

Feeling Data: Touch and Data Sense

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Introduction

People's encounters and entanglements with the personal digital data that they generate is a new and compelling area of research interest in this age of the ascendancy of digital data. The emergence of novel modes of generating digital data about humans and their activities and movements has the potential for new ways of learning about and conceptualising bodies, selves and social relations. The experience of everyday life in many parts of the world is now increasingly datafied – rendered into digital data forms. People's interactions online, their use of mobile and wearable devices, and other 'smart' objects and their movements in sensor-embedded spaces all generate multiple and constant flows of digital data, often about intensely personal actions and preferences, social relationships, and bodily functions and movements. They are encouraged to take the opportunity to view and reflect on this information and use it to optimise their lives, improve their health and wellbeing, contribute to their memories or achieve self-knowledge (Lupton, 2016a; 2017; Nafus and Sherman, 2014; Selke, 2016). In response to the continual data streams and traces generated about them, people are learning to come to terms with how their personal information is generated and what meanings and value it offers them. They are now called upon to engage with a variety of forms of information about themselves and to confront the complexities of how these data are used by others.

Responding to personal data is a highly sensory experience, involving people to engage in complex negotiations between assessing the information they receive from their embodied senses and that generated from digital devices. The ways in which their personal details are translated from digital data into material form are important to people's sensory engagements with their data. Most discussions of personal digital data materialisations have focused on two-dimensional visual renderings: data

visualisations that are primarily designed to be looked at. This article is intended as a contribution towards understanding the sensory dimensions of personal digital data, with a particular focus on the haptic. I explore the topic of how personal digital data and their circulations can be made more perceptible and therefore interpretable to people with the use of three-dimensional materialisations that invite not only viewing but also touching and handling, and in some cases, the senses of hearing, taste and smell as well. I argue that these forms of data materialisation are potentially integral to new modes of understanding and incorporating personal data into everyday life, living with and alongside these data.

The discussion is structured into several parts. In the first part, I review some of the relevant literature on human embodiment, the senses and digital technologies, establishing the theoretical basis that is further developed in the article. This is followed by a discussion of how the ontologies of personal digital data may be theorised. I then introduce the notion of data sense, drawing attention to the sensory dimensions of how people interpret their data. I then discuss the ways in which personal digital data can be fabricated into three-dimensional forms using 3D printing technologies – data physicalisations – so that they can be experienced and responded to in multisensory ways. I provide examples of objects created from personal digital data that can be handled, displayed as decorative artefacts, worn on the body as jewellery and even eaten. Finally, I address the politics of personal data and their materialisations. The concluding comments raise some directions for further research emerging from this discussion.

Human embodiment, the senses and digital technologies

My discussion here draws on sociomaterialist theoretical perspectives to conceptualise humans' encounters with their data as dynamic entanglements of human and nonhuman actors. Human sensory responses are highlighted in some sociomaterial scholarship. Sensory engagements are considered as both vital to humans' experiences of the world and to meaning-making, and as mediated via their encounters with other humans and with nonhumans. Humans learn and act with and through their bodies, including their encounters with nonhuman objects, which generate sensation and feeling in human bodies (Paterson, 2007; Ash and Simpson, 2016; Paterson, 2009; Pink, 2015).

As the French philosopher Merleau-Ponty (1962; 1968) reminds us, we are embodied subjects and experience the world through our bodies and our senses. Our experiences and our judgements are always part of our 'being-in-the-world'. For Merleau-Ponty, 'being-in-the-world' is always intersubjective. Our embodiment is always inevitably interrelational or intercorporeal. We experience the world as fleshly bodies, via the sensations and emotions configured through and by our bodies as they relate to other bodies and to material objects and spaces. We respond to these bodies

and objects with all our senses, and this is essential to human experience, social relations and knowing our worlds. Embodiment and interembodiment are now frequently mediated via digital technologies. Digital devices may move on or with the human body (as in mobiles and wearables), or they may be *in situ* and directed at documenting the movements of bodies (as in CCTV cameras and movement sensors embedded in public spaces). Bodies, spaces and places are therefore simultaneously digital-material (Pink, Sinanan, Hjorth and Horst, 2016; Pink, 2015).

Haraway's (1995; 1985) concept of the cyborg has been seminal in emphasising the heterogeneous and historically situated intertwinings of humans and nonhumans. She argues that human ontologies must be understood as dynamic and emergent, established through relational encounters, including with technologies and other objects. In her more recent work, Haraway (2015; 2003) has developed the metaphor of 'companion species', which she describes as 'post-cyborg entities' (Haraway, 2015), assemblages of humans and nonhumans that live alongside and co-evolve with each other. She notes that these assemblages generate new forms of liveliness, relations and socialities. Hayles (2012) makes similar points in her work on technogenesis, in which she argues that humans think through, with and alongside digital media, and each works to change each other. She describes human agency, thought and embodiment as enmeshed in and extended through digital devices and networks. Hayles positions digital databases as vital components of technogenesis, particularly in the ways that knowledges are constituted and archived.

Recent scholarship in digital media studies has begun to focus on the role of the senses and the materiality of digital technologies in people's experiences and practices. Some of this research has addressed the phenomenology of touch. For example, tactile ethnographic studies by Pink and colleagues (Pink et al., 2016) and Moores (2014) have drawn attention to the role of the haptic sensations encountered by the hand when handling and touching digital devices, and how these sensations contribute to ways of knowing. This research emphasises the emplaced, contingent and emergent nature of digital technology use. It focuses on identifying the details of how people incorporate digital devices into their mundane routines, how these devices feel 'right' or 'comfortable' or not, the improvisations in which people may engage when using these technologies and how these devices are part of more-than-human multisensory worlds.

Theorising the ontologies of personal digital data

This scholarship provides a basis for beginning to think through the ontologies of personal digital data, and how these data are incorporated into concepts and practices of selfhood, social relations and embodiment. Given the mobility and ubiquity of contemporary digital devices, they may be understood as lively technologies,

inhabiting and accompanying us in our physical spaces and residing on or with – and indeed, as in the case of some digital medical implants or ingestible ‘smart pills’, sometimes in – our bodies. These devices have become companions and co-habitants with humans (Ash, 2013; Lupton, 2016a, 2016b; Moores, 2012). So too, the digital data that these devices generate may also be conceptualised as lively. The first element of the vitality of digital data relates to the ways in which they are generated and what happens thereafter. The personal digital information that is constantly generated contributes to data assemblages that are heterogeneous and dynamic, their character changing as more data points are added and others removed. Digital data may be described as having their own social lives as they circulate in the digital data economy and are purposed and repurposed (Lupton, 2016a).

Human fleshly bodies interact with digital technologies and lively data to produce personal digital data assemblages (Lupton, 2016a). These assemblages should be understood not simply as ‘data doubles’ (Haggerty and Ericson, 2000), which suggests a two-dimensional shadow of an individual, but as three-dimensional configurations. Rather than a static ‘data double’, these assemblages are constantly changing as new forms of data are generated and incorporated. The term ‘data double’ also suggests an individuated, autonomous materialisation of digital data about an individual. In contrast, the digital data assemblage concept emphasises the inextricable intertwinings of humans and their data. It also draws attention to the material elements of the human-data configuration, such as the spaces, places, digital devices and other objects beyond the digital that contribute to these assemblages.

Social research has shown that people often have difficulty conceptualising exactly what types of information are generated by or for them as part of their engagements with digital technologies. They are also only dimly aware of what happens to their personal data beyond their own use, and how other actors and agencies may be using their data. Research on public understanding of personal digital data has revealed that for most users of online technologies, the ways in which their interactions are monitored by companies for targeting them with customised advertising is obvious. But beyond these potential uses of their personal data, many people have little knowledge of where their data go and who uses them. They feel powerless about how others collect data on them and how these data are used (Andrejevic and Burdon, 2015; Rainie and Duggan, 2016; Madden and Rainie, 2015; Kennedy and Moss, 2015; Stark, 2016; Lupton and Michael, 2017).

It is not surprising that public knowledges about the social lives of their personal data are limited. Digital data assemblages are dynamic, responsive and distributed forms of selfhood; because of their mutable nature, they are elusive, hard to pin down and confront (Lupton, 2016b, 2017). Part of learning to live with our digital data assemblages and giving them meaning is coming to terms with their nature. We have to work hard to find figures of speech and ways of thinking to

encapsulate the ontology of digital data (Puschmann and Burgess, 2014). The concept of digital data, at first glance, appears to describe a wholly immaterial phenomenon that does not engage the senses: there seems to be nothing to look at, touch, hear, smell or taste. Although the devices that generate, transmit and store digital data – mobile and wearable devices, desktop and laptop computers, tablets, sensors embedded in objects and physical spaces, servers, modems – are material objects that are readily touchable, the data themselves are not. In most conceptualisations, digital data are invisible and intangible, to the point that they can be used to conduct surveillance – ‘dataveillance’ (van Dijck, 2014) – on people without their knowledge.

An approach drawing on sociomaterialist perspectives recognises the entanglements of personal digital data assemblages with human action. Personal digital data assemblages are partly comprised of information about human action, but their materialisations are also the products of human action, and these materialisations can influence future human action. The emergence of digital representations of phenomena have stimulated profound questions concerning discerning the nature of the ‘real’ and the ‘virtual’, the ‘material’ and the ‘intangible’ and the role of the senses in this process.

Drawing on Haraway’s companion species concept, I have elsewhere (Lupton, 2016b) suggested that thinking of personal digital data assemblages as companion species may be a productive way of conceptualising the ontologies of these assemblages. Just as we might reflect on how our lively companion devices live alongside us, we might also think about our lively personal digital data assemblages co-habit with us. As we co-habit with our devices and our data, we co-evolve with them. The design of the devices is conceptualised bearing in mind how users may interact with them, and users’ habits of practice as they appropriate the devices into their everyday lives are responses to the devices’ designs. So too, humans co-evolve with their personal digital data assemblages. The data are configured in response to, and about, humans’ experiences and bodies. In turn, humans may change their modes of being and concepts of selfhood in response to their data assemblages. With both our devices and our data, we are interembodied and intersubjective.

From data literacy to data sense

The term ‘data literacy’ has become employed in some quarters to describe how people learn from data and also how they learn to learn from data (Frank, Walker, Attard and Tygel, 2016; Wolff, Gooch, Montaner, Rashid and Kortuem, 2016). This perspective has developed predominantly from literatures in informatics, education, library services and information literacy research. Contributors to this scholarship tend to take a cognitive-centric approach, representing learning as a disembodied

process. They focus on how people interpret and evaluate the validity of digitised information and their competencies in accessing and analysing big digital datasets.

While these aspects are important, the ways in which people generate and respond to their own digital data requires greater research attention. I use the term ‘data sense’ to encapsulate a broader meaning than data literacy. This concept brings the body back in. It acknowledges the use of the human senses in people’s responses to data, including their personal data as well as big datasets. It also recognises the participation of technological sensors. Data sense, therefore, involves entanglements of human senses and digital sensors with sense- making. This approach underlines the embodied, affective and material nature of engaging with and learning from data (Fors, Bäckström and Pink, 2013; Sumartojo, Pink, Lupton and LaBond, 2016); or, as Stark (2016) puts it, the ‘viscerality of data’.

Data materialisations offer a technology for ‘freezing’ lively data assemblages at a certain point in time and place, providing data objects that help people make sense of their personal information (Lupton, 2017). These data objects represent a specific digital data assemblage that existed at the time of freezing – and then goes on to change again as more data points are generated and configured into new versions of the assemblage and as people engage with them and incorporate them into their everyday lives. The privileging of the visual is evident in the ways in which digital data are typically presented. The term ‘data visualisation’ is commonly employed to refer to the manifestations of digital data that can be configured as visual objects. It is a sub-field of information visualisation. In human-computer interaction (HCI) research, both information and data visualisation design is directed at communication: specifically, facilitating people’s understanding of and engagement with information (or, in HCI language, their ‘processing’ of the information). The proceedings of major HCI conferences such as the annual Conference on Human Factors in Computing Systems (CHI) feature many examples of this type of research.

Data visualisations involve taking pieces of information and rendering these into visual formats, involving the mapping of this information onto a property such as shape, colour, size and position and arranging these properties in space so that they have a relationship to each other that is designed to convey the meaning of the information. These formats are most often two-dimensional images: charts, maps, graphs, infographics and other diagrams, some of which may be interactive, moving when clicked. Those who work in ‘data viz’ endeavour to produce spectacular and aesthetically-pleasing images that not only communicate information clearly, but do so in a visually-arresting form.

When they are encountering visualisations of their personal data, people are challenged with interpreting the visualisations in relation to other information about their bodies and selves derived from their embodied sensations. It is clear from empirical research that for many people the data visualisations generated from their personal information is sometimes more ‘real’ to them than the knowledges that their

bodily sensations provide (Lupton, 2016a). Thus, for example, in research with colleagues involving people who track their physical exercise using digital devices (Lupton, 2017; Sumartojo, Pink, Lupton and LaBond, 2016) we found that people often talked about trusting the ‘numbers’ that they see on the data visualisations that their app or other software provides them. They talked about not really ‘knowing’ how their bodies were responding the exercise until they glanced at their heart rate monitor while running or cycling, or reviewed their data after their exercise. These data were often viewed as more ‘truthful’ or ‘accurate’ than the haptic and other sensations they felt from their bodies as they were exercising. Yet these self-trackers also engaged in complex acts of data sense-making that involved drawing on their past experiences of self-tracking their cycling trips, their sensory knowledge of how their bodies felt at the time of the rides (whether or not they were feeling tired, injured or ill, for example) and their sensory judgements of the weather and spatial conditions in which the trip took place (how windy or hot it was, how much traffic and other road users there were inhabiting the same spaces, whether the roads were slippery with rain and so on).

In these situations, people are challenged with interpreting and making judgements how the details generated by digital sensors, including those about their own bodily senses (how their bodies move, function, feel, recover, perform, rest and so on), can be trusted and incorporated into their lives. Such encounters with mundane data require people to engage in continuing negotiations with the information they view on personal visualisations and the knowledges afforded them by their bodies. These kinds of phenomena are rarely considered in data literacy research.

Data physicalisation and haptic sensations

While the visual materialisation of data remains a dominant concern, a counter-trend in the HCI and design literature focuses on the other senses and how they contribute to representations and understandings of data. Some digital devices, such as the Apple Watch, now rely on haptic sensations (or in Apple’s parlance, ‘tactics’) to deliver notifications to wearers, including reminding them to move if the device has sensed that they have been sedentary for too long. On its website, Apple describe this ‘taptic’ function as serving to provide alerts intimately and ‘with a more human touch’ (Apple, 2014). Visual displays are considered to be less effective than the opportunity to tap a wearer of the Watch on the wrist to alert them to notifications and incoming messages.

A field of research that has emerged in HCI devotes attention to the ways in which data can be rendered into three-dimensional physical artefacts, commonly referred to as ‘data physicalisations’ or ‘physical visualisations’ (Jansen, Dragicevic, Isenberg, Alexander, Karnik, Kildal, Subramanian and Hornbæk, 2015; Alexander, Jansen, Hornbæk, Kildal and Karnik, 2015; Stusak, 2015). This research focuses on how these data forms can support cognition, communication, learning, problem-solving

and decision making. The idea that multisensory experiences are richer and better understood than those that tend to emphasise only the visual dimension is evident in this literature. It is argued that such artefacts facilitate knowledge of data that otherwise would not be available by using such features appealing to haptic sensations as texture, stiffness, temperature and weight (Jansen et al., 2015; Alexander et al., 2015; Stusak, 2015). Stusak (2015: 439), for example, refers to 'haptic memory', or the recollection of data that touching or handling data physicalisations can evoke.

In the 1960s and 1970s, work began on haptic interfaces that sought to provide tactile feedback such as vibrations or the use of motion to human users as part of the operation of computing equipment. Some of these initiatives were directed at rendering scientific data into three-dimensional artefacts and available to haptic sensations. From the late 1960s, for example, Brooks et al. (Brooks Jr, Ouh-Young, Batter and Jerome Kilpatrick, 1990) in their Project Grope worked to represent scientific data – force fields of interacting protein molecules – as 3D materialisations. These developments gathered pace in the 1990s. In one project, Fritz and Barner (1999) developed a design to render mathematical data into haptic forms for people with visual impairments, using the properties of friction and texture. The technologies of embodied user interfaces were also developed in the 1990s, in which the user interacts with computing technologies by direct physical manipulation. Embodied user interfaces, involving the user manipulating the computer device directly, usually by tilting it, rotating it or other modes of moving it, is one paradigm of embodied user interfaces (Fishkin, Moran and Harrison, 1999).

Tangible user interfaces is another paradigm of embodied user interfaces. This paradigm used devices that engaged haptic responses to digital data by developing graspable objects which controlled virtual representations. Hiroshi Ishii and his colleagues (Ishii and Ullmer, 1997) were pioneers in the field of tangible user interfaces. They used their work on their Tangible Bits project to attempt to bring together the world of 'bits' (digital information) with that of 'atoms' (physical objects and architectural surfaces) and people. As demonstrated on the 'Data Physicalization Wiki' (Data Physicalization, 2016), human societies have rendered information into physical forms for millennia, including the clay tokens used by the Mesopotamians, the quipus, or knotted ropes used by the Incas, and the Marshall Islanders' stick charts (many more examples are listed on this wiki). Ishii and colleagues were inspired by the scientific instruments that had been invented in previous centuries to collect and comprehend information. They contended that the richness of understanding the manipulation of such physical objects developed had been lost with the contemporary focus on two-dimensional data visualisations.

Designers and data artists have started to use materialisations of data that invite haptic responses by rendering them into three-dimensional forms. The concept of 'data sculptures' has been taken up in many design and data art projects. It is used to describe the physicalisation of data that goes beyond the direct representation of

the data to incorporate aesthetic artistic qualities. This brings together information physicalisation with tangible user interfaces and creative art making (Stusak 2015). Thus, for example, data artist Mitchell Whitelaw used meteorological data from his home city of Canberra, Australia, to fabricate a 'weather bracelet' that could be worn on the arm. He notes on his blog post about the process that he found that people responded with fascination to the bracelet:

The bracelet makes weather data tangible, but also invites an intimate, tactile familiarity. People interpret the form with their fingers, recalling as they do the wet Spring, or that cold snap after the extreme heat of February; it mediates between memory and experience, and between public and private – weather data becomes a sort of shared platform on which the personal is overlaid. (Whitelaw, 2009)

Personal data physicalisations

Thus far, only a small number of designers or HCI researchers have extended the data physicalisation idea to render personal data into objects that can be touched. One example is a project undertaken by researchers from The Exertion Games Lab at RMIT University. This team experimented with using 3D printers in different ways to materialise personal body data. Their SweatAtoms project (Khot, Mueller and Hjorth, 2013; Khot, Hjorth and Mueller, 2014) involved five different material manifestations of participants' physical activity, fabricated on home 3D printers. These artefacts included a 3D graph of heart rate data, a flower shape where the length and width of the petals represent heart rate duration and intensity, a frog shape that changed in size according to the amount of physical activity carried out that day, a die representing the six zones of heart beat data and a ring displaying the number of hours the person was active. Participants in this project could hold or display their artefacts and compare the size of each one with others.

In researching user engagement with their physical data physicalisations, this team found that viewing and handling the objects helped people gain a better sense of their bodily data and engaged with it emotionally. They observed that the emotional connections people had with their personal data were strengthened by being able to handle and display these objects rather than simply viewing visualisations of the data. Their participants enjoyed viewing and touching the objects, showing them to others and arranging them as decorative items in their homes or on their desks at work. They manipulated and displayed their data artefacts in various ways to get a better understanding of their data.

Another HCI team (Stusak, Tabard, Sauka, Khot and Butz, 2014) has drawn on the concept of data sculptures to develop 'activity sculptures' – 3D printed artefacts made from physical activity data extracted from popular apps (collecting information

on the duration of users' runs, distance covered, average speed and calories expended). The artefacts included a human figure, a necklace, a lamp and a jar; each designed to be modular so that separate pieces could be fabricated after each of the participants' runs and formed together to make the sculpture. The participants expressed some interesting responses to the sculptures made from their physical activity data. The researchers noted that such factors as curiosity, playfulness and aesthetics began to influence the ways in which the participants planned their runs, as they tried to control the shape of the pieces that subsequently would be fabricated from their data using the 3D printers (Stusak et al. 2014).

Some data physicalisations using personal data have sought to stimulate not only haptic responses but also other sensory encounters as part of encouraging people to learn more about and from their data. Design researcher Stephen Barrass employed the technique of acoustic sonification to render personal self-tracked data into objects, or 'as a medium for telling stories about numbers' (Barrass, 2014). He used his own data from a year of blood pressure monitoring to produce a version of a Tibetan singing bowl – or what he called the 'Hypertension Singing Bowl'. The bowl was fabricated from stainless steel using 3D printing. The act of rubbing the inside of the bowl with a special stick produces a sound of a certain frequency. Barrass's personal bodily data were thus configured into an object that has unique visual, tactile and aural properties. Each set of data produced a bowl that is slightly different in its proportions and, therefore, its acoustic properties. Barrass argued that people can see and hear this physical manifestation of their blood pressure readings and also use the sound it makes as a reflective stimulus, helping them calm their bodies and reduce their blood pressure accordingly. This 3D data materialisation, therefore, can act as both a manifestation of personal data and an intervention in the type of data that the individual may generate in the future.

In their Edipulse project (Khot, Pennings and Mueller, 2015), researchers fabricated chocolates using 3D food printers and software files with digital data of people's self-tracked heart rate after physical activity. Based on each person's data, the 3D chocolate printer made a customised chocolate in the shape of an emoticon or words providing encouraging messages. The chocolates' size depended on the amount of physical activity in which the participants had engaged. They therefore acted as rewards that could be eaten by the participants. These participants could not only view and touch their data, they could taste and smell them as well.

The politics of personal data materialisations

I have focused thus far on the potential for data physicalisations to help people engage in sense-making in response to their personal digital data. They offer ways of bringing into data sense new versions of the possibilities of these data. Beyond this use lies a further opportunity for such phenomena to uncover the social and political

dimensions of personal data practices and cultures. Personal data materialisations, whatever form and shape they take on, are inevitably very limited representations of bodies and selves. The tools used to generate data materialisations work to single out some aspects of information over others. The role played by design and concepts of aesthetics and indeed, choices about what phenomena are considered to be 'information' are all central to the versions of their data that are delivered to people for their review; and by extension, what counts as knowledge and how people should learn from these visualisations.

A body of literature has begun to develop from scholars who take critical approaches to digital data visualisation. Writers who have contributed to this literature have insisted on approaching data visualisations as politically-charged phenomena that are the product of and serve to reproduce tacit assumptions, knowledges and power relations. They contend that data visualisation is a form of ideological knowledge production, in which certain elements are chosen to be manipulated in specific ways to create and emphasise relationships while others are ignored or under-emphasised. Powerful interests and existing biases and discrimination are frequently reproduced as part of the decisions made in creating data visualisations (Gregg, 2015; McCosker and Wilken, 2014; Kennedy, Hill, Allen and Aiello, 2016; Kennedy and Hill, 2016; Adema and Hall, 2016). These materialisations, indeed, can be considered data 'performances', not only conveying but creating meaning (Adema and Hall, 2016).

The persuasive power of these visually-compelling images often overwhelms such critical analysis. Such visualisations often tend to be accepted as politically neutral and value-free (D'Ignazio, 2015; Hill, Kennedy and Gerrard, 2016). Little attention is paid to where the information that is represented in such aesthetically-pleasing images comes from, who collects it, how accurate it is and whose interests it serves. The decisions made about what data are included and which are not, and indeed, what features even count as data, for example, are elided in most data visualisations. Like other popular culture artefacts, data visualisations can work to stigmatise, marginalise and trivialise disempowered social groups. Some of the most interesting work related to data visualisations has come from feminist critics of geographic information systems. They have challenged the positivist scientific practices and assumptions of this method of mapping and called for alternative practices that highlight injustices and inequalities, such as 'counter mapping', or generating cartographic representations that challenge taken-for-granted assumptions and highlight aspects that previously were not visible (for example, Kwan, 2002; Elwood, 2008; Pavlovskaya, 2006).

In some cases, such counter mapping involves the use of material other than two-dimensional visual images. For example, feminist geographer Mei-Po Kwan (2002) has used 3D digital mapping technologies to generate what she describes as 'body maps' of women, portraying their movements as life paths in three-dimensional space

and comparing these maps with those of women of different socioeconomic status and ethnicity. Other feminist geographers have employed qualitative rather than quantitative data in geographic information systems by adding voices and other sounds, hand-drawn images, photographs and videos, seeking to display and emphasise the richness of information that lies outside numerical data (Pavlovskaya 2006).

Just as visual representations are enactments of tacit assumptions and embedded power relations, any mode of sensory knowledge, including the haptic, is shaped via social, cultural and political processes. There are several levels of mediation and remediation operating when embodied sensations are rendered into digital data. The sensation of touch, as well as other sensory responses, is mediated through the flesh, skin, nerves and receptors of the human body. Physical interactions with technologies extend and reconfigure these mediations (Paterson, 2009). Material dimensions of human embodiment and practice are mediated via their interactions with digital technologies and transfigured into digital forms of information that can be transmitted to computing archives. These digitised forms of information can then be remediated into digital displays and in some cases, combined and recombined with other datasets to generate new data materialisations. Personal data materialisations, once delivered back to the people who generated them, can then be used to change their practices and attitudes in some ways. They can therefore have material effects on people's lives, which in turn can generate new data assemblages, and so on. The data they materialise, and the materialisations themselves, will always be limited and reductive, identifying only some elements of embodied sensations and practices.

Applying this critical perspective to data materialisations involves examining the interpretation of individuals' personal data and recognising ways these may be used for their own ends as well as promoting their awareness of what happens to these data beyond the individual. This may include developing an understanding of the sociocultural dimensions of data materialisations themselves. Intensifying the visceral properties of digital information can also serve to provoke people into responding more intensely to issues concerning what happens to their personal digital data. The emotional responses that data physicalisations can evoke may lead people to engage more actively, including at the political level, in challenges to violations of their personal data privacy and security (Stark, 2016).

Some artists have employed 3D printing technologies as part of their critique of the ways in which personal data can be used for surveillance purposes. In her art work 'Stranger Visions' (2016), Heather Dewey-Hagborg takes digital genetic data files, turns them into phenotypes (the physical manifestations of genomic data) and then prints out data sculptures of human heads based on the genetic data. She uses cast-off objects that she finds in public places to derive the DNA traces she uses: masticated chewing gum wads, fallen strands of hair, cigarette butts or finger nail clippings. Her point is to emphasise the extent and range of the detailed information that can now be

collected about people, right down to their genetic profiles, and the inferences that can be made about them using these details. This work is designed to be a reminder to people of how their bodily traces can be datafied and used for the purposes of others, possibly revealing their identities or other sensitive information in the process.

Such projects suggest the potential of using multisensory data physicalisations not only to help people interpret their personal data but to consider their political implications. Several HCI projects seek to use 3D-printing technologies as a method of inviting members of the public to engage in the act of creating their data objects. The idea of such work is to encourage reflection and conversations about the information and help people feel as if they have more control of and engagement with their personal data by allowing them to make their own artefacts. It is argued that if these acts of fabrication take place in a communal setting, they may become less individualised, resulting in shared and social experiences of generating personal data physicalisations.

Thus, for example, Nissen and Bowers (2015) have experimented with encouraging people to engage in 'data making by producing 'data-things' from their own data. These physical data representations become personal data artefacts. Nissen and Bowers refer to such activities as 'participatory data translation'. Such digital data physicalisations, they argue, are experienced as less 'alien' than mass-produced things because their makers have better knowledge of how they are fabricated and they have a far more personal provenance. One example of these data-things is the objects that were created from the tweets generated by attendees at a conference. The number of tweets using the conference hashtag created by each attendee over a period of 24 hours was fabricated into an object that could be worn as a brooch representing the extent of that person's Twitter engagement. The researchers argue that through engaging in this process of data translation, participants can gain a sense of the reconfigurations that data undergo; or, as I would put it, the liveliness of the data becomes more visible.

Concluding comments

In this article, I have brought together some different literatures to explore the ways in which personal digital data are materialised and interpreted. I have developed the concept of data sense as a way of thinking through the intersections and entanglements of human bodies, software code, digital devices, space and place and the digital data that are generated from these entanglements. Three-dimensional personal data materialisations invite users to 'feel their data'. 'Feeling data' has two meanings: the sensations of touching these three-dimensional objects and the visceral responses that are generated from these and other sensory encounters with data. This acknowledges that humans, digital technologies and digital data participate and work together in feeling in complex ways.

As I have argued, the negotiations in which people engage when feeling their data implications for personal digital data meanings and practices and for data sense. Apart from some of the HCI research cited above concerning user experiences, we as yet know little about the sensory dimensions of how people interact with their personal data materialisations (whether two-dimensional or three-dimensional). While these objects are static forms of data, they are also potentially lively – they may incite or provoke further embodied and sensory responses. Further research into these engagements would go far to provide insights into data sense, including a focus on how people collect and engage with their data as part of the sensory routines of everyday life.

A sociomaterialist approach to the body focuses on how bodily assemblages possess certain forms of new capacities and power to act by asking ‘What can a body do?’ (Fox, 2015). This type of critique raises some compelling issues for further practice and scholarship related to three - dimensional and other multisensory materialisations of personal data. We might not only ask ‘What can a body do?’, but also ‘What can digital data assemblages (which include bodies) do?’ We might also investigate what the ‘felt phenomenologies’ (Paterson, 2007) of these assemblages are: how do people incorporate them into their everyday lives and what are the sensory dimensions of this incorporation? In Merleau-Ponty’s terminology, how are data physicalisations and the haptic and other sensations they incite part of ‘being the world’ experiences? In what ways do the senses work together – or work against each other – when people are engaging in sense-making in response to their digital data assemblages?

Drawing on the notion of ‘mundane frictions’ articulated by Fors (2015) these forms of haptic media might begin to raise important questions about where fit become uncomfortable, unsettling or disturbing – where and how they do not ‘feel right’. As Frosh and Becker observe, the presence of friction does not need to imply conflict or hindrance. Rather, it can be viewed as a productive and positive mode of generation of knowledge, identifying dissonances that are central to critique. The visceralities that data physicalisations can offer evoke these types of discomforts, and in doing so, potentially awaken people to where digital data may not work, fail to fit, lose their seamless nature and create friction. Discomfort and disquiet can become more than personal affects – they can provoke political responses. We can, perhaps, begin to think about a type of haptic politics that may be enacted via data physicalisations and data visceralisations, where data simply do not make sense because they do not ‘feel right’.

Returning to the political possibilities of data visceralisation, going beyond simply seeking to create sensually- engaging objects in the cause of challenging entrenched assumptions and interests can be a way to engage with these issues. Approaches that adopt a perspective leading to responses to personal data which invite users to take up ludic, creative and improvised engagements (Gaver, Bowers, Boehner, Boucher, Cameron, Hauenstein, Jarvis and Pennington, 2013), create their

own data-things (Nissen and Bowers, 2015), encourage them to invest objects with even more personal and intimate features by overlaying a patina of personal data on them (Lee, Son and Nam, 2016) or demonstrate to them the vulnerability of their data, as in Hewey-Dagborg's art work, may be one way forward. These approaches provide possibilities for the generation of alternative or counter perspectives and greater opportunities for people to 'feel' their data in ways which make sense in the context of their own lives. In the process, they may well develop data sense in the tripartite meaning that I have introduced here. This acknowledges the entanglements of digital sensors, human senses and human sense-making as well as the political and ideological implications of data and their materialisations.

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