concluded that 'key uncertainties' remain around usefulness of digital contraceptive technology due to it not having been compared to other contraceptive methods that are known to be highly effective and are available free of cost (NICE, 2021). Although the body is sympathetic to user needs, it has decided that such technologies do not provide enough clinical value to be systematically adopted in National Health Service practice. Some fertility app platforms (e.g. Femm) do give users the option to connect to a clinician, but these are the exception rather than the norm. Thus, datafied knowledge networks facilitated by fertility apps do not rely extensively on clinicians and their expertise. It is currently unclear if and how such technologies come up in doctor/patient conversations and whether there will be any attempts to integrate them in clinical practice, thus leaving most clinicians outside of data assemblages and knowledge networks facilitated by fertility apps.

Additionally, fertility apps amplify users' role in knowledge production and datafied assemblages. Rather than engaging with clinical expertise more widely, fertility apps have been focused on a message of lay empowerment and lay knowledge exchange communities, thus reinforcing their users' key role in the maintenance of fertility data assemblages. Although online communities where fertility is discussed also exist on social media sites (e.g. Facebook and Reddit), apps can allow users to post fertility charts and ask for tracking advice from others who engage in digital self-tracking. Thus, apps produce signifiers that represent a snapshot of the reproductive body consequently making reproductive processes intelligible to others through cycle charts produced with user data. Such knowledge exchanges can sometimes also occur through the same application that the individual uses to track their fertility. For example, the developers of fertility app Kindara portray it as a fertility app that prides itself on connecting users to a 'community:'

> The app enables women to do more than manage data. It's a portal to the Kindara community. In addition to a wealth of reproductive resources, the app's social features provide a great place to share and gain support from others [...] Community support is vital to Kindara users, and the app enables users to find connections through a unique and robust system of tags, communal feeds, and direct messaging.
> (Inspiring Apps, 2023)

Users are not only encouraged to disseminate datafied reproductive knowledge about their own body on platforms. Companies also market app use and user sharing of data as a contribution to increased knowledge about women's health, thus making them 'participants' in the private/public production networks described here.

DISCUSSION

Using a critical data studies approach to understand fertility apps, this article seeks to open new directions in the analysis of such technologies and in understanding knowledge shifts in reproductive health. The discussion is thus focused on elaborating what this approach and the findings presented here contribute to what we already know about such apps and digitalisation in reproductive health. Although scholars have shown great interest in reproductive health apps, this literature tends to focus on micro-level data flows between devices and individuals (Algera, 2023; Dudoudet, 2022; Grenfell et al., 2021; Hamper, 2022; Wilkinson, 2020) and critiques of app design and surveillance (Ford et al., 2021; Lupton, 2020; Mishra & Suresh, 2021). This article contributes to this literature by: 1) highlighting wider data flows and their connection to knowledge production in reproductive health and 2) offering a conceptual basis for further study and critique of reproductive health apps. A critical data studies approach to fertility apps avoids conceptualising digital technology as a discrete entity that acts upon or is acted upon by users. The research study asked how the proliferation of fertility apps shape datafied knowledge and associated practices more broadly. By looking at data as it is deployed as an object of knowledge in the data assemblages of fertility apps, I here argue that apps act as mediators between stakeholders, data and datafied outputs, thus facilitating particular forms of expertise and private/public knowledge production networks. Fertility apps also help establish links between existing medical knowledge and new forms of datafied fertility knowledge. Finally, the data assemblage of fertility apps is maintained through legitimation discourses and practices.

The analysis presented here also moves away from the risk/benefit framework that is used in the critical literature discussing the pitfalls of digital apps in reproductive health (Ford et al., 2021; Kressbach, 2021; Lupton, 2020; Mishra & Suresh, 2021). Although I share some of the concerns of this literature, namely the problematic nature of commercialisation and surveillance, I here show that commercialisation processes, in particular private/public knowledge production networks are already entrenched and sustained through data assemblages. As such, I would suggest that a more productive critical research exercise would be to look at how private companies use data infrastructures and knowledge practices to maintain influence. This opens opportunities for researchers to identify how potentially problematic datafied reproductive technologies are legitimated. Although narrative legitimation perspectives outlined in the introduction (Foley & Faircloth, 2003; Lambert, 2012; Perrotta & Geampana, 2020) have been used in studies of new medical treatments, they also have use in understanding the endurance

of commercial apps, as this research study shows when discussing legitimation practices related to the data assemblages of fertility apps. The findings emphasise some of the ways in which datafication and the creation of new data assemblages influence knowledge and knowledge production networks (Iliadis & Russo, 2016; Kitchin & Lauriault, 2014). Specifically, I show that app developers become important players in the production of new knowledge about reproductive health through analysis of data collected through digital devices. In a world where data are becoming increasingly valuable (Ruppert et al., 2017) coupled with the fact that women's health has been historically underserved (Moss, 2002), this helps maintain the relevance of apps in vital knowledge production practices. Again, I would suggest that awareness of such practices will lead to a more effective critique of commercialisation through the proliferation of health apps. The article is not meant as a comprehensive analysis of everything that datafication changes or achieves in reproductive health. Rather, by focusing on fertility apps, it aims to open different avenues for the further conceptualisation, theorisation and understanding of digital technologies in reproductive health.

Fertility apps bring together and reconfigure relationships between datafied medical knowledge about fertility, users, measurement, automation and tracking. The social science literature on reproductive health apps (Ford et al., 2021; Kressbach, 2021; Levy, 2018; Lupton, 2020; Mishra & Suresh, 2021) tends to treat fertility tracking as novel and explore this phenomenon only in relation to digital technologies. In her historical analysis of contraception, Drucker (2020) notes that reproductive technologies and ideas often get repurposed and new life is infused into old techniques. By showing how FAM knowledge becomes datafied, I here also suggest that we need to attend to how ideas and knowledge get reused and modified in digital reproductive health. This enables us to see larger trends and trajectories in innovation. By drawing on decades-old medical knowledge about menstrual cycles and fertility indicators, digital apps have not only automated existing knowledge through algorithms, but have arguably popularised it for users that might not have tracked their cycles otherwise. The growing popularity of fertility apps occurs in a context where many individuals are disillusioned with hormonal contraception (Dudoudet, 2022; Geampana, 2019a, 2019b) and are looking for a 'natural' option that will not interfere with their cycle. This is also true of those who want conception solutions that are natural (Grenfell et al., 2021). The allure of 'natural' solutions is enmeshed with discourses of wellness and 'holistic' wellbeing. Interestingly, the precision in measurement and algorithm accuracy that is touted by fertility apps seeks to change the association of the 'natural' with the 'unscientific.' Thus, fertility apps are in a way a paradox: on one hand, they might be perceived as 'natural' in that they are generally non-invasive, but, on the other hand, they are sold as 'scientifically proven' high-tech innovations, thus adding a layer of scientific respectability to what were once perceived as messy tracking activities.

The article shows how users' data work that has been emphasised in the previous literature (Algera, 2023; Della Bianca, 2022; Grenfell et al., 2021; Hamper, 2022; Wilkinson, 2020) is key to producing further knowledge using app data. This raises questions about the app as mediator between the user, understandings of the body and reproductive health knowledge more widely. Apps can be seen as a complex layer between the user and the interpretation of data about the body. This layer is governed by proprietary algorithms and developer decisions around level of cautiousness necessary in the output apps deliver. This side of data practices needs more research and this article has only provided a starting point. For example, a recent article (Manhart & Duane, 2022) shows that there are differences in how conservative companies are with classifying days as fertile/non-fertile. While apps hail themselves as a source of self-

knowledge, they also distil this information in particular formats. The reasoning behind such choices might not be readily available to users. To add to the critique of commercialisation in the reproductive health app literature (Ford et al., 2021; Kressbach, 2021; Lupton, 2020; Mishra & Suresh, 2021), this research contends that the datafication of fertility is changing known ways of measuring fertility, while also taking this knowledge in unexpected directions and away from public scrutiny. While traditional FAM are documented in detail in the medical literature, apps create significant fragmentation in how these methods are further developed and automated. This in turn raises doubts about the value of commercialisation in the production and dissemination of knowledge. Such questions are especially vital when legal avenues are used by companies to challenge outside expert opinions. But if commercialised digital technologies are to be recognised as scientifically sound, openness to criticism is vital.

Some might welcome easy user access to health technologies (Lievevrouw et al., 2022). This might seem desirable especially in reproductive health where we have seen sustained paternalism towards women and systemic inequalities in how care is delivered (Moss, 2002). What many commercial digital innovations do is give users the option of relying less on medical expertise, as shown here. Often, such technologies are viewed with suspicion by professionals even as user numbers grow. Some contend that it might be useful for us to start by looking at the reasons why women want to use fertility apps (Dudoudet, 2022; Lowe, 2018). At the very least, this might lead to an acknowledgement that user needs are not entirely met by the current medical landscape. If fertility apps are not the solution, then those needs must be discussed and met through other means.

CONCLUSION

Through the use of a critical data studies approach, this article makes the case that fertility apps shape knowledge-making processes and fertility knowledge in particular ways. Specifically, it argues that the apps facilitate private/public knowledge networks and expertise. They also datafy previous fertility knowledge and use data to create new knowledge. To maintain their relevance, they make use of legitimation practices. Understanding reproductive digital health in relation to wider data practices is important for seeing not only where the shortcomings of big data promises come from, but also how they might be addressed. Considering the increased datafication of health, looking at changing data assemblages illuminates how knowledge about the reproductive body is made and remade and by whom. This study calls for future research studies to conceptualise digital technologies as platforms that connect actors and knowledges in wider data assemblages rather than think of apps as well-delineated artefacts. The latter runs the risk of obscuring the wider politics of technological adoption and change.

AUTHOR CONTRIBUTIONS

Alina Geampana: Conceptualization (lead); Data curation (lead); Formal analysis (lead); Investigation (lead); Methodology (lead); Writing – original draft (lead); Writing – review & editing (lead).

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DATA AVAILABILITY STATEMENT

The data (documents and notes) that support the findings of this study are available from the corresponding author, upon reasonable request.

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