Risks and benefits of smart toilets

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ABSTRACT

Smart toilets promise convenient 24/7 health and wellness monitoring. However, privacy risks of smart toilets have not been carefully studied. Here, we present a thematic analysis of an expert focus group on smart toilets that record health data. The themes indicate severe privacy and systemic risks, many of which could be mitigated but currently are not. Our analysis suggests that health benefits outweigh risks only in specific application contexts.

KEYWORDS

smart toilet, IoT, E-health, privacy risk

1 INTRODUCTION

"Smart Toilets" have been envisaged and produced for a few years now. Those currently in use, e.g. widely in Japan, collect little data on their users, other than biometrics to allow individualised customisation of services. While there are risks associated with smart homes and IoT (Internet of Things) devices in general, this paper focuses on smart toilets that by their design collect significant data on users. They are typically developed from a medical perspective, as part of two future directions of medicine. "*Precision medicine*" aims for the best possible individualised treatment of patients on the basis of collecting maximal health and lifestyle data [4]. "*E-Health*" is the remote monitoring of patients and delivery of healthcare, aiming to give patients more and longer independence, as well as seeking to cut costs of healthcare of an aging population. An overview of health-related IoT applications is included in [6]. Smart toilets provide a convenient and practical opportunity for regular health measurements beyond those that are directly related, including heart rate and blood pressure [2]. Smart toilets have also been considered for use in epidemiology, e.g. Covid testing [3].

To reliably attribute recorded data to individuals, smart toilets need authentication, which is typically provided via biometrics – using traditional or context-specific novel methods, such as anal

print [7] or toilet seating habits [12]. As far as we can find, their suitability as a biometric has not been established.

This paper investigates the risks and benefits of smart toilets that generate health data based on an expert focus group that considered three specific smart toilet designs.

2 BACKGROUND AND RELATED WORK

We focus on three toilet designs from the academic literature that have progressed to actual practical implementation. All of them send their recorded data to the cloud where it is then analysed.

The Heart Seat[TM] [2] records heart rate and other measurements related to heart health. The smart toilet developed by startup company Coprata based on research at Duke University[1] [13] takes stool images after flushing. The "Precision Health Toilet" developed by a group at Stanford University [7] has four cameras, for authentication and recording of a wide range of toilet behaviour and excreta. A recent analysis by the Stanford group [4] touches on many risks of smart toilets. These include data protection and privacy concerns, particularly for children and in the light of cultural diversity, as well as secondary use risks of collected data.

While the research literature on specific risks of smart toilets is very limited, many of the known privacy and security risks of IoT products obviously also apply in this specific context. A survey of ethical issues around health IoT is given by Mittelstadt [6], with focus on physical and informational privacy.

Most smart toilets record their data in the cloud. There have been serious data leaks from cloud services [10]. Data subjects in IoT-collected data may also be at risk from those who collect or have legitimate access to the data. Data collected may be excessive, giving intrusive views of people's habits, that can be extrapolated to more general behaviour or monetised. IoT-collected data may also be sent to third parties [9]. Third parties observing internet traffic may draw inferences of user behavior and device ownership from this. Ownership may be stigmatising, or imply a security and safety risk. [8]. Insecure IoT devices may be systematically discovered, and used to spy on their owners, or in a botnet [11].

While according to [1] there is a lack of evidence that hacking is a relevant clinical problem, *security* issues of existing medical products have consequences extending beyond confidentiality. Attacks on availability or data integrity on networked pacemakers, etc., give way to *safety* problems, i.e., put human lives at risk.

3 METHODOLOGY

We used a *focus group* of experts recruited from a community grown from Twitter and face-to-face round table events (advertised open-to-all on social media). While for this research only the small number of three experts participated, (see Table 1), this nevertheless represents a huge amount of expertise and experience. Each of

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[1]https://smarttoilet.pratt.duke.edu/research

Table 1: Participants and their expertise

Participant	Expertise
P1	Data protection officer for local government authority
P2	Privacy and data protection lawyer with medical degree and experience
P3	Privacy and data protection consultant with security expertise

them has at least a decade of professional experience in privacy and data protection, including advising on and leading impact assessments; in addition, between them they add significant experience in information security, law, and medicine and medical practice.

In addition to information and consent sheets, the participants were given descriptions of the three toilets and questions drawn up by the researchers, see [5]. The questions are in the spirit of GDPR data protection impact assessment, focusing on "what could possibly go wrong", aiming to identify wide-ranging risks to rights and freedoms that follow from the data processing involved, i.e. well beyond a compliance-oriented view of data protection.

Discussions were recorded and transcribed. Subsequently we applied thematic analysis, resulting in three overarching themes: *functionality and perception* is about what smart toilets do, their design, and how they may be perceived by the public (Section 4); *data protection and security* is about data practices including choice and control for users, as well as security issues including authentication and data confidentiality (Section 5); and *effects and side-effects* concerns the benefits of smart toilets as well as negative effects they may cause, including medical effects, discriminatory effects, mandated or coerced use, and effects on specific population groups (Section 6). The themes elicited from the focus group discussion are illustrated with representative quotes from the participants.

4 SMART TOILETS: FUNCTIONALITY AND PERCEPTION

This overarching theme gathers issues directly related to the operation of these smart toilets and the public's perception of them.

4.1 Features

A smart toilet designed to discover health issues, maybe even as a medical device in a legal sense, may lead to an issue of liability: who is responsible for making sense of the recorded data?

> "And if the toilet doesn't detect something, are the manufacturers liable?" (P3)

> "Presumably, all they're doing is recording the data and outsourcing the headache that comes with any abnormalities to you and your own healthcare provider." (P2)

There may be operating costs beyond the initial purchase, – will the toilets need regular maintenance, e.g., in terms of refilling reagents? How much power will they need?

> "it's got urinalysis, [. . .] there's going to be maintenance" (P1)

4.2 Design process

For innovative devices, what has driven the design: an actual perceived need (here, a health problem), or an economic opportunity?

> "there's an incentive to monetize everything instead of actually solving the problems, because those two are not necessarily in alignment" (P3)

Particularly for devices that solve a problem using invasive data processing, like here, data protection law demands necessity and proportionality. To what extent have alternative solutions, possibly collecting less data, been explored (and found inferior)?

> "they don't look like horrible ideas unless you know how the world of data and technology and power dynamics works" (P3)

> "I would want to see evidence that there was a whole range of potential ideas looked at, and why this is the best; and the answer, 'because it will make us the most money,' is not eligible" (P3)

Solutions based on data collection should have privacy preserving approaches built in – for moral reasons, because they exist; legally (e.g. *privacy-by-design* in GDPR), and to reduce security risk. The operator/manufacturer of the product should be considered a potential adversary, who might re-share data, or apply function creep on data they do not really need to obtain in the first place.

> "pseudonymize that data that they're storing" (P1)

> " It's all very well when the good guys are doing it, but you have to think about what would happen if this was being operated by the bad guys." (P1)

The need for privacy by design puts an onus on product designers to have awareness of the available methods.

> "the basic premise that we've got all of these sensors now. They're small. They're easy to manufacture. There are lots of people out there just thinking, 'well, what can we stick them in? And badge in some way that makes it work – 'it's going to be for your health'." (P2)

Product designers may have great intentions, but this may actually complicate getting privacy protections into products.

> "people with the noblest of intentions are probably the least likely to critically self-analyse." (P3)

> "if you try and point out the risks, then they get terribly offended and defensive" (P3)

4.3 Data versus knowledge

The smart toilets may well record data in large quantities, but this data need not correspond to a medical diagnosis, or even necessarily information about medical conditions.

> "what you do through this sort of technology is you identify anomalies. You have no real sense of what those anomalies mean, or what their implications are in real health terms" (P2)

> "they report back to you your bowel habit is abnormal because it lies outside of the 95% normal range. Now over to you. Do whatever you want with that." (P2)

Sensing and recording large amounts of data is easy, cheap, and easy to automate. However, interpretation and making sense of the data requires much more significant investment.

> "the algorithm for analysis, is there any human in the loop or are they just feeding everybody's data and expecting it to come up with conclusions?" (P3)

> "is it a person looking at that?" (P2) – "And are they qualified?" (P3)

In addition to individuals getting information about their health, the recorded data can allow far more wide-ranging inferences, not just about individuals but also their families.

> "you could infer data in relation to people's diets [...] their routine as far as that is spent in their home." (P2)

> "They might have enough data that they've pieced together about me to know that heart disease runs in my family or dementia runs in my family" (P1)

4.4 Public perception and understanding

Will there be actual transparency about the data processing?

> "Most people who look at that technology think, 'well, I'm wearing the watch. I'm seeing the data. That's all that's happening,' and are completely blind to even the possibility that it's being hoovered up and transmitted elsewhere and used for other purposes" (P2)

> "Joe Bloggs on the street who maybe doesn't understand some of it and doesn't read privacy notices" (P1)

Smart toilets are likely to hit a wide range of expectations of privacy and perceptions of data sensitivity.

> "lots of people will be happy with Alexa and Ring doorbells, but yeah, taking pictures of your bum on the toilet, I think most people go, 'what? That's too far."' (P1)

> "Some people would be horrified by that. Some people will be like, 'I want one. I need to check whether I'm ill or not,"' (P1)

However, clever marketing or a perceived need can override privacy concerns.

> "we've seen that with all smart technology, whether it's your Ring doorbell, or your Echo or your Alexa, people are like, 'ooh, shiny gadget. I want one of them."' (P1)

Potential users have no intrinsic reason to trust the manufacturers of smart toilets. However, assurances about data sharing from a trusted provider may help alleviate privacy concerns.

> "would people feel differently if this was your doctor saying, 'we can issue you with one of these toilets on the NHS[2] and the data just comes back to the NHS,' as opposed to, 'you could buy one of these and the data is processed in this cloud by this private company,'?" (P1)

> "[with] confidence that the data was simply being used for the [intended] purpose, telling you what was going on or providing that information to your trusted healthcare professional, people would be relatively content" (P2)

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[2]NHS (National Health Service) is the publicly funded healthcare system in the UK.

However, people may have limited trust in private corporations, especially when it concerns handling of health data.

> "lack of trust in authority and a definite lack of trust in private health corporations, especially Americans, which is all about making money out of your health data" (P1)

On the other hand, people are often quite trusting in health care situations, assuming devices are safe because they are allowed to be sold, or prescribed.

> "I assume that just because it's being offered for sale, everything about it must therefore be safe and lawful, for which I have two words – *radium condoms*." (P3)

Altogether, potential users need to balance benefits against risks. They may well be aware of economic costs and privacy impacts, but these may be worthwhile trade-offs against a health benefit. This is likely to be an individualistic choice, but especially older people or those with existing health conditions may lean towards the health benefit. This also indicates that smart toilet providers have (or should have) a particular duty of care to protect user privacy.

> "[if] you're already a higher risk of harm, that might make you give up some of those privacy risks if it means it'll save your life one day." (P1)

> "Is this all going to be worth it for me as an individual to pay a lot of money and give up [...] privacy?" (P2)

In line with literature reports of *alert fatigue* from health IoT devices, feedback from toilets sold as lifestyle or wellness products might be repetitive, and thereby become an annoyance.

> "I think I'd just get annoyed by it. [...] If my toilet every single day is going, 'drink more water, eat more fruit and veg, cut down on the processed food and the sugars,' I'll just switch it off. I know all those things; my toilet doesn't need to tell me." (P1)

Smart toilets also impact on social interactions. Having smart devices in the home raises questions of transparency and consent for visitors. For most people, smart toilets may be more awkward to explain to their guests than, for example, smart speakers.

> "Can you imagine your friends coming around for dinner? And they look at your toilet [..] 'what's that?' 'They're just cameras. They're just looking at your bum."' (P1)

Feedback from smart toilets may also influence social interactions with healthcare providers and doctors.

> "And will I start crying wolf and will the GP keep going, 'God, she's back again because the toilet's told her again. There's nothing wrong with her?"' (P1)

> "the doctor perhaps has the same attitude towards patients researching their own symptoms and instantly goes, 'this is a mental health problem, not a physical one.'" (P3)

5 DATA PROTECTION, PRIVACY, AND SECURITY

Several themes arose from the focus groups in relation to data protection, privacy and security, in addition to necessity and perceived privacy impacts (already considered above).

5.1 Choice and control

One important dimension of privacy is an individual's control of what is shared about them and with whom. Smart toilets could and should offer such choices, for example at configuration during setup. However, rather than giving users genuine control, this may also lead to cognitive overload.

> "Do you want to use it offline? Do you want it to upload automatically? Do you want to send the data to A, B, C, D, or a combination?" (P1)

> "That sort of thing is a massive cognitive load, and after about five different kind of questions and settings, people are just going to be like, 'urgh.'" (P3)

An obvious choice that may or may not be available is whether the *smart* functionality can be avoided, using just the functionality of the *toilet* by itself.

> "Can you flush it if you haven't done fingerprint recognition? How much choice do you get in real terms?" (P2)

The choice does not just apply to being able to flush without authenticating first, it is also about allowing use of the toilet without triggering data collection (which may be done by sensors hidden in the plumbing).

Medical data should not be stored centrally (e.g. on the cloud) in an identifiable form; decentralised storage under the user's control (e.g. on their phone) allows local processing for privacy protection and data minimisation.

> "It's not collating that data in an identifiable form centrally, it's about giving you the data to do with it what you want to do as an individual, and then it's up to you who you share it with." (P1)

> "I don't want people to have photographs of my poo in the cloud" (P1)

> "why not just pair it with your phone instead of having to send in [data]" (P3)

The acceptability of cloud storage depends on who the cloud entity is, e.g., a private company vs. a public health provider.

> "depending on where the data's going. Is it going to the cloud? Is it a private company? Is it under contract with the NHS?" (P1)

5.2 Authentication

Authentication is relevant because toilets may be used by more than one person, including guests who do not know that this is a smart toilet and have not consented to any data collection.

> "How does the toilet know it's you?" (P3)

> "what happens if other people sit on it?" (P1)

Authentication options for toilets in the study were fingerprint and anal print [7], but do they work?

> "anal print is used for authentication, and you suddenly come down with a bad case of piles. Does that mean you can't [use the toilet]?" (P3)

> "when you have to do your thumbprint on your phone, when you set it up and you have to do a few different

ones, do you think you have to like to sit around on the toilet seat a few times like that to get it right?" (P1)

5.3 Access Control

Especially in settings like nursing homes, the device may be installed by someone who has no legal authority over the users' personal data. In that situation, it is worth asking who controls the accounts, and who has access to the collected data.

> "who holds the account that has access to all the data? Who sets up a new user?" (P2)

5.4 Confidentiality and integrity

Local storage, cloud storage, and transfer to the cloud all incur risks of data loss, both of identifiable medical data and user account data.

> "your password is exposed in association with your email address, [...] that's got nothing to do with your toilet" (P2)

There may also be a risk of hacking into the toilet.

> "the amount of fear you could cause somebody from hacking their smart toilet and having it tell them that they were dying, or even having it tell them that they were fine when they are actually ill." (P3)

5.5 Data practices

The data generated by smart toilets is sufficiently rich and extensive to raise concerns about its destination and about purpose limitation.

> "who is going to get the data and what else are they going to do with it?" (P1)

> "private companies and insurance companies in particular, getting their hands on our health data" (P1)

Data practices can also change over time, and it is hard for users to trust initial assurances.

> "how do they ever get to a point where they could confidently walk into a shop and buy one and know that there is none of this murky stuff designed into it?" (P2)

> "some sort of certification scheme: [...] We have audited and reviewed their privacy practices and we are satisfied in fact that the data is only used for the purposes that you would envisage." (P2)

If data processing and sharing is based on user consent, then smart toilet makers as well as other entities (e.g., insurance companies) could design incentives to make more users consent.

> "not 'we will increase your premium,' but, 'if you install one, we will decrease your premium.'" (P2)

> "it becomes manufactured consent, because you don't always have the choice to say no" (P3)

The toilet maker's business model may depend on monetizing generated data directly, or using it for follow-up sales of remedies.

> "You have no real sense of what those anomalies mean, or what their implications are in real health terms, but they afford an opportunity to sell stuff" (P2)

"smart technology is just the new radium. Everyone's rushing to monetize it and commercialize it, and the people buying it are assuming a good faith on the part of the sellers that simply isn't there." (P3)

6 EFFECTS AND SIDE-EFFECTS

6.1 Benefits

Alongside what could possibly go wrong, potential benefits of smart toilets also emerged from the focus group discussion. Data can be used to help people and prolong or improve their lives.

"for some people, this would probably be really good because they don't have to think about it every day. They do go to the toilet automatically [..] particularly people with memory loss and dementia and elderly people" (P1)

"If I've already got a heart problem, I [will] do everything I can to monitor myself and take care of myself" (P1)

Some people enjoy having data about themselves to look at.

"there is a cohort of people out there who are obsessed about self-quantification and having information" (P2)

6.2 Medical effects

The development of these smart toilets is driven by the desire to find a health benefit, but this needs to be demonstrable. Is there evidence that the recorded data can support medical conclusions or decisions? Far more data is recorded on people with no acute serious medical problem than would be in traditional health care.

"this sort of technology [identifies] anomalies. You have no real sense of what those anomalies mean, or [their implications] in real health terms" (P2)

"you've now had a brief episode of what looks like a-fib [atrial fibrillation] once, because we've been monitoring your heart for 24 hours a day for the last three months. Is that of any significance?" (P2)

People may remain acutely aware that they are constantly being monitored, and this could induce anxiety.

"is all I'm going to be doing making myself anxious because I'm going to be seeing once every three weeks that I've got something funny, a blip, or my blood pressure has gone down and now I'm panicked about that?" (P2)

"you put clinicians in a very difficult position because they'll say, 'well, I've got an anxious patient now. Their anxiety needs to be addressed. There's some vague indication of something abnormal and the only routes that I now have to take this any further are invasive tests, which carry risk." (P2)

"you could see for some people this sort of feedback being incredibly stressful because I'm not pleasing my toilet. My toilet is a disappointed in me." (P2)

People may frame their health in terms of what sensors measure, possibly with undue focus on one part of their health system.

"if it's kind of framing metrics in terms of heart health, you could very well miss a pituitary tumour that causes the same effects" (P3)

"Or it says you need to be eating more vitamin D, and you eat a hell of a lot of vitamin D, and it still says you need to be eating more vitamin D and you go, 'well, it must be faulty,' and don't consider the fact that you might have a tapeworm" (P3)

The quantification of health may also interact with the framing of health and wellness as something that individuals have a personal responsibility and choice in – especially in areas where that does not fairly reflect their reality.

"It also generates this idea that health and wellness has to do with metrics, and you're well if your metrics tell you you're well." (P2)

"I have a chronic genetic condition. I'm always a bit broken. Am I healthy? And can I improve my health? Well, no, except by changing my genes" (P3)

The increasing amount of diagnostic information produced by health devices may lead to an increasing load on the health system.

"I'd be at the doctors every few days, I think." (P1)

"what good is detecting signs of illness when the infrastructure to treat them is already overloaded?" (P3)

"Eventually, the only thing you can do is a potentially dangerous investigation like a colonoscopy because your toilet has told you. [...] So, are you going to see a spike in colonoscopies because that's the only solution for this problem? [...] As a consequence, you're getting a massive increase in the number of false negatives, of negative colonoscopies, but you're exposing the patients to risk, and eventually one of them is going to have a perforation or suffer a serious adverse consequence" (P2)

"if it is genuinely saying to me, 'hey, you might have cancer,' great. I need to go as early as possible. Brilliant, fantastic news. But how accurate is that prognosis? And then am I just wasting everybody's time." (P1)

Where devices observe "anomalies", there are risks associated with where the baselines for such considerations come from, and how accurate or biased they are.

"if you buy one of these things and you've already got cancer and don't know it, it's going to build a baseline on a state which you don't want to be in in the first place." (P3)

"there's quite a wide range of variability in how human bodies function and at the moment, anyway, the baselines are all taken from white males." (P3)

There may be little or even a negative health benefit, due to bias or undue focus on the smart toilet data analysis.

"The health yield is going to be pretty low if there is any at all, because it's going to be people that have the money who are seduced by technology, who are probably comparatively young and healthy" (P2)

"Or somebody's feeling dodgy, but their loo says they're fine, so they don't go to the doctor" (P3)

"The false reassurance, because your toilet's telling you that you need to eat more fibre and you think, 'well, that's the solution. More fibre,' but in fact, what you really

need to be doing is taking whatever symptoms you have seriously and getting it checked out." (P2)

6.3 Discriminatory effects

When extra health analysis and more diagnosis is introduced, this could lead to discrimination against people with illnesses, e.g., through higher insurance premiums.

"I'm not aware that when I get that quote, they've bumped it up because they know from my data I'm at risk" (P1)

"you run a nursing home and you're doing a cost-benefit analysis on the types of residents you want to take in, so you run a study from all this clever, smart data that you have the account details of because you were the purchaser [...], and you decide people with these particular conditions are a better return on investment." (P3)

Discrimination against people with dark skin tones is also a worry.

"Have they been tested to make sure they work for dark skin, because most skin sensor technology doesn't?" (P3)

6.4 Mandated or coerced use

The use of smart toilets should be with full consent and knowledge. Covert or mandated use by employers or other organizations could lead to adverse scenarios.

"it's entirely possible that that could be installed without the user knowing, and then when your employer or your insurance company or your landlord [...] says that these are necessary security vetting checks, and you can't have your whatever without it, and the creeping incremental intrusion and loss of autonomy is pretty major." (P3)

"with the fingerprint recognition, if you install that in the offices, then you have a way of monitoring whether somebody who says they're on a toilet break is actually on a toilet break." (P2)

There is precedent for this, not yet at the individualized level of smart toilets, but indicating that there may be substantial institutional demand for smart toilets.

"There are university campuses in America where they have detectors in the sewage system to sound the alarm if certain metabolites or certain drugs are picked up" (P3)

"I think the uptake will be in the areas where the individuals don't get to make the choice for themselves." (P3)

6.5 Effects on specific groups

Elderly people and people with specific conditions might benefit more.

"If I'm 87 with a lot of illnesses, maybe I'm past caring about anybody knowing my anal print at that point if it means I get another few years." (P1)

The rights of people who lack capacity need to be guarded.

"people that are lacking capacity, [...] elderly people, vulnerable people and children. What rights have they got with this sort of technology if a care home installs it, for

example, and they don't have any choice; that's the toilet that they've got to use [...] in the care home?" (P1)

7 CONCLUSION

"From a societal point of view, if it helps a tiny minority of people and harms the majority of people, is that a case for saying, '[...] Actually, we're not going to encourage this sort of thing. We shouldn't be doing it.'" (P3)

It is clear that smart toilets can be extremely beneficial in some scenarios. This includes where there is a medical need for continuous monitoring of specific health parameters, where other means of monitoring would be too onerous (e.g., time-consuming to travel to hospital) or error-prone for the patient (forgetting to record).

The trade-off between privacy risk and broader risks, and potential health benefit must be carefully considered. It looks like for broad and general use, the health benefit is likely too low in view of privacy risks and negative effects they may cause.

However, smart toilet makers can take steps to address the privacy risks. They can implement technical measures, such as privacy enhancing techniques including local data processing and pseudonymization of recorded data. Two main issues with this are:

- published designs and academic literature do not show evidence of sufficient expertise in privacy(-by-design) and data protection at the point where the toilets are designed;
- the business model most likely relies on exploitation of health data in some form, and therefore implementing privacy-preserving measures is not attractive for smart toilet makers.

Fitting smart toilets in with existing regulation on medical devices would address several of the concerns. Smart toilets should therefore be classed as medical devices and not sold as consumer products, due to numerous negative effects including systemic effects.

Further research involving more participants, including medical experts and potential users of these devices could give more and deeper insights.

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