

Exploring Interpretations of Data from the Internet of Things in the Home

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The ‘Internet of Things’ (IoT) can be expected to radically increase the amount of potentially sensitive data gathered in our homes. This study explores the social implications of the presentation of data that could be collected within the household. In particular, it focuses on how ambiguities in these data, combined with existing interpersonal relationships, could influence social dynamics. Thirty-five participants were each presented with three separate household scenarios, involving ambiguous data that were collected and presented via near-future IoT technologies. Each participant was asked to respond to a series of open and closed questions about how they would interpret the data, how they would react to it and their general opinions of the technologies presented. Through qualitative and quantitative analysis of their responses, we contribute an understanding of how people interpret information about those around them. We find a common willingness to make inferences based on ambiguities within the data, even when participants are aware of the limitations of their understanding. We also find that sharing data produced via tagging of everyday objects raises a high level of privacy concern, and that, in a somewhat incoherent stance, users are more comfortable in sharing data publicly than in a targeted fashion with commercial organizations. Our findings also suggest that the age of the target user group has a greater effect on ease of use judgements than the nature of the technology, and we find some evidence that user’s interpretations can be biased by an individual’s age.

STUDY HIGHLIGHTS

- This study explores the implications of data produced by the Internet of things technology in the home.
- We examine the social impact of ambiguous personal data.
- Storyboards are used to present vignettes involving near-future technologies.
- Significant effects are found with regard to privacy, interpretation and generation/age.

Keywords: Internet of Things; Generation; Data Ambiguity; Privacy; Storyboards; Age Stereotype; Home; Social Implications

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1. INTRODUCTION

In the visions of computation and networking embedded in everyday objects that form the Internet of Things (IoT) (IERC, 2011), the availability of increasing amounts of data may have ramifications for our social interactions and relationships. In many cases, shared technologies will capture personal

and potentially sensitive data about individuals. For example, monitoring appliances in the home can lead to personally identifiable information being collected about the activities of members of a household (Karotz, 2012; Soppera and Burbridge, 2006). Research is required to understand how people interpret and react to these new kinds of data to inform

design and identify the social consequences of introducing these technologies.

Through a review of literature and a vignette-based survey study, this paper explores how forms of data collected through systems that characterize the IoT vision might be interpreted by humans. In particular, we are interested in how ambiguities in these data, combined with the specific relationships between individuals (e.g. different generations or roles in a family), could play a part in how the information is interpreted. Based on this research, we discuss some potential implications for design.

1.1. The IoT

The myriad definitions that have been presented for the IoT (Atzori *et al.*, 2010; Gigli and Koo, 2011; Haller, 2010; Haller *et al.*, 2008) contain several core themes: computation in a wide range of objects, networking to share data and provide access and, in many cases, ‘smart’ behaviour as a result of this combination. Blurring the distinction between computational devices and all entities is also key to the IoT concept. Srivastava (2011) states that the IoT represents the greatest level of technological convergence that we can currently imagine. Moving from an Internet of user-generated content to ‘thing-generated content’ will produce a new level of sensory awareness, with the ultimate goal of increasing our control over time and space.

The IoT vision is one where things are connected that we would not previously have considered relevant to computation or feasible to integrate with a network. This change will allow various forms of data to be collected from all kinds of objects around us, from the use of appliances and lighting through to door locks, clothes or toothbrushes (Green Goose, 2012).

1.2. The human perspective

In 2009, the European Commission concluded that the ‘interconnection of physical objects is expected to amplify the profound effects that large-scale networked communications are having on our society, gradually resulting in a genuine paradigm shift’ (European Commission, 2009). This paper is primarily concerned with how IoT technologies will impact our everyday lives. As such, this section provides a brief overview of key human–computer interaction, psychology and sociology research related to this topic, in order to highlight some of the salient points raised in four specific areas. Through a broad literature review, we concluded that data ambiguity, intergenerational issues, perceptions of age and privacy represent well-established and understood phenomena from other domains. We focused on these as each has a rich history of well-developed research in other domains, but simultaneously, a lack of context-specific studies that could help guide the design and development of IoT technologies.

1.2.1. Data ambiguity

The forms of data collected by IoT technologies, whilst potentially rich and useful, will inevitably include a range of ambiguities. For example, energy monitoring tells us whether an appliance was in use, but not the purpose or context of this use. Furthermore, the designers of these technologies are likely to have some scope to adjust the ambiguity or represent data in different ways, e.g. by providing cumulative totals or fine-grained access to real-time data.

Gaver *et al.* (2003) propose that while mainstream HCI sees ambiguity as a purely negative element in design that causes frustration and inefficiency, it can be used as a resource for designers to capture interest, increase engagement and encourage interpretation. They propose three core types of ambiguity. ‘Ambiguity of Information’ is found in the artefact itself, be it physical or digital. ‘Ambiguity of Context’ describes the sociocultural environment in which the artefact is experienced. Finally, ‘Ambiguity of Relationship’ is more personal and describes how the individual evaluates and interprets the artefact.

Aoki and Woodruff (2005) explore how the ambiguities inherent in the design of various communications technologies can be a useful feature in avoiding awkward social situations and saving face. Introducing existing and potential designs to users, they find that ambiguity supports multiple explanations of intentions. For example, if a person is unresponsive to communication, a lack of context information means that a caller is open to multiple explanations (e.g. the person could be in a meeting or travelling) rather than assuming that they are being ignored.

Alternatively, ‘Confirmation Bias’ may mean that ambiguous data are misinterpreted to support existing stereotypes and biases. Originally studied in philosophy, this theory suggests the tendency for people to bias the information they receive so that it confirms beliefs they already consider or hold (Nickerson, 1998).

It is clear from this range of research that ambiguity can have positive and negative consequences. IoT technologies have the potential to reduce ambiguity by providing information about objects and the people that interact with them, but the data collected and presented will often introduce a different kind of ambiguity related to its interpretation. It is important that designers of these technologies understand the balance between the potential undesirable effects of ambiguity and its potential for social benefit. It is worth noting that this and other previous research suggests that ambiguity is a complex construct with many potential types and sources, exploring these in depth lies outside the remit of this paper.

1.2.2. Intergenerational issues

Family hierarchy can have a significant impact on how individuals communicate with each other. Williams (2003) reviewed current research into communication and relationships between parents and adolescents and suggested that the main

factors at work in terms of communication negotiations are three dialectical forces: autonomy versus connection, privacy versus open boundaries and individual versus intergroup. [Furman and Buhrmester \(1992\)](#) found a peak in parent–child tensions during early-to-middle adolescence, due to differences in perceived conflict, influence and relative power.

Parents may see these technologies as a tool to monitor child behaviour, in an attempt to reduce delinquency. While previous studies have shown a direct link between parental knowledge of youths' activities and reduced delinquency ([Patterson and Stouthamer-Loeber, 1984](#)), a more recent study by [Stattin and Kerr \(2000\)](#) shows that reduced delinquency is in fact linked only to parental knowledge of youths' activities if it is disclosed by the youths themselves. This research suggests that the application of IoT technologies that simply monitor youth activity rather than supporting voluntary disclosure may not help to reduce delinquency, although it will have an impact on privacy and potentially damage intergenerational relationships.

For a sociological point of view, [Mannheim's \(1956\)](#) 'Sociology of Generations' theory and work based upon it ([Pilcher, 1994](#)) suggests the socio-historical environment of our youth forms social generations each with a unique social consciousness. This consciousness influences how each generation approaches social change, in turn effecting the socio-historical environment for the youth of the next generation. In studying generational differences, we should be aware of the important distinction between this concept of social generation—those who grew up in the same era and were subject to similar major life events—in contrast to generation as the static relationships between grandparent, parent and child.

More recent work has focused on specific issues relating to inter-generational technology use. For example, the [Khoo et al. \(2009\)](#) study explores the opportunities and difficulties in designing intergenerational family entertainment technologies, which provided insights into how games can support intergenerational play. Their findings highlight the value of using those proficient with technology to empower novice user to interact with digital technologies.

1.2.3. Perceptions of age

Our perceptions of age and expected behaviour could also be important in how we interpret and act upon ambiguous data about each other generated by IoT technologies. [Bengston \(1971\)](#) states: '[that] our perceptions of others determine our behaviour towards them is one of the central premises of social science. That age represents an important parameter of social interaction is a central premise of life-cycle sociology and psychology'. He also explores how the term 'generation-gap' shows that persons perceive substantial differences between age groups, and that these differences have behavioural consequences: 'competition, conflict, and coercion between age strata'. [Giles et al. \(2008\)](#) found that people linked old age with increased benevolence and decreased vitality. Older protagonists were also seen as less accommodating and more often

avoided. Although these perceptions are more evident in the young, they are still present at a significant level in older adults.

[Schmidt and Boland \(1986\)](#) identified a range of 'trait clusters' that university students associate with the elderly. Their findings suggest that individuals (university students) associate both positive and negative traits with the elderly, ranging from Matriarch/Patriarch and Sage-like through to vulnerable, impaired, bitter and nosy. This work highlights the complex stereotypes of the elderly.

Looking at the other end of the spectrum, much less research has explored the presence and impact of ageism and age-related perceptions of the young. While this issue has repeatedly been highlighted in the media ([Amble, 2006](#); [Armour, 2003](#)), research is generally domain-specific with little in terms of generalizable findings ([Topper, 2009](#)). This is perhaps related to the perception that it is only a temporary issue for those discriminated against for their youth ([Garstka et al., 2004](#)).

1.2.4. Privacy

It is clear that pervasive technologies embedded in objects around us have the potential to radically reduce our privacy, and that designing these technologies such that they are acceptable to users with regards to privacy is essential, particularly in the home ([Graeff and Harmon, 2002](#)). [Schwartz \(1968\)](#) argues that 'Patterns of interaction in any social system are accompanied by counter-patterns of withdrawal. . . . There exists a threshold beyond which social contract becomes irritating to all parties; therefore, some provision for removing oneself from interaction and observation must be built into every establishment'.

Privacy is a highly researched area with hundreds of articles published across many domains. [Smith et al. \(2001\)](#) reviewed 320 papers and 128 books in the area of information privacy, across various disciplines. They found that although a wealth of theoretical and descriptive development has been made, relatively little empirical evidence has been produced to back it up. They also argued that most of the existing research has focused on privacy concerns, and more needs to be done to understand the antecedents to these concerns and the actual outcomes of holding these concerns.

Our use of technologies and their implications for our privacy are linked in complex ways. Focusing on personal data, [Graeff and Harmon \(2002\)](#) explored the relationship between awareness of data that is collected, concerns about personal data privacy and Internet shopping behaviour. They found that despite universal concern about personal data privacy, awareness of how personal data are currently collected is generally low. Looking at a more specific example, evidence suggests that users of Facebook tend to report high levels of concern about personal data privacy, but this is not strongly correlated with actual behaviour, i.e. many 'concerned' individuals share great amounts of personal information ([Acquisti and Gross, 2006](#)).

[Soppera and Burbridge \(2006\)](#) raise a range of privacy concerns in relation to the emergence of pervasive computing

technologies that are embedded in the fabric of everyday life. They first note that these devices will ‘disappear so effectively that end users will lose awareness of the devices’ presence or purpose’, and, in this case, they point out that if ‘you cannot interact with the computer, how can you tell what data is collected, where the data is flowing to, and more importantly, what the consequences of your actions are?’. To further explore these issues, they refer to principles that form the Organisation for Economic Co-operation and Development privacy guidelines (OECD, 2009)—a common basis for standards in countries around the world. First, they argue that pervasive technologies disrupt the notion of ‘personal’ data, as devices may collect volumes of data not directly related to any one person, but from which personal information can be ascertained through collation. Secondly, they note that guidelines on data collection suggest that this should be limited to appropriate situations where consent has been given, and for a specified purpose, but in pervasive systems, notifying and asking for consent could be difficult or impossible. Finally, the guidelines state that individuals should have the right to obtain data held about them. However, pervasive technologies may mean that there are many more hosts holding data about us, and less awareness or capability to identify whose these might be.

From a different angle, the work of the philosopher–sociologist Bauman (1991) argues that European modernity itself is bought at the cost of privacy. He states that modernity involves removing uncertainties via control over nature, rules, bureaucracy and categorization; all in an attempt to remove personal insecurities. He goes on to identify the downsides of modernity such as a lack of freedom and fear/resentment of the unknown or uncontrollable. If fully realized, the IoT could be a vivid example of Bauman’s idea of modernity, giving us unprecedented knowledge about the location and actions of people and objects. Bauman suggests that the most insidious downside of modernity is the tendency to ostracize objects and people that do not fit into the controlled and known view of the world, and the implications of this for an IoT home and the family dynamics within it should not be dismissed.

2. METHOD

The aim of this study was to explore how participants would interpret ambiguous data produced in near-future IoT scenarios. Storyboards were used to present vignette style scenarios to users and followed by a survey containing a range of open and closed questions relating to their opinions and interpretation of the scenario. This specific method was chosen as it is both easy to elicit data from large groups of participants, and can be applied to as yet un-implemented technologies.

This approach is based on the ‘vignette’ methodology often used to understand responses to phenomena that are sensitive or difficult to study *in situ* (Hughes, 1998; Ottman, 2004; Perks *et al.*, 2005). As many technologies that may form the

IoT are yet to be realized, the vignette approach is a useful tool for exploring the behaviours we could see in response to technologies before they become widely available. In conducting a review of vignette methods, Hughes (1998) notes that ‘Vignettes are valuable ... as they recognise the socially situated nature of individual behaviour and provide participants with an opportunity to discuss aspects of their own lives’. He also notes that an important consideration in using vignettes is the way that people draw upon various sources in their own lives to interpret and relate to the vignette. On the other hand, the detachment from the real world found in a vignette response has to be considered a limitation when using vignettes to understand detailed interactions. While it is difficult to define absolutely how a response to a vignette will align with a response to a real-world situation, there is considerable evidence for the validity of data gathered through vignettes (O’Connor *et al.*, 2003).

Our *visual vignettes* used storyboards combining both pictures and text, in adherence with the guidelines for effective storyboarding developed by Truong *et al.* (2006). These guidelines cover issues such as using the minimum level of detail to highlight only essential features, using only three to five panels in each storyboard, using only small amounts of text where needed for explanation, and including people in the storyboards only when necessary. This specific type of vignette was selected in preference to, for example, video vignettes, as it affords designers easier control over the level of detail presented, as well as providing information in two modalities to reduce any confusion about the nature of the scenario. Storyboards also have the advantage of being practical in an industrial design setting, because they are relatively quick and cheap to produce.

2.1. The scenarios

A total of three scenarios were developed, each depicting a technically feasible near-future IoT technology in the home. Each scenario is an exemplar of technologies currently under development, selected following a technical review of current IoT technologies (Brown *et al.*, 2007; Chen and Helal, 2011; Karotz, 2012; Lou and Jin, 2006; Xiaofan *et al.*, 2009).

2.1.1. Smart Fridge 5000 scenario

The first scenario describes a smart fridge that detects what food is bought and used in the house (see Fig. 1). The Smart Fridge uses this information to alert family members of any unusual patterns of food purchase and consumption. The storyboard used the example of an alert that fruit purchase had risen drastically in the last week. Fruit purchase was chosen as a rise could be interpreted in either a positive (healthier eating) or a negative (wasting money on food that would not be eaten) fashion.

2.1.2. Energy meter scenario

The second scenario explores the issue of energy monitoring. The storyboard shows a new monitor being installed that

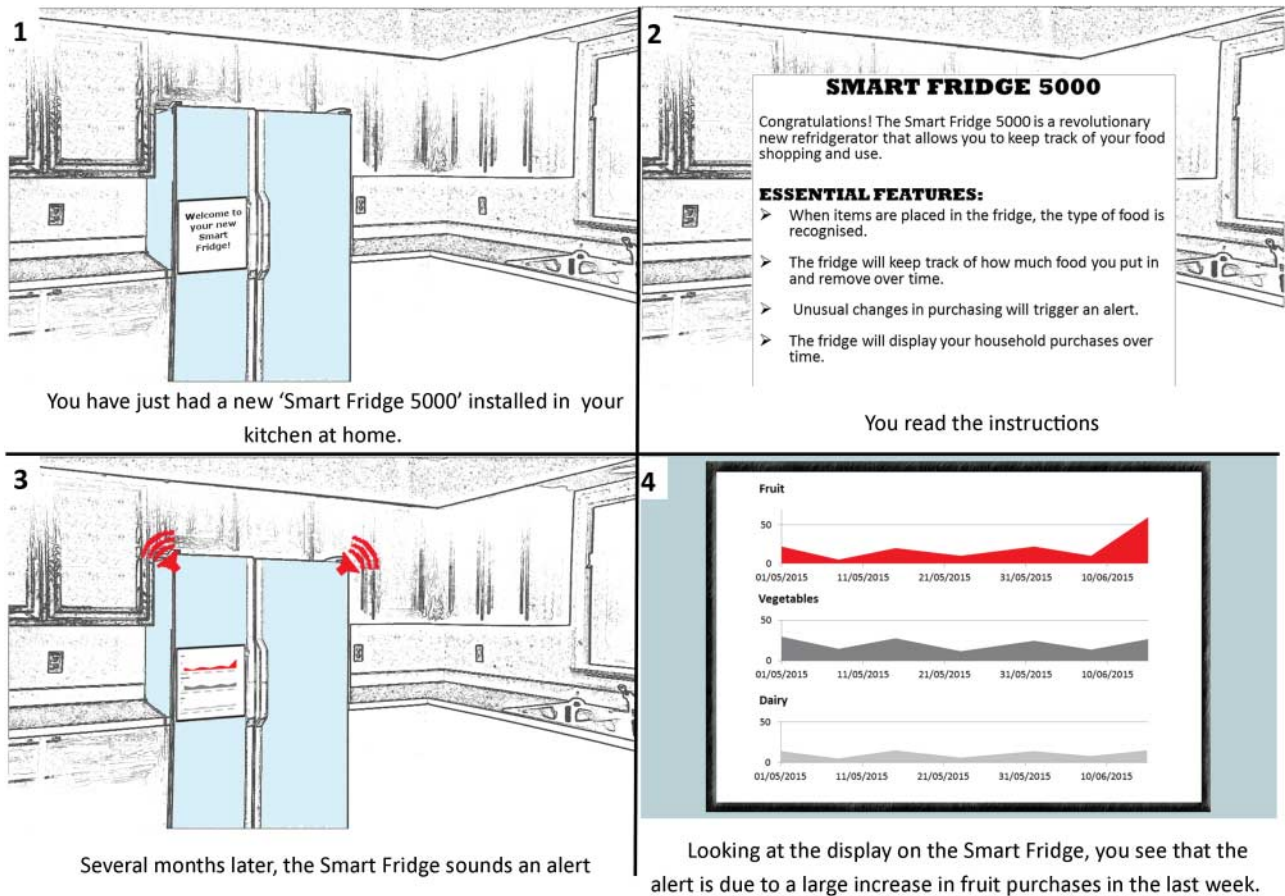


Figure 1. Smart Fridge 5000 storyboard.

individually monitors the power used by each appliance in the house (see Fig. 2). In the final frame, it is revealed that 'Jane's TV' is using much more power than every other appliance in the house. Participants were randomly presented with one of the two versions of descriptive text in the fourth frame. One described Jane as the daughter in the household and the other describes her as the grandmother. This variation was used to explore the impact of the target's generation on interpretation of the ambiguous data.

2.1.3. Proximity portrait

The final scenario describes a concept technology called 'Proximity Portrait' that aims to allow family members to share experiences through a live family portrait that show which objects members of the household are currently interacting with. The storyboard describes the technology, gives an example of it in action and finally presents example data, in the form of a snapshot of the portrait in the middle of the day (see Fig. 3). Again, participants were randomly shown one of the two versions of this scenario, this time altering both the image and text to explore the impact of the target's gender and age on interpretation of data (see Fig. 4).

2.2. Design

A mixed methods design was used with each participant being presented with one version of each storyboard. After viewing each storyboard, participants were asked to complete 18 closed and 3 open-ended questions about the scenario described (shown in the Results section, Fig. 5). The closed questions all consisted of statements about the technology with a 5-point Likert-type response (strongly disagree [1], disagree [2], neither agree nor disagree [3], agree [4], strongly agree [5]). These questions were developed based on key issues discovered following a literature review of the four research themes identified above. The sequence of storyboard presentation was randomly assigned to counterbalance any order effects.

2.3. Participants

A total of 35 participants took part in the study; of which, 17 were female and 18 were male. Ages ranged from 20 to 80 years, with the majority (26 years) falling into the 21–40 years range. Much of the recruitment used university mailing lists and

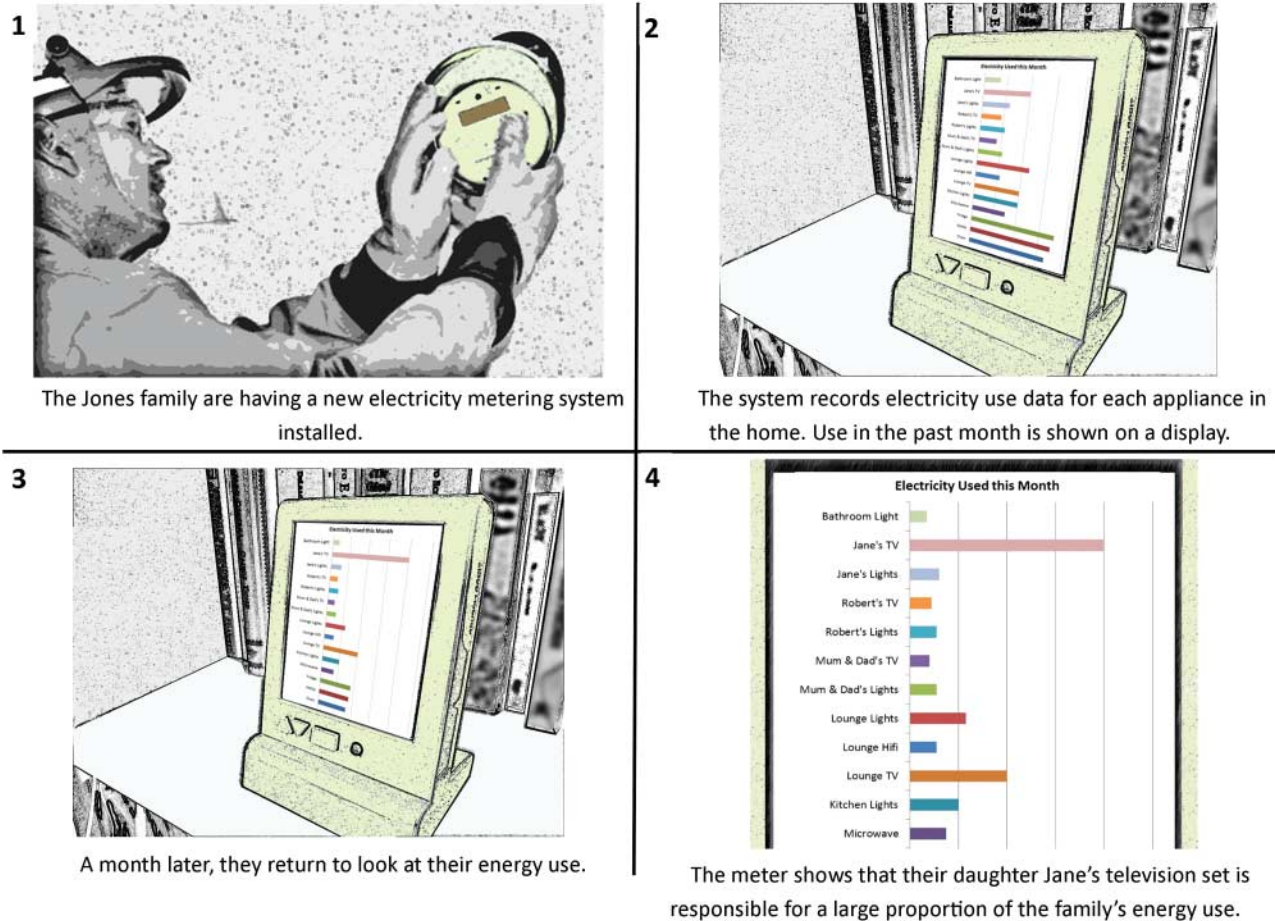


Figure 2. Energy monitor storyboard.

contacts, so it is likely the sample contained a high number of students and professional academics.

3. RESULTS

Having completed the study, the results were then analysed separately based on question type. Responses to open-ended questions were explored using qualitative methods, while the responses to the Likert-style questions were analysed using non-parametric statistical testing.

3.1. Qualitative results

Each participant was asked three open-ended questions about each scenario. The first asked them to interpret the information presented in the last frame of the scenario. In the second, they were asked to describe how they would respond to seeing this information. Finally, they were prompted to describe why they would or would not like to have the technology described in

the scenario in their home. Space was also provided for general comments, which were included in this analysis when given.

The full sets of responses were coded thematically. Codes from the data were created in an exploratory inductive process as there is currently no applicable conceptual framework. In addition to general thematic coding across the data set, responses to the first question (Interpretation) were analysed in detail for content that suggested how respondents interpreted the data presented. Responses to the second question (Response to Information) were analysed for content that suggested if and how respondents would react to each scenario. The frequency of coding references was then compared across the scenarios to suggest patterns and differences in each case.

3.1.1. Interpretations of data

The scenarios presented different forms of ambiguous information to respondents in order to explore their interpretation of it. As such it is interesting to see what the respondents assume in deciding what they think has happened.

Table 1 shows that in the cases of the Energy Monitor and Proximity Portrait scenarios, a majority of respondents made

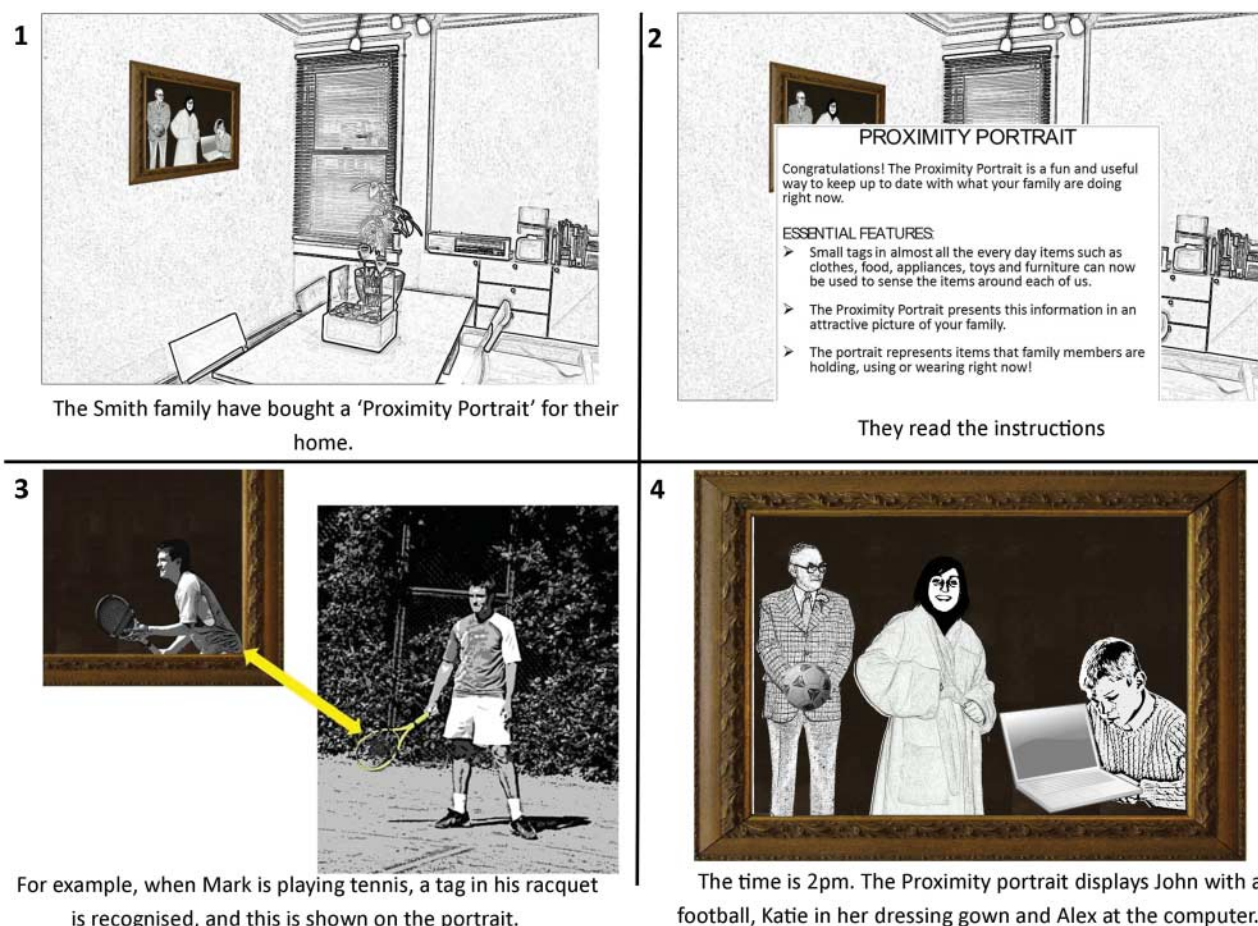


Figure 3. Proximity Portrait storyboard.

inferences about the behaviour of others, which we define as adding information that was not included in the storyboard itself as part of their responses to question 1. However, relatively few respondents made similar inferences in the Smart Fridge scenario.

Table 1 shows that at least some of the participants were conscious that they were adding information to 'fill in' ambiguities when looking at the data, e.g. *'it's difficult to say because they are many possible scenarios – my answer above is a best guess'*. Ambiguity was most commonly recognized in relation to the Proximity Portrait, for example, stating that *'just because someone is touching an item does not mean they are using it in the way that would be most obvious to the casual observer'*. Another participant suggested that the ambiguity of data related strongly both to the usefulness of the system and to privacy concerns, noting that *'It would be uninteresting if I did not know about enough activities and could be uncomfortable if it was too precise'*.

In the case of the energy monitor, common interpretations included that the TV was being left on standby rather than

switched off entirely (10 responses), that the TV set was old and inefficient (8 responses) and that Jane spends a huge amount of time in watching television (7 responses). Some responses built upon the age of the scenario character: four assumed that the grandmother's TV use was high because of restricted mobility or being confined to the house, another suggested that a larger, brighter display was being used as the grandmother had poor eyesight. In one response, it was suggested that—as a daughter—Jane preferred to be alone rather than sitting in the lounge with her parents.

Most interpretations occurred in the Proximity Portrait scenario, but this partly reflects the three characters in each case and therefore more potential for interpretation to occur. Holding a football suggested either playing (22), watching (3) or teaching football (1) in the majority of cases, but could also—where the character holding it was an adult woman—suggest tidying up the house (3 responses). The dressing gown object was the subject of a wide range of interpretations, including having just had a bath or shower (16), getting up or going to bed (13) and being unwell (3).

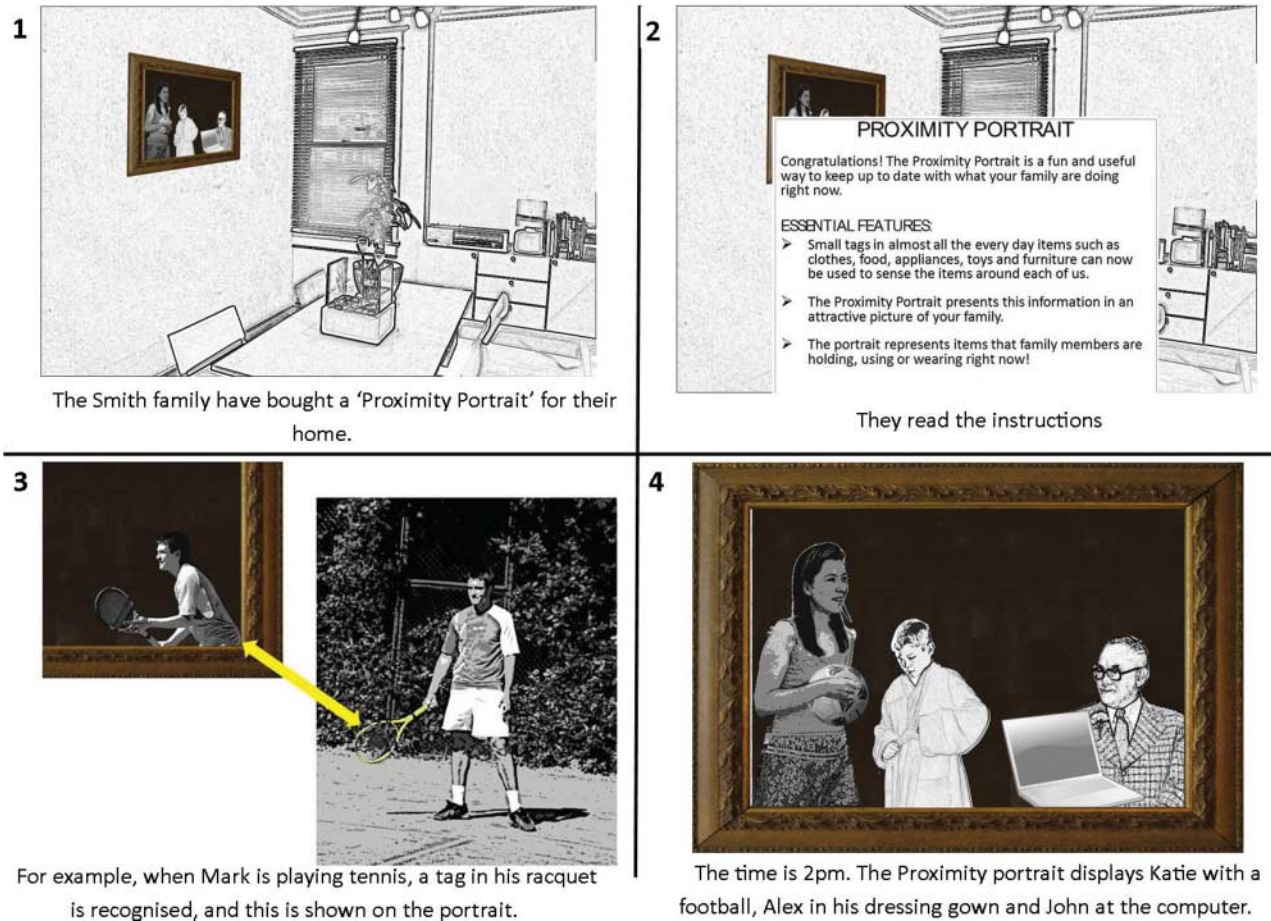


Figure 4. Proximity Portrait, alternative frame 4.

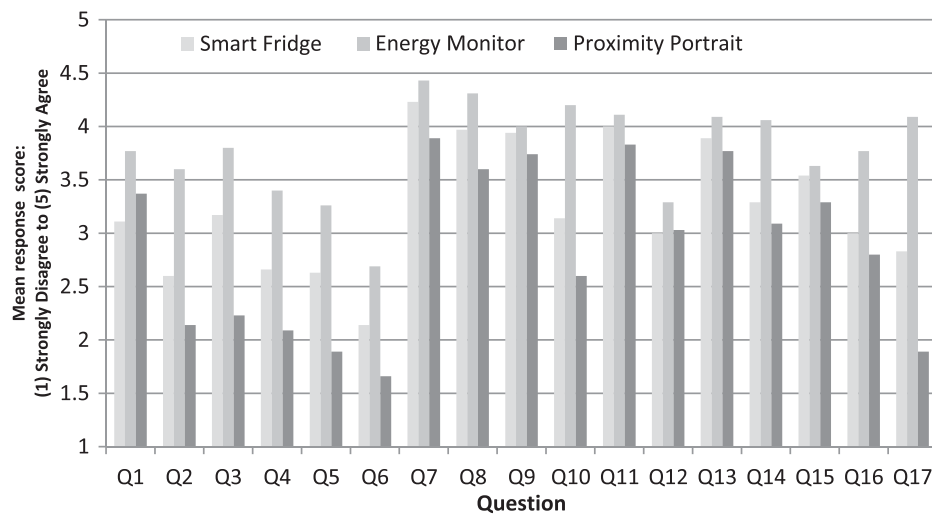


Figure 5. Mean responses by scenario.

Table 1. Inferences and ambiguity in responses to question (1)

	Smart Fridge	Energy Monitor	Proximity Portrait
Inferences made about behaviour of others	11	29	33
Reference to ambiguity in data/scenario	9	6	12

Table 2. Coding of responses (*n*) to question (2). Whether respondent intends to act based on the scenario

Response to information	Smart Fridge	Energy Monitor	Proximity Portrait
Would definitely act	15	31	4
Might act	7	2	2
Would take no action	13	2	29

Table 3. Themes found across responses relating to consequences of seeing data

Type of response act	Fridge	Monitor	Portrait
Ask people to change behaviour	0	17	0
Change own behaviour only	9	7	2
Affect purchasing behaviour	6	22	0
Investigate why this is the case	8	6	1
Show data to others	0	4	0

3.1.2. Acting upon information

Of the responses to the Energy Monitor scenario, the vast majority suggested that they would definitely act in some way in response to the presented information. In contrast, less than half of the respondents would definitely act based on the Smart Fridge information, and fewer still would definitely act based on the Proximity Portrait information (see Table 2).

Exploring the range of actions further, it is clear that the energy monitor information could provoke complex actions that could significantly affect life in the household. Table 3 shows that actions in response to the energy monitor scenario commonly involved asking others to change their behaviour. In several cases, this would involve showing others the data itself as part of a conversation. However, the Smart Fridge scenario—if it affected behaviour at all—was only likely to prompt the person to change their own behaviour, or to investigate further to understand why the alert had occurred—e.g. *‘I guess if I wasn’t the cause I would investigate’*.

Responses to the Energy Monitor scenario also addressed the welfare of family members, e.g. *‘To speak with the grandmother and other household members about whether there were any other activities or pastimes that the grandmother was able / would like to take up in addition to watching television ...’*. Other responses suggested approaches to family dynamics with

children would utilize the data from the energy monitor, e.g. *‘Tell Jane that if she gets her TV use down to her brother’s next month, I will give her some free stuff’*. A large number of responses suggested that some change to purchasing would occur; this encompassed buying new televisions, reducing energy use and changing food purchasing behaviours. It can therefore be expected that some IoT technologies will have dramatic economic effects if they become mainstream.

The individual accountability resulting from the Energy Monitor data (e.g. that this was Jane’s TV) could be considered key in the kinds of responses seen here. One respondent living in a shared house suggested that Jane *should ‘turn her TV off fully or ... pay a higher share of the electric bill’*. Another respondent suggested that this could have negative consequences, making *‘people feel bad about using particular appliances’*.

In contrast, actions in response to the Smart Fridge scenario generally related to changing one’s own behaviour, e.g. *‘I would try to keep track on when I need to eat the fruits, to make sure nothing gets spoiled’*, and *‘Ensure that meals are planned to ensure the fruit is used’*. While some actions in response to the Proximity Portrait again suggested that they may have an effect on social interactions, e.g. *‘I’d presume that Katie will be hungry when she returns home (from football), so plan for a larger dinner. I’d check on Alex to see if he was OK. I’d leave John alone because he’s working’*. These effects were only reported by a small subset of participants as highlighted in Table 3.

3.1.3. Privacy

The theme of privacy was raised in response to the Proximity Portrait scenario in a majority of the responses (35 references across the three open questions, made by 24 individual participants). These varied from highly negative (*‘creepy’*, *‘intrusive’*, uncomfortable about *‘the prospect of being tagged’*), to concern only based on specific details (e.g. whether a person could *‘opt out’* or decide which objects were tagged).

In contrast, there were far fewer references to privacy issues in relation to the Energy Monitor (5) or Smart Fridge (2). Where these were raised, they commonly suggested that it was the potential sharing these data with the public or commercial organizations that caused concern rather than sharing in the home. Some participants felt that, whilst they could see potential issues with the Energy Monitor, the benefits competed with this, e.g. *‘I would like one, not as a spy tool to see how much TV the kids are watching, or a stick to beat my housemates with, but as a tool to save money and see where I’m wasting electricity’*.

3.2. Quantitative results

Following the qualitative analysis of the open-ended questions, the responses to the Likert style questions were analysed statistically. Initial descriptive statistics revealed insufficient

Table 4. Mean scores and results of Friedman tests between scenarios

	Statement	Smart Fridge	Energy Monitor	Proximity Portrait	Friedman test (χ^2)
Q1	I can tell a lot about what people have been doing based on looking at ... (the scenario).	3.11	3.77	3.37	7.848
Q2	I would like ... (the scenario) to provide me with information about people that I live with.	2.60	3.60	2.14	39.018^a
Q3	I would be comfortable with the people I live with using ... (the scenario) if it included information about me.	3.17	3.80	2.23	39.631^a
Q4	I would like to see information about the general public collected through ... (the scenario).	2.66	3.40	2.09	31.88^a
Q5	I would be comfortable with the general public viewing anonymized information about me that was collected through (the scenario).	2.63	3.26	1.89	34.308^a
Q6	I would be comfortable with commercial organisations viewing anonymized information about me collected through (the scenario).	2.14	2.69	1.66	26.247^a
Q7	I understood what (the scenario) does.	4.23	4.43	3.89	9.8
Q8	I understood what was happening in this scenario.	3.97	4.31	3.60	17.797^a
Q9	... (the scenario) is easy to use.	3.94	4.00	3.74	3.155
Q10	... (the scenario) is useful.	3.14	4.20	2.60	36.505^a
Q11	People under the age of 21 would find... (the scenario) easy to use.	4.00	4.11	3.83	5.915
Q12	People under the age of 21 would find... (the scenario) useful.	3.00	3.29	3.03	3.5
Q13	People aged 22–60 would find ... (the scenario) easy to use.	3.89	4.09	3.77	3.057
Q14	People aged 22-60 would find ... (the scenario) useful.	3.29	4.06	3.09	21.121^a
Q15	People aged over 60 would find ... (the scenario) easy to use.	3.54	3.63	3.29	0.711
Q16	People aged over 60 would find ... (the scenario) useful.	3.00	3.77	2.80	24.065^a
Q17	I would like to have ... (the scenario) in my home.	2.83	4.09	1.89	49.333^a

^aSignificant at $df = 2$, $P \leq 0.05$ with Bonferroni correction. The bold just further highlights the significant findings indicated by ^a.

evidence of normal distribution of the data,¹ so non-parametric methods were used throughout.

3.2.1. Between scenario differences

The first stage of the analysis involved inspecting the differences in response to individual questions between the three scenarios. The highest mean scores (most agreement with the statements) were recorded for the Energy Monitor, followed by Smart Fridge and lowest of them Proximity Portrait for almost every question (see Fig. 5). Friedman tests at $df = 2$, $P \leq 0.05$, revealed significant differences for 10 of the 17 statements (see Table 4).

¹A majority of the variables reported significant results from the Shapiro–Wilk test at $n = 35$, $P < 0.05$

3.2.2. Within scenario differences

To further explore some of the issues highlighted in the qualitative analysis, a number of within-scenario comparisons were performed. These explore differences in respondents' willingness to share data across the scenarios.

Privacy and willingness to share data. To explore the importance of privacy in each scenario, difference testing was performed between responses to question 3 'I would be comfortable with the people I live with using (the scenario) if it included information about me', question 5 'I would be comfortable with the general public viewing anonymised information about me that was collected through (the scenario)' and question 6 'I would be comfortable with commercial organisations viewing anonymised information about me

collected through (the scenario)' (see Fig. 6). Friedman tests revealed significant results at $df = 2$, $P \leq 0.05$ for each scenario (see Tables 5 and 6).

Post hoc comparisons were performed using the Wilcoxon signed-rank test. These tests revealed significant results at $n = 35$, $P \leq 0.05$ between all items for Smart Fridge and Energy Monitor, and between questions 3 and 6 for all scenarios, see Table 6.

Influence of age. The final quantitative analysis explored the influence of the age of the target on judgements of how 'Easy

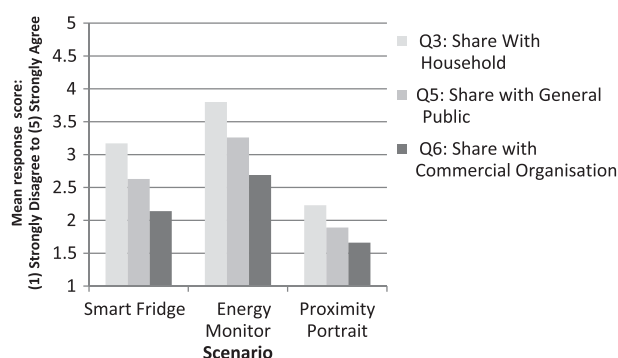


Figure 6. Mean scores to data-sharing questions.

Table 5. Mean scores and Friedman Tests for data sharing questions, higher scores indicating higher level of comfort sharing information.

	Q3: Share with household	Q5: Share with general public	Q6: Share with commercial organization	Friedman test (χ^2)
Smart Fridge	3.17	2.63	2.14	20.759 ^a
Energy Monitor	3.80	3.26	2.69	26.967 ^a
Proximity Portrait	2.23	1.89	1.66	8.149 ^a

^aSignificant at $P \leq 0.05$ with Bonferroni correction.

Table 6. Post hoc multiple comparisons Wilcoxon signed-rank tests between data-sharing questions.

	More comfortable with (Q3), sharing with household, than with (Q5), sharing with organization	More comfortable with (Q5), sharing with household, than with (Q6), sharing with organization	More comfortable with (Q3), sharing with household, than with (Q6), sharing with organization
Smart Fridge	40.00 ^a	21.00 ^a	27.00 ^a
Energy Monitor	25.00 ^a	38.50 ^a	6.50 ^a
Proximity Portrait	43.00	12.50	32.00 ^a

^aSignificant at $n = 35$, $P \leq 0.05$ with Bonferroni correction.

to Use' and 'Useful' they felt others would find the technology described in each scenario (see Figs 7 and 8). This provides a further dimension of understanding of how perceptions of age may affect the technology use. Friedman tests revealed significant results at $df = 2$, $P \leq 0.05$ for each scenario in terms of ease of use and in both Smart Fridge and Energy Monitor for Usefulness (see Tables 7 and 8).

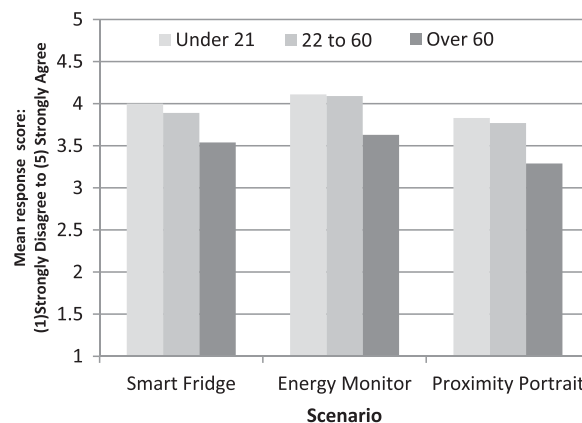


Figure 7. Graph of mean score for ease of use by age.

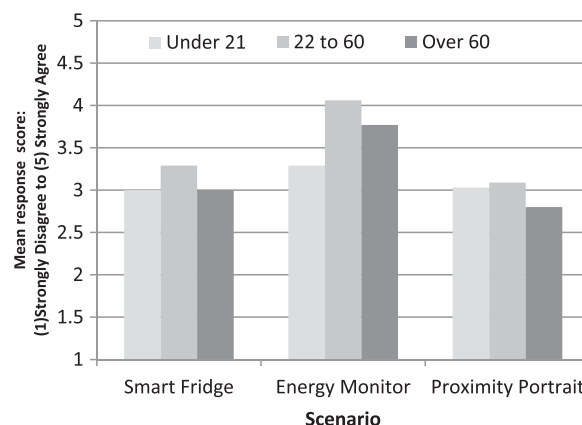


Figure 8. Graph of mean scores for usefulness by age group.

Table 7. Mean score and Friedman test for ease of use by age group

	Age			Friedman test (χ^2)
	Under 21	22–60	Over 60	
Smart Fridge	4.00	3.89	3.54	20.652 ^a
Energy Monitor	4.11	4.09	3.63	23.277 ^a
Proximity Portrait	3.83	3.77	3.29	15.395 ^a

^aSignificant at $df = 2$, $P \leq 0.05$ with Bonferroni correction.

Table 8. Mean score and Friedman test for usefulness by age group

	Age			Friedman test (χ^2)
	Under 21	22–60	Over 60	
Smart Fridge	3.00	3.29	3.00	9.415 ^a
Energy Monitor	3.29	4.06	3.77	24.604 ^a
Proximity Portrait	3.03	3.09	2.80	6.5

^aSignificant at $df = 2$, $P \leq 0.05$ with Bonferroni correction.

4. DISCUSSION AND CONCLUSIONS

Drawing together the qualitative and quantitative findings, this section revisits the themes highlighted in Section 1. On a general level, it is worth mentioning the universal preference reported for Energy Monitor, followed by Smart Fridge and finally Proximity Portrait suggesting significantly different levels of acceptance for each technology.

4.1. Impact of ambiguity in data

One of the key aims of this study was to investigate the interpretation of ambiguous data created by IoT technologies. It appears that perceived ambiguity in data does not negatively impact participants' willingness to make inferences based on that data. For example, Proximity Portrait showed the highest rate of inferences about others' behaviour, but also the highest frequency of mentions of the ambiguity of the information. This finding could have important implications for the design of IoT technologies as it suggests that informing users of the potential ambiguity in the data collected/reported will not reduce their willingness to (mis)interpret the meaning of that data.

The analysis also revealed a wide variation in the willingness to act upon information presented by IoT technologies. The nature of the actions proposed also differed between scenarios, with participants generally only willing to change their own actions based on Smart Fridge data but much more willing to approach others in the Energy Monitoring scenario, suggesting further complexity within this issue. In terms of design, these findings highlight the importance of identifying potential ambiguities in data produced by IoT technologies and subsequently understanding their implication.

4.2. Age effects

Qualitative analysis revealed indications that the age of the target affects interpretation of ambiguous information, with a number of references to the old requiring assistance or having special considerations when using the technology. The statistical analysis supports this finding, showing that participants perceive those over 60 as finding the technologies less useful and less easy to use (see Tables 7 and 8). Comparing this finding with the lack of significant differences between scenarios for each ease-of-use statement suggests that people see the age of the user more influential on ease-of-use than the nature of the technology itself.

4.3. Privacy concerns

Each of the scenarios involved sharing very different types of data with a household. The Smart Fridge showed shared food purchase behaviour over a period of weeks, the Energy Monitor revealed energy use on an appliance-by-appliance basis over a month, and the Proximity Portrait showed live data about current proximity to items. Both the qualitative and quantitative analyses suggest that participants had the most concerns about the privacy in the Proximity Portrait scenario and least about the Energy Monitor (see Fig. 5 and Table 4). Although further research is needed, the results of this study suggest that the source of these concerns potentially includes being worried about the type of information shared (proximity to objects), or that the information is current rather than historical. The results of our survey suggest that participants found the impact of the Proximity Portrait on their privacy unacceptable because they do not perceive the technology to be particularly beneficial. In contrast, the Energy Monitor is perceived as being more useful, even though providing potentially sensitive information, and therefore some loss of privacy seems to be considered acceptable.

Another interesting trend observed in the study is participants' willingness to share data with the general public is higher than their willingness to share data with commercial organizations. This could be explained a number of ways, such as they conceptualize the general public as not including commercial organizations, or they are happy to share their data with everyone, but to give control of these data specifically to those with commercial interests are unacceptable. It is important that future research explores the intricacies of this issue in order to inform both design for, and communication of, the broad issues relating to data sharing and privacy in the IoT technology. Therefore, it is important that when designing IoT technologies that privacy implications are appropriately and clearly communicated with potential users.

4.4. Critique

Performance of this study and the preceding analysis revealed a number of strengths and weaknesses of the techniques

used. As mentioned earlier, it is likely that the sample of participants contained a high number of university students and staff, and thus relatively high levels of education. This may have influenced the results and will be explored in future studies.

The Likert-type questions used seemed to be effective, with few participants failing to understand the questions, no obvious skew, floor or ceiling effects, and the results permitting uncomplicated statistical analysis. The use of all positive questions did introduce the possibility of acquiescence bias, but this was controlled for by the use of a repeated-measures design; lack of ceiling effects in the data suggest that it was not a major issue.

4.5. Future directions

The results of this study have highlighted some of the complex psychological and social issues surrounding the implementation of the IoT within households. Future work should go into more depth exploring the details of specific issues related to the implementation of IoT technologies, such as impact on social dynamics in the home, the use of stereotypes to interpret ambiguous information and how privacy concerns arise and influence the acceptance of a technology. This should be realized by applying a wide range of methods in order to both validate our findings and gain more specific insights in the key area. There are also a wide range of other research themes relating to the social, psychological and technological dynamics of the home such as assistive technologies (Scherer, 2001), social ambivalence (Hillcoats-Nétamby and Philips, 2011) and security (Ellison, 2002), which need to be explored with IoT technologies in mind.

Another important avenue for future research is further development and validation of the storyboard method used to probe technologies yet to be realized. While previous studies have shown some evidence for the validity of vignettes to study possible future behaviour, no such work has been done in the domain of future technologies. One limitation highlighted in the critique that should be addressed in the future is the uncertainty surrounding individual's interpretations of a given scenario. Techniques to control for or capture participants' interpretations of a vignette would be a valuable addition to this method. Once refined methods have been developed, it may also be possible to study the impact of more futuristic technologies with even greater potential to affect the dynamics of the home.

4.6. Reflections on the method

Having performed an internet-based survey using storyboard vignettes, it is worth briefly reflecting on the lessons learned from applying this relatively novel method. On the one hand, it is difficult to interpret the results without validation against more traditional methods, but it is clear that we were able

to gain in-depth responses from a relatively large number of households in a short time frame. While a situated technology would undoubtedly produce rich ecologically valid data, doing so would inevitably require several orders of magnitude more research and developer time. For this reason, we initially recommend this method for testing of early concepts and prototypes potential impact within a home setting.

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