Algorithmic assemblages of care

imaginaries, epistemologies and repair work

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Abstract: This paper takes outset in the figure of the algorithm and unpack the relations through which an algorithmic system, designed to 'take on' the role of a physiotherapist in physical rehabilitation programs in Denmark, was designed and made to work in practice. On the basis of ethnographic fieldwork, it is demonstrated that algorithms and their effects are fragile accomplishments and outcomes of negotiations between algorithmic imaginaries and anticipations, and ongoing adjustments of IT workers, patients and professionals. Drawing on recent work on the incompleteness of algorithms, it is suggested that the algorithmic system needs to be creatively 'repaired' to build and maintain enabling connections between bodies and algorithmic systems in arrangements of care. The paper concludes by addressing accountability for the workings of advanced algorithmic systems in medical practice, suggesting that such questions must also be discussed in relation to the various forms of 'repair work' needed to enable algorithmic systems to work in practice. Such acts of accountability cannot be understood within an ethics of transparency, but are better thought of as an ethics of 'response-ability', given the need to intervene and engage with the open-ended outcomes of algorithmic systems.

Algorithmic assemblages of care: imaginaries, epistemologies and repair work

Introduction

In the past decade, the figure of the algorithm has emerged as a new matter of concern (Latour 2004) in discussions about the current state of the health care sector and what it may become. While the increasing capacity to produce and store 'big data' has for long been depicted as the revolutionizing driver behind a more effective and evidence-based health care sector (Prainsack 2017), the role of algorithms – the coded instructions through which data is filtered, sorted and processed – has recently attracted attention (Ruckenstein & Schull 2017). It has been argued that data sets in themselves do not bring transformative value to data and the health care sector; rather, it is the algorithmic processing of data (Obermeyer & Emanuel 2016). This emphasis on the role of algorithms in the realization of a more efficient and evidence-based health care sector has been followed by an increased interest in the design of algorithmic systems, to 'take on' professional tasks in clinical practice and care, such as predictive diagnosis and the selection and application of treatment regimens (Burt & Volchenboum 2018).

The distribution of tasks to algorithmic systems and their role in medical treatment and decision-making has been widely debated. On the one hand, medical scientists and policy makers are enthusiastic about the promise of efficiency and better care generated by the design of advanced algorithms in medical practice. This vision is particularly attractive to the many countries worldwide which face the challenge of demographic ageing and a rise in the number of people with chronic diseases (European Commission 2015). Reflecting those hopes and visions, medical algorithms have become objects of investment in a global market (Gartner 2016), and political declarations are being made about boosting research and competitiveness in the field (European Commission 2018).

On the other hand, scholars working in the interdisciplinary field of 'critical data studies' (Iliadis & Russo, 2016) have raised concerns about the power and agentic capabilities of algorithms in health and other fields (Beer 2017, Cheney-Lippold 2011, Dourish 2016, Gillespie 2014, Introna 2016, Lustig et al. 2016, Ziewitz 2016). The concept of 'algorithmic authority' has been suggested to describe how algorithms increasingly have come to shape both individual lives and large-scale social, economic and political processes, while at the same time operating through complex processes of calculation which are often dispersed and not directly amenable to scrutiny (Cheney-Lippold 2011, Lustig et al. 2016, Pasquale 2015, Shirky 2009). As the philosopher Frank Pasquale argues, while we may know what goes into the computer and what the outcome is, we know nothing about what happens to data during processing; this process is black-boxed (Pasquale 2015, 21).

The delegation of professional tasks to algorithmic systems constitutes a new 'geography of responsibility' in the contemporary health care sector, in which patients and professionals are expected to engage in the production of data and simultaneously respond to various forms of digital feedback (Schwennesen 2017, Schwennesen 2016). While medical researchers, politicians, and critical digital data studies scholars have started to take notice of algorithms and their introduction into health care practices, little is yet known about how the introduction of advanced algorithmic systems may come to reconfigure medical practice and the relationship between patient and professional. As Ruckenstein and Schull argue, we still need more rigorous accounts of the actual reality of 'datafication of health' as it takes shape in diverse practices, and twists in unforeseen directions (Ruckenstein & Schull 2017).

In the following, I focus on the configuration of an algorithmic system and how it interacts with patients and professionals in the field of physical rehabilitation. I begin from an ethnographic study on the design and use of an algorithmic system – a smart phone application with five wearable sensors – designed for use in physical rehabilitation in Denmark. The technology embodies the vision of designing an intelligent 'virtual trainer', which can act as a stand-in for a 'real' physical trainer when the patient is doing her home-training (Ruttkay & Welbergen 2008), and operates through the algorithmic processing of patients' movement data. The study follows the process of designing and introducing the algorithmic system into physical rehabilitation programs in a Danish municipality, asking: What are the imaginaries and relations that enable the algorithmic system to come into being? What are the processes through which algorithmic authority is produced, negotiated or sometimes broken down? I trace those relationships and entanglements through three empirical sites: the production and design of the algorithmic system; the interaction between algorithms and patients; and the relational encounters between algorithms, patients and professionals in arrangements of care.

The notion of the algorithm as an apparatus which is both powerful and inscrutable at the same time has come to structure current discussions on algorithms and their role in the contemporary health care sector (Beer 2017, Neyland 2016). In these discussions there has been a tendency to detach the algorithm from its surroundings, and to treat it as a technical and impartial form of knowledge. For instance, media scholar Cheney-Lippold, discussing the social impact of algorithms in internet marketing, argues that algorithms work as a new mode of control, increasingly regulating our lives and telling us 'who we are, what we want and who we should be' (Cheney-Lippold 2011). Likewise, Steiner argues that algorithms have invaded and almost run our lives (Steiner 2013). He states that we are facing an algorithmic revolution, in which algorithms will displace humans in a number of fields, warning that 'algorithms can and will do strange things, when left alone' (Steiner 2013, 3). Similarly, more enthusiastic proponents emphasize the capacity of advanced algorithms to 'revolutionize' medical diagnosis and prognosis in the 21st century (Obermeyer & Emanuel 2016). In turn, both enthusiastic proponents of the capacities of algorithms to direct the health care sector towards greater efficiency and better care, as well as critical digital health scholars focusing on the algorithm as an invisible regulatory power, share an understanding of the entity of the algorithm as a powerful force, capable of acting on its own. In this paper I challenge the proposition of the algorithm as an entity that possesses transformative power in and of itself. By exploring the socio-material entanglements whereby the algorithmic system is made and enabled to work in practice, I illustrate that agency or authority do not inhere in the algorithm itself. Rather, its agentic capabilities are produced through associations made between social and material agencies, such as algorithmic imaginaries, policies, sensors, smartphones, IT workers, private companies, municipalities, physiotherapist and patients. Exploring how these agencies are connected together through the three sites, allows us to see how algorithms and their effects are emergent, malleable and contingent, as they are made, negotiated and transformed through various socio-technical relationships. By drawing on recent work on the fragility and incompleteness of data and algorithms (Jackson 2014, Pink et al. 2018, Tanweer et al. 2016) I illustrate how the algorithmic system needs to be adjusted and creatively 'repaired' to build and maintain meaningful connections that may enable a productive relationship between the system and bodies undergoing rehabilitation. I conclude by discussing who or what we should hold accountable for how algorithmic systems come to work in medical practice. While algorithmic accountability has most often been discussed in relation to questions such as transparency (the need for disclosure of the factors that influence decisions being made by algorithms) and bias (the norms and values embedded in algorithms which might have unfair and discriminatory effects), I suggest that we also have to discuss questions of accountability in relation to the actual and concrete encounters between algorithms, health professionals and patients, and the various forms of 'repair work' needed to enable algorithmic systems to work in practice.

From algorithmic entities to algorithmic assemblages

In order to provide an analytical framework which allows for contingency and emergence, I draw on STS in my analysis of the configuration of the algorithmic system. This directs attention away from the algorithm itself, towards the heterogeneous socio-material assemblages through which the algorithmic system is produced and designed and made to work in practice. The notion of the assemblage refers here to the ongoing flow through which social and material agencies make connections with one another and come to constitute the agential capacities of an entity (Bennet 2010, Latour 2005, Wahlberg 2017). It relies on a constructivist ontology, which states that entities (algorithms, patients, professionals) are not distinct and definable, but are fundamentally inter-twined with each other in socio-material networks, gaining their specific qualities through these relations (Barad 2007, Latour 1999, Mol 2002). That is, no a priori assumptions about the existence of certain entities are made from the outset. A controversial tenet, therefore, is that agency is not to be considered a property of any pre-given entity (algorithms or humans) but an effect of relational associations consisting of both human and non-human actors (Barad 2007, Latour 1999). As such, everything that can be observed to cause an effect on the course of a situation or an event can be conceived of as an actor (Latour 1999, 124). The question of algorithmic power or authority hence must be considered an effect of the connections established between various human and nonhuman elements in the algorithmic assemblage; it is the emergent interactional encounters between the elements which decide the function of the algorithm and its agentic capabilities.

Working with the analytical framework of 'algorithmic assemblage' rather than 'algorithmic entity' enables exploration of the ongoing processes through which heterogeneous elements such as algorithmic imaginaries, policies, sensors, smartphones, IT workers, companies, physiotherapists and patients form connections with one another in a range of sites and temporalities. From this perspective, the algorithm is but one element of the broader socio-technical assemblage in which it is embedded. In my analysis, I combine this analytical approach with theories on the mutual constitution of bodies and technologies in the field of health and telecare (Langstrup 2013, Mol 2000, Oudshorn 2008, Pols 2012); social studies of self-tracking devices (Kristensen & Ruckenstein 2018, Lomborg, Thylstrup & Schwartz 2018, Lupton 2013, Schull 2016); recent studies on bodily sense-making and engagements with data (Lupton & Maslen 2018, Lupton 2018); and studies that have pointed to the fragility and incompleteness of data and algorithms (Jackson 2014, Pink et al. 2018, Tanweer et al. 2016).

The Danish Case: Digitalization of the public sector in Denmark.

Denmark is a welfare state in the Scandinavian tradition, with a tax-based, universal health care system. Like many countries in the world, Denmark faces the challenge of demographic ageing due to the increasing longevity of life; it is expected that the cost of care for elderly citizens and those with chronic diseases will rise significantly in the future (Danish Government 2016). As a potential solution to the 'problem' of demographic ageing in the Danish welfare state, the Danish government has increasingly invested in the development of public-private innovative partnerships, with the aim of transforming its know-how on care services into the design of innovative welfare technologies. This transformation is being promoted by several political strategies and initiatives. A recent, highly profiled initiative was the establishment of the SIRI Commission, whose leading officials and experts were to explore the potential for using artificial intelligence in health care services (Siri Commission 2018). Under the heading, 'Health and the good life is what we aim for – data and artificial intelligence is the means', the commission recommended that Denmark in the future should become a specialized 'hub' for experimentation with, and development of, new digital technologies in health, and suggested a number of initiatives aimed at reaching this goal (Siri

Comission 2018). By exploring and investing in the development of new digital welfare solutions, the intention was not only to make care work more efficient by making those products available for use by the Danish welfare state, but also to export them to a global market, thereby providing the basis for an economically sustainable welfare state in the future. These strategic and political acts can be seen as elements in a broader socio-technical imaginary (Jasanoff & Kim 2015) of a future Danish welfare state, in which high tech solutions and processes of automatization are positioned as 'curators' of its sustainability. The desirable future, in this case, is a transformation of the Danish welfare state, which was previously 'fueled' by its agricultural economy, to a nation sustained by the export of high-tech digital welfare solutions. This collective vision both serves to justify new investments in new digital technologies and reaffirms the state's capacity to act as a responsible servant of the public good; it is currently being materialized through the launch of an ambitious dgitalization strategy in the public sector. Physical rehabilitation has been mentioned as particularly well suited to further digitalization, and municipalities have been encouraged to invest in new digital technologies in this field (Danish Government 2017). Following this call, several municipalities in Denmark have invested in the algorithmic system, and it is now being offered to patients who are referred to municipal physical rehabilitation units after hip replacement surgery.

Method and background

The present work is based on an ethnographic study of the production and use of the algorithmic system at a rehabilitation center in a municipality in Denmark. The algorithmic training system consists of a smartphone with an app and five wireless sensors equipped with elastic rubber bands, which the patient wears during home-training: two on each leg and one on the back. The sensors are virtually connected to the smartphone and produce data on bodily movement that serve as input to the algorithmic system. The sensors monitor the movement of the different parts of the body where they are placed (upper leg, lower leg, back), and measure the angles between them. The data on bodily movement is translated and transformed into immediate digital feedback to the patient, with the aim of guiding and motivating the patient during training. The data appear as text messages (e.g., 'keep up the good work') and visual images (between one and three stars) on the smartphone interface, and a digital voice correcting the patient's movement (e.g., 'lift your knees to a higher position'). In addition, an avatar on the interface of the smartphone imitates the patient's movement.

The patient's movement data flow through a digital system, to which both therapist and patient have access. The system calculates the number of exercises which have been performed at home, and indicates with a color code the quality of those movements: exercises evaluated as not good enough are marked in red, exercises evaluated as good in green, and exercises evaluated as in between are in yellow. In order to make the rehabilitation process most efficient, the system is programmed to progress automatically with new and more demanding routines when a number of exercises have been performed correctly.

On the company's home-page, the system is presented as an 'intelligent trainer', which enables supervised and flexible home-training. This image of the system as a competent proxy for a 'real' physiotherapist is reflected in the ways in which the technology is implemented in the arrangement of physical rehabilitation. Whereas patients were previously offered group-based training sessions at the rehabilitation center for one hour twice a week, patients who want to use it are only offered one session per week. The assumption is that the technology is able to guide the patient at home, which to a certain extent can substitute for training with a 'real' physiotherapist. Thus, responsibility for guidance and professional supervision is partly delegated to the algorithmic system, and patients are expected to actively engage in the process of generating and responding to data on bodily movement.

For six months in 2016-17, I followed thirty people undergoing physical rehabilitation who had been offered the use of the technology, attending weekly one-hour training sessions and physiotherapist-patient conversations about the technology, and engaging in informal conversations with physiotherapists and patients. Additionally, I interviewed sixteen patients in their homes and observed their home training with the technology. I also interviewed five physiotherapists who were primarily responsible for the training session with users, a health consultant who was engaged in the process of developing the technology and an IT worker who was responsible for the algorithmic system. Extensive field notes were taken in clinical encounters at the rehabilitation center and during home training, which were written up immediately after leaving the site. Subsequently, field notes were analyzed across sources and sites. Interviews were transcribed and general themes were identified across the field notes and the transcripts, with a focus on the imaginaries and relationships influencing the design of the algorithmic system and its functioning in physical rehabilitation arrangements.

Analysis

Transferring expertise from health professionals to algorithmic codes: Designing the algorithmic system

The algorithmic system was designed with the intention that it would act as a proxy for the health professional in its interaction with patients. Through algorithmic transformation of movement data into digital feedback (oral, textual and visual), the vision was to create a device which was able to interact with patients. The process whereby the algorithmic system was designed reflects this vision of substitution as it relied on the idea that human expertise can be transferred from humans to algorithmic codes. The developers describe the development of the design as a bottom-up process.

Professionals were at first invited to identify all the parameters that they saw as important in their assessment of whether or not particular exercises were sufficiently carried out.

> HC: With each exercise, we were at first just sitting and writing everything down: 'What do we look at in a squat? We look for knee flexion in both legs; we look at how far one goes down in hip flexion; is the weight evenly distributed on both sides?' All the things we'd like to know, we wrote down – and then we sort of had the developers take a look at what the system can then say something intelligent about. And what it can't say anything about.

This process of identifying parameters for professional assessment of different exercises was followed by one of selection and prioritization of specific parameters. Professionals were asked to sort and prioritize the parameters that they found most important:

> HC: As physiotherapists, we had to sit down and be pretty tough in setting priorities in relation to the kind of parameters feedback should be given on... I mean, I think we've sometimes sat down with 20 to 25 and ended with 4 to 5. So we have actually cut it down quite a bit. You could say that there has also been a natural selection, because, I mean, of course we started just by writing everything down: 'What am I looking at in this exercise?' right? And with the sensor setup we have – for this target group it's on the legs – then it's only the lower extremities that we can say anything about. So for example, if there were some parameters that dealt with what one does with the arms or something else, then of course, we could say, 'The sensors can't say anything about that.' So of course, that was automatically discarded.

What comes to the fore here is that specific parameters for assessment of bodily movement were not only decided by the physiotherapists' professional assessment of what it takes to do an exercise well, but also by the capabilities of the algorithmic system and the sensors. The set-up, with its sensors on the lower extremities of the body, is not able to measure the movement of the upper part of the body, and some parameters were excluded because of the sensors' inability to process data on them. Hence, the specific parameters that went into the algorithmic system were not decided by professional expertise alone, but were regulated by the technological ability to produce data on identified parameters.

In addition to the process of selecting the parameters that serve as in-put data for the algorithmic system, physiotherapists also had to suggest where to draw the lines between 'good', 'bad' or 'in between' bodily movement in relation to the parameters. These evaluative boundaries express three different intervals of angles between monitored body parts, and was contested among the physiotherapists:

> HC: Every exercise has been made with three levels, and there we have sort of sat around and had these very loud discussions about how many degrees it takes before it's accepted as a good performance. And then we've sometimes had to adjust it downwards, because we've found out that we may have been a bit too tough in relation to what the target group was actually capable of. And other times it's been the other way around: we've had to dial up some of the parameters because it's been too easy to carry it out. And actually, we still do that on an ongoing basis here now: the more municipalities, the more users we get on board, that's where we get some feedback on how well it fits the target group, right? So it's kind of an ongoing process.

The selected intervals of angles between body parts being measured serve as input data to the algorithmic system, and decide whether the patient will receive corrective or encouraging feedback. The distinction between 'good' or 'bad' bodily movement not only divides movement into different categories; these divisions are also attached to a valuation of the quality of bodily movement. By deciding on the particular intervals of angles between 'good' and 'bad' bodily movement, the physiotherapists enact a performative 'agentic cut' (Barad 2007) through which bodily movement is evaluated and assessed. Barad uses this concept to emphasize that apparatuses of knowledge production are not objective observers, but must be considered as productive and part of the very phenomenon they seek to measure (Barad 2007, 115). From this point of view, it is the algorithms and the created boundaries between 'good' and 'bad' bodily movement which articulate the body as moving 'well' or 'poorly'. While the algorithmic processing of patient movement data is built on a vision of professional substitution, the algorithmic articulation of bodily movement does not correspond to professional expert assessments. Tellingly, the health consultant emphasized that the algorithmic apparatus represents a limited version of professionalism, one which conflicts with a more holistic approach in which bodily movement is assessed in relation to the movement of the body as a whole.

In opposition to a view of algorithms as a fixed way of ordering and processing data, data processing emerges through a temporal flow of knowledge production, through which digital feedback is created. An IT worker describes the algorithmic system as a complicated process of calculative steps, consisting of predefined rules for how to proceed to the next step, through which input data are transformed into feedback. Hence, the system can be described as a sequence of calculative steps with defined criteria for whether or not to move forward to the next calculative step.

> IT worker: It's sort of like having a recipe [sic] for a computer, with a list of instructions that the computer follows. … in our system, we have the sensors that tell us about whether the angles are this way or that way, and then a number appears based on that. In an exercise, you can then say that, ok, we have a start position and an end position, and then the system receives various inputs underway that determine if some defined conditions have been met, if the end position has been reached. When it then says that, then it jumps to the next step and waits until the input indicates that you have met the conditions for a start position, et cetera.

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What comes to the fore here is that the action of the algorithmic system has a temporal flow which decides the 'doing' of the algorithm. The 'doing' of the algorithm is constituted by the calculative steps embedded in the algorithmic system, rather than in particular parameters or codes themselves. Specific rules were added to the temporal flow of the algorithmic system, based on assumptions about human behavior and motivation (at least 15 seconds between corrections, only repeated 'bad' movements will trigger a correction, the same correction can only occur twice etc.). These rules reflect the attempt to add sensitivity to the algorithmic processing of data in order to keep patients motivated during training and provide a balance between judgement and re-enforcement, which is expressed below:

> HC: At least 15 seconds need to pass before it mentions a new correction, so you have time to take it in, right? Then you can also have the situation where it'll only be in the next set that you get that correction. And again, we've also placed a message into the sensors saying that if this is not a recurring mistake, then it's not important. I mean, if it's something you do several times, then it's a mistake that needs fixing. But if it's because you just happened to lose your balance, then it's not a mistake to be fixed. So in that way, we've tried to make it fit as much as possible with real life, because you'll often find yourself making maybe a single mistake and then you don't need to be beaten over the head and told 'remember to distribute the weight equally across both legs', because you know to remember to do that... There's also something about the same correction only being able to appear two or three times, because, if you keep getting the same correction, it can become irritating for the patient. There are also the voiced corrections that are played while doing the movement. When you are done with the exercise, there is a written correction, and there is only room for one on the screen, and it will always be the one that you have had the hardest time doing well. And then you might say, in reality there could be three messages, but there, for the sake of user friendliness, we have said that it should be the one they have had the toughest time with... There are, after all, tolerance thresholds for patients in relation to how many corrections one can receive without becoming demotivated, so it's a fine line to walk.

In addition to the stricter focus on professional assessment of bodily movement (as illustrated in the previous section), sentient rules were added to the algorithmic processing of data, to 'sensitivize' the digital feedback the patient receives during training. As the health consultant says, this is to 'make it fit as much as possible with real life'. In real life, interaction between physiotherapist and patient is not only regulated by strict professional assessments and corrections of bodily movement, but also by human empathy and care. As she further points out, choosing the level of corrective feedback to the patient is a 'fine line to walk', so that the patient does not lose the motivation to continue with the training.

There is clear inspiration here from the growing self-tracking industry, which offers individuals various forms of tracking devices designed to monitor and measure health and behavior (e.g., Fitbit, Vivofit, Endomondo, Apple Watch etc.). Anthropologist Natasha Schüll, in her study on self-tracking technologies, offers a detailed account of how they are designed to govern users through real time 'micro-nudging' (Schüll 2016). Nudging is a strategic method for guiding human behavior and decision-making in a specific direction through positive reinforcement, in contrast with other ways of achieving compliance, such as legislation or enforcement (Sunstein & Thaler 2008). As Schull shows, many self-tracking technologies today operate within a gamified logic designed to keep users on their platforms through real-time nudging (Schull 2016). This new ‘behavioral-informatics mode of regulation’ is designed to ‘hook’ the user into engaging in a constant state of data production. Similarly, the algorithmic processing of data is designed with foundations in human anticipations and assumptions about human behavior and how to keep patients ‘hooked’ when they are training at home.

While the algorithmic system is founded on a socio-technical imaginary of the possibility of replacing professional work with advanced algorithmic codes, it is clear that the process of transferring professional expertise to algorithmic codes is not straightforward. The making of the algorithmic system and the digital feedback it creates are outcomes of a complicated process involving a variety of human (physiotherapists. IT workers) and non-human (algorithmic imaginaries, policies, sensors, parameters, computers) and various judgements and assumptions about patient motivation and behavior. Moreover, the algorithmic system is not a final and clear cut entity, but is better understood as a temporal sequence of actions and decision-making, designed with the intention of keeping the patient ‘hooked’ during training. The complex character of the algorithmic system was described by an IT worker using the analogy of ‘spaghetti’ to illustrate the tangled and opaque connections between parameters, algorithms and codes that make up the system, thus emphasizing that an algorithmic system is a messy and fragile accomplishment, rather than a closed and stable system of calculation. In the following section, we see what happens when this specific form of bodily valuation and articulation interacts with patients and professionals in real-time arrangements of care.

Producing and interacting with digital feedback during home training.

The algorithmic system consists of a daily training program which the patient must complete at home. Most patients welcome the possibility of supervised training in their homes as promised by the technology. After undergoing hip replacement surgery, many find it difficult to move around in everyday life, and travel back and forth between home and rehabilitation center are experienced as a hassle. Free transportation is offered by a municipal transportation agency; however, this would often involve many hours of waiting. Hence, for most patients, training with the technology was perceived as a means to greater flexibility and independence in their movement towards recovery.

Like telecare applications for chronic disease management, the technology promises 'care at a distance' (Langstrup 2013, Oudshorn 2008, Pols 2012) by mobilizing the home as a new space for care. Moving care from institutions to the homes of patients in need of care demands the emplacement of various objects and activities in everyday life (Langstrup 2013). In this case, patients had to rearrange the home to allow for physical training, often explaining how they had to move furniture and the bed around to make enough space. Moreover, before every training session, smartphones and sensors had to be calibrated, which involves a careful spatial re-arrangement of the body, the smartphone and the sensors. A distance of at least three meters between the smartphone and the five sensors, along with a specific angle between them, were required for successful calibration. During calibration, a digital voice guides the patients on how to move the body correctly. During the process of calibration, a relation between the sensors, the body and the smartphone is established, which serves as in-put data for the algorithmic processing of movement data. In order for the calibration to be successfully completed, the body, the sensors and the smartphone must be carefully arranged; the sensors must be located at specific places on the body, the distance and angle between the body with the sensors and the smartphone must be correct, and so on. In many cases the patients experienced problems:

> Lena: It's all about whether it calibrates [correctly]. That's the key. Something went wrong the last time I used it, and it looked like one of my legs was a little bent on my phone avatar. Now, I place the phone on the floor when I start. That helps. If I instead place it on the table, then when I get up from the chair, the avatar's body goes into the floor instead of up, and then it doesn't count my exercises and makes the avatar on the phone look odd.

This patient experienced problems when she placed the smartphone on the table, but found that if she placed the smartphone on the floor, the calibration could proceed successfully. This process of tinkering with the elements in this new socio-technical arrangement of physical rehabilitation (body, sensors, smartphone, chair), illustrates the need for arranging and putting human and non-human actors 'in place', for the system to be able to produce and process data on bodily movement.

If calibration proceeds successfully, the algorithmic system guides the patient through the exercises with a digital voice which counts the exercises when a movement is registered in the system as input data; it then tells the patient what kind of exercises will ensue:

> Digital voice: One, Two. Three. Four. Five. Six. Seven. Eight. Nine. Ten. You have now completed the first set. Take a small break before continuing with the next set. Switch to your left side. One. Two. Three. Four. Five. Six. Seven. Eight. Nine. Ten. Switch to your right side.

During and after a set of exercises, the patient receives various forms of feedback (as described above): stars on the smartphone interface indicating the overall quality of a sequence of exercises; digital text messages communicating encouragement; and a digital voice giving immediate corrective feedback. In many ways, the interaction between the technology and the patients resembles the relationship between a patient and a health professional. The patients trust the competence of it and try to obey the corrective feedback they receive. They are emotionally affected by its responses: pleased when it gives positive feedback and frustrated when it communicates corrections. In their analysis of relational encounters between medical technologies and users, Pols and Moser argue that affective ties to technologies can be created when the technology promises something which is of great value to the user (Pols & Moser 2009). The algorithmic system promises a flexible pathway to 'efficient recovery' after hip replacement surgery, which is a value shared by patients, professionals and municipal administrators. Through the mechanism of the affective relationship that develops in its interaction with the patients, the patients adapt and react to the technology in order to obtain the value (efficient recovery) that it promises.

This process of affective attachment is generated by a relationship of trust in the technology and its ability to act as a competent stand-in for a health professional; the patients believe that following the training program and acting according to its feedback provides the most efficient route to recovery. This trust is reinforced through its anthropomorphized digital voice. In interviews, when discussing their encounters with the technology during training, patients describe it as a human being, and ascribe a gender to it.

However, over time, the relationship between the technology and patients often became more ambivalent. Many patients felt that the corrections they received from the system were sometimes not logical, or were difficult to understand:

Digital voice: Keep the knee stretched.

Rose: My knee's already stretched, see? I can't stretch it more than this, can I?

Nete: No.

Rose: I get so mad at him.

Digital voice: Four. Five. Six. Seven. Eight. Nine. Ten. You have now completed the second set. Take a small break before continuing with the next set. Switch to your left side. One. Keep the knee stretched.

Rose: Just look - I'm stretching it as much as I can.

Nete: Yes, I see that.

Rose: Isn't that absurd?

Digital voice: One, two, three, four, five, six, seven. Eight. Nine. Ten. Switch to your right side.

The patients experienced a gap between expectations of the technology as a competent stand-in for the physiotherapist, and the behavior of it as the exact opposite; this generated frustration, anger and a feeling of being trapped, with no possibility of satisfying the technology:

Ruth: You think you're doing everything properly, and you do them [the exercises] believing you're doing it right; you try to correct yourself, and then you think, 'Damn it, he still won't shut up. This is just too much,' you start to think.

Nete: So you get mad at the voice?

Ruth: ... I start to think, 'All right, now he's really annoying me and he needs to stop,' [laughs] because we've just discussed it, or, well, we haven't discussed it, but I heard him the first time.

This tension between initial high expectations, and actual experience of the technology as a less competent stand-in for the physiotherapist, opened up a space where questions of authority, trust and responsibility were negotiated. In encounters between digital feedback and bodily movement, patients appeared, as we have seen, not only as knowing or perceiving bodies, but also as sensing bodies. Recent work on digital meaning-making in the context of self-tracking emphasizes the role of the body in processes of making sense of data (Lupton 2018). This work has emphasized the 'liveliness' of data, whose meaning is grasped as a result of encounters between bodily senses and digital data in everyday lives, thereby pointing towards an ongoing tension between sensory, affective and digital input in and around the activity being tracked (Kristensen & Ruckenstein 2018, Lomborg et al. 2018, Lupton 2018, Pink et al 2017). The training program and the speed with which it progressed over time occasionally clashed with the speed of bodily recovery. In some situations, this tension created what was described by health professionals as 'over-compliant' bodies: bodies that gave authority only to the algorithmic system, rather than to the sensing body itself. These patients could experience severe pain and possible bodily regression, rather than progression.

For other patients the tension opened up a space of potential creativity and improvisation, where the authority of the system was negotiated in relation to bodily sensations and pain. This generated a transformation of the relationship between the system and patients, whereby the technology came to occupy a liminal space somewhere between a competent, trusted physiotherapist and a thing without any meaning.

Carla: Well, we all know that it is just an algorithm, it is just a machine, it is not a human being.

The liminal character of the algorithmic system would not only change the technology but also the patient and how she related to the digital feedback. In some situations patients started to exercise without using it; some even hired a private physiotherapist to guide their training progress. In these situations, the algorithmic system was not able to uphold its authority and became a worthless object without any meaning. Other patients decided to continue to do their physical training with the technology; however, they would increasingly take on responsibility for the training. In these trajectories, patients would not become emotionally affected by the systems digital feedback; they would skip exercises experienced as particularly painful, take a break when sensing pain (even though it encouraged progression) and adjust the daily training program according to their other physical activities. When patients took on the responsibility of acting as a competent trainer in this way, it also deprived the algorithmic system of authority.

The various forms of encounters between algorithms, devices and patients illustrate the liveliness of algorithms, as algorithms are articulated and incorporated into everyday lives (Lupton 2018). Lupton uses the notion of liveliness to account for the situated and emergent articulation and sense-making of algorithms and data, as patients negotiate between their sensory and affective knowledge of their bodies and the knowledge generated by algorithms (Lupton 2018). I suggest that we might think of this tension between bodily sensing and digital feedback, and the creativity and improvisation involved in the ongoing sense-making of data, as instances of 'broken data' and 'repair work'. Pink and colleagues introduce these metaphors to account for the materiality of data, and the incomplete and fractured character of digital data, when data are made sense of in everyday encounters (Pink et al. 2018). I suggest that we might see patients' negotiations with digital feedback as examples of 'repair work' which sustains and enables the algorithmic system to work in practice.

Interacting with algorithms in fragile arrangements of care

Research on telecare illuminates how the introduction of communication technologies to existing care arrangements constitutes new 'geographies of responsibilities', redistributing expectations, roles and tasks between health care professionals and patients, as well as between humans and machines (Pols 2012, Schwennesen 2017). Hence, the algorithmic system enters a relationship between patient and health professional that contains expectations and roles that each party is expected to undertake. The algorithmic system was designed with the intent that it should work as a substitute for physiotherapists, something emphasized by its anthropomorphic appearance and digitally voiced feedback. Like the patients, however, physiotherapists experienced a gap between the planned substitution and their actual experience when working with it. While they saw the technology as an element which could bring fun and entertainment to physical rehabilitation programs, possibly encouraging patients' motivation, they saw it as an incompetent version of a physiotherapist:

> I think technology will never be able to replace a physiotherapist. It can't, I don't think it can. … I think it's a fine alternative that may suit some people who'd find it fun and something they can incorporate into their life, so I think those options should exist. So, I'm certainly an advocate for technology, but there's also something about it that makes me think – well, I don't know how to explain it. I also think there's something wrong about it. I mean, I feel that a computer's basically a computer, you know? And like I told you as well, it's uncomprehending, which is basically because it's only been programmed to act according to certain standards. So it's not intelligent as such; it's just been programmed by humans to do what it does. What I might sort of feel sometimes is a bit, well [sigh]. I mean, it's because it doesn't understand that the human body can vary considerably between people, so even though the technology has been designed by people who understand that, there are still some difficulties; there can still be some problems it doesn't understand. For example, it keeps correcting an exercise that the patient can't do any differently, because there may be some purely anatomical issues.

The notion of the technology as an incompetent version of a physiotherapist expressed here, also came to the fore in interactions between patients and professionals during the weekly one-hour training session at the rehabilitation center, when patients often asked questions related to the ambiguous feedback they received during home-training. When they complained about the technology and its lack of responsiveness, health professionals often replied that the it was 'thick-headed', 'not very bright' or 'not able to deal with complex detail'. In doing so, the health professionals de-authorized the system, and gave authority to the patients to judge for themselves when to obey the feedback and when not. However, for many patients, this was not experienced as a considered response to their experienced problems.

> Sandra: When I tell them that it hurts, they just tell me that I am training too much. Well, yes, I am training too much, but what do they want me to do? I just follow the exercise program. ... The program doesn't take my specific body into account, and I can't adjust the training program myself. I am not educated in this; this is the first time I try it. … I don't think that the physiotherapists take responsibility for this.

As this quote shows, some felt they were left alone with the impossible task of deciding for themselves when not to follow the feedback, how much pain they should accept before stopping the exercises, how often to train and so on, which, as we saw in the previous section, caused frustration and, in many cases, a loss of trust. During sessions at the center, patients raised many questions and doubts about their experience with the technology at home, calling for alternative assessments of their bodily movements by the physiotherapists. Most physiotherapists found this new type of 'inquisitive patient' difficult to handle, but engaged occasionally in the production of alternative feedback, as expressed by the physiotherapist below:

> They have a lot of questions – 'Is this wrong or right?'; 'This part is hurting, what does that mean?' – a lot of questions, also in relation to the technology. 'That machine is constantly complaining, even though I feel like I'm doing it right'; 'Am I doing this right?' And that's when we occasionally delve into it and the conversation goes something like, 'Exercise 3, that's a pelvic lift, how do you do that? It says I should lift more.' And then we look at it and assess the exercise and say, 'That looks great. If you do it like that at home, that would be really good. Sometimes you kind of have to ignore what he's saying, you know?'

By allowing for the production of alternative feedback, a competitive relationship between algorithmic system and the physiotherapists was established, which delegated authority to patients to respond selectively to the digital feedback. This supported the patients in becoming better able to take a more critical position on the feedback they received during training at home, and to engage in the necessary 'repair work' that would allow for a more productive relationship with the system. Physiotherapists also emphasize the problem of 'over-compliant' bodies, and their sense of responsibility about identifying those who may be training too much with the technology. The physiotherapist below explains that she would recommend 'over-compliant bodies' to engage in 'repair work' by skipping some of the exercises or only doing the exercise program every other day. She also stresses, however, that she finds it difficult to get a feeling for all the patients in this new arrangement of care, where they only see patients once a week instead of twice.

> [W]e also have to make sure they don't exercise too much. … If it leads to them being in greater pain than before, then we simply have to ask them to only do the exercises every other day or skip some of the exercises if they find them painful to do. It's a little more difficult to get a sense of how the person is doing when you only see them once a week – to have a sense of how things are going otherwise, to follow up on everything. It's easier if you see them twice a week; then we're better able to follow up on what we've talked about previously, because there's a lot we have to remember if we only see them once a week. And they also have so many questions, after all, and sometimes it's a bit 'woah', so it's a little hard to control. ... [I]t's different if you see them twice a week. Then the questions are more spread out, and they're not always so full of questions.

The sense that it was difficult to get a feeling for every patient during the weekly one-hour training session was combined with a sense that the initial intention of cost-efficiency – of being able to save time by reducing the number of weekly training sessions – was not experienced as an overall gain in time. Even though the number of weekly training sessions was reduced, they had the sense that the saved time was used up on all the extra work needed to make the arrangement function in practice, such as introducing the system to the patients, checking up on patients' movement data before the training session and so on.

> We don't get more time just because we only see them once a week. They also need to be introduced to the technology. That's an hour you have to put aside for that. And we still have to put time aside to check how they are doing at home. I try to put time aside to do that once a week, but it's difficult. … It's hard to find time for that during some periods. And that's when I have to push it down the priority list, to be honest. Anything that doesn't directly concern the patient gets pushed down the priority list.

Not unlike the invisible work that patients and professionals carried out, in Oudshoorn's study on cardiac telemonitoring technology, this repair work took time and introduced new work for patients and professionals (Oudshoorn 2008). In opposition to the anticipated imaginary, that more advanced algorithmic systems, will lead to more efficiency and better care, the metaphors of 'broken data' and 'repair work' invite us to make visible and reflect on the work that is needed to make these algorithmic arrangements work in practice.

Conclusions

In this paper, I have unpacked the set of relations that enable an algorithmic system to come into being, examining how it is made and remade in three empirical sites: the production and design of the algorithmic system itself; the interaction between algorithms and patients; and the relational encounters between algorithms, patients and professionals in arrangements of care. In opposition to singular understandings of algorithms and the contemporary imaginary of algorithms as revolutionizing forces in themselves – commonly held among enthusiastic proponents and critics alike – I have illustrated that algorithms do not inherently possess agency or authority. Rather, their agentic capabilities are produced through situated connections being made between various socio-material actors, such as algorithmic imaginaries, policies, sensors, smartphones, IT workers, private companies, municipalities, physiotherapists and patients. By studying the anticipations that go into the design of an algorithmic system, and the negotiations and lively 'repair work' appearing in encounters between algorithms, patients and professionals, it becomes clear that algorithms are not just the creations of IT workers or programmers, or the effects they create based on certain input, they also consist of the imaginaries that shape our thinking about what we can expect from them, and what patients and professionals make of them in concrete interactions. As we have seen, the algorithmic system is only one element in a broader apparatus through which bodies and movements are articulated and evaluated in physical rehabilitation, and cannot be understood merely as a technical, objective or impartial mode of operation or form of knowledge; algorithmic systems are fragile accomplishments and not objects that can meaningfully be studied as units in themselves. Imposing the metaphor of 'broken' data on situations where digital feedback emerged in unanticipated forms, or caused pain, enabled me to understand the work needed to uphold the algorithmic system as 'repair work' – undertaken by both patients and professionals – in order to align arrangements with patients' bodily progression.

As algorithms are emergent and constantly unfolding across time and space, their outcomes must be considered as always local and situated. Working in conjunction with an algorithmic system designed to take on professional tasks, whether as a patient or a professional, implies sensing, learning and becoming intimate with it in order to build and maintain meaningful connections that enable a productive relationship between the system and particular bodies. How patients and professionals interacted with the system, and what form such repair work took in this study, subtly changed and was reshaped through the engagement with algorithmic processing of movement data over time. This means that, if we are to understand how algorithms affect medical practice and relationships between patients and professionals, we have to replace singular ethnographic snapshots of interactions and entanglements with in-depth accounts of the ongoing practical and sense-making 'repair work' which enables the systems to work over time.

The analytical move from algorithmic entity to algorithmic assemblages has implications for how we can think about accountability in relation to algorithms. Algorithmic accountability has most often been discussed in relation to the need for transparency and disclosure of the values, decisions and normativities that go into the creation of algorithmic systems, and their bias and potential discriminatory effects (Pasquale 2015). Such questions of accountability rely on an understanding of algorithms as a stable mode of knowledge production, and do not take into account what happens when algorithmic systems come to interact with patients and professionals in arrangements of care. To conclude, I suggest that we also have to discuss questions of algorithmic accountability in relation to actual and concrete ongoing encounters between algorithmic imaginaries, algorithmic systems, health professionals and patients, and the various forms of 'repair work' needed to enable algorithmic systems to work in practice. As we have seen in this paper, such 'repair work' is necessary if bodies are to be made to move and be affected by the algorithmic system explored here, in ways which generate bodily progression and recovery, rather than broken bodies. Such acts of accountability cannot be understood within an ethics of transparency, but are better thought of as an ethics of 'response-ability' (Martin et al. 2015) directed towards the need for intervening and engaging with the open-ended nature of the possible outcomes of algorithmic systems. This requires an algorithmic system and a wider arrangement of care which makes itself available to respond to the various ways in which particular bodies are moved and affected by the system, without knowing ahead of time what form such a response might take.

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