Int. J. Human-Computer Studies 98 (2017) 169–178

Contents lists available at ScienceDirect

Int. J. Human-Computer Studies

journal homepage: www.elsevier.com/locate/ijhcs

CompanionViz: Mediated platform for gauging canine health and enhancing human–pet interactions

Jonathan K. Nelson[a,*], Patrick C. Shih[b]

[a] GeoVISTA Center, Department of Geography, Pennsylvania State University, University Park, PA 16802, USA
[b] School of Informatics and Computing, Indiana University, Bloomington, IN 47405, USA

ARTICLE INFO

Article history:
Received 30 June 2015
Received in revised form
5 February 2016
Accepted 10 April 2016
Available online 29 April 2016

Keywords:
Animal–Computer Interaction (ACI)
Personal visualization
Quantified other
Canine
Animal wellbeing

ABSTRACT

Advancements in personal data collection and visualization – commonly referred to as the quantified self (QS) movement – allow individuals to self-track health and other attributes. We extend quantified self (QS) concepts to the quantified other (QO) to explore how the use of technology, collection of data on one's pet dog, and personal visualization affect pet owners' understandings of, and relationships with, their pets. We introduce the term Human–pet–computer interaction (HPCI) as the study of how technology can be designed and used to advance human–pet companionships. As an example, we describe *CompanionViz*, a personal information visualization prototype designed to inform pet owners on their dogs' caloric inputs/outputs, as well as exercise and movement habits. We present a user study of *CompanionViz* featuring a twelve-participant survey and one field study, consisting of three unique use cases, and show that by providing pet owners with quantifiable awareness of their dogs' health and exercise habits using personal visual representations, pet owner–dog bonds can benefit.

1. Introduction

According to a 2014 report by the Humane Society of the United States, pet ownership in the Country has tripled since the 1970s. Statistics published by the American Pet Products Association revealed that in 2014 Americans spent a record $58.04 billion on pets. The U.S. remains the highest-ranking country for canine ownership with 83.3 million owned dogs and 47% of households that own at least one dog in 2012. Yet, just over 50% of U.S. dogs are overweight and at least 16% are obese, accounting for some 43.8 million dogs (Association for Pet Obesity Prevention, 2014). Pet owners care deeply about their companions, but often lack quantifiable awareness of their dogs' health and exercise habits.

Paralleling these trends in increasing human–dog companionships and subsequent spending is the quantified self (QS) movement. The QS is an individual who self-tracks biological, physical, behavioral, or environmental information (Swan, 2013). The Pew Research Center's Internet & American Life Project (2013) found that 69% of American adults engage in some form of personal health tracking, 21% of which said they use technology to do so.

QS activity, however, is more than the quantitative collection of personal measurements. How individuals explore, seek to understand, and reinvent their lives through personal data collection, interaction, and casual information visualization is a dynamic, intimate, and subjective process (Pousman and Stasko, 2007). These data are personal, tightly coupled to the user, and often provide reflective, rather than analytical insight. The impacts of personal data collection and understanding can alter behavior, relationships, and overall quality of life.

Ongoing, continuous, and real-time interaction between individuals and their data is a unique big data challenge, in that data must be unbound from scientific practices and made usable and meaningful to all. Individuals may not have the tools, expertize, or interest for storing, querying, and manipulating their personal data. Discovering meaningful patterns may require screening through and integrating large, heterogeneous data and data sources. Interfaces that foster effective QS reasoning must empower individuals with intuitive, qualitative insights founded on highly complex underlying processes. Such interfaces transform the QS into the qualified self (Swan, 2013).

While the QS movement has prompted productive new studies on assessing how humans perceive personal activity data, few have focused on understanding how people perceive the visualized data of their peers, family members, and specifically pets. We extend the QS concepts to the quantified other (QO) to explore how the use of wearable technology, collection of data on one's pet dog, and visualization affect pet owners' understandings of, and relationships with, their pets. Providing pet owners with an outlet to engage with their dogs mediated through human–pet–computer interaction (HPCI) can strengthen bonds between owners and

* Corresponding author.
E-mail address: jkn128@psu.edu (J.K. Nelson).

http://dx.doi.org/10.1016/j.ijhcs.2016.04.002
1071-5819/

companions, while also promoting healthier lifestyles for both.

In the proceeding sections, we first situate HPCI in the emerging Animal–Computer Interaction (ACI) discipline, and highlight relevant research in these niche areas. Next, we introduce *CompanionViz,* our personal information visualization prototype designed to inform pet owners on their dogs' caloric inputs/outputs, as well as exercise and movement habits. We review the components of, rationale behind, and initial response to our visualization gauged from a survey with 12 participants. Insights gathered from a field study of three *CompanionViz use cases* are then explored. Finally, we discuss future directions for our prototype, as well as research in HPCI more generally.

2. Background

This section defines Animal–Computer Interaction (ACI), details its aims, and explores how HPCI relates. A survey of ACI research is presented with an emphasis on canine-related studies. HPCI-centric studies are highlighted, and our research questions and contributions detailed.

ACI is a growing discipline that aims to understand how the interaction between animals, domestic and non-, and computing technology can improve animals' life expectancy and health; support and empower animals in legal contexts surrounding the processes in which they are involved in; facilitate intra- and interspecies communication; and, foster relationships between humans and animals by promoting understanding between them (Mancini, 2011). ACI takes a user-centered approach to technology design guided by animals' needs and preferences. Thus, the primary users of new technologies developed from this approach are the animals.

Research in ACI has often been directed towards the development of technology that aims to foster human-companion animal interaction, while benefitting both human and animal. For example, Cheok et al. (2011) developed Metazoa Ludens, an interspecies computer game, in which humans and hamsters play an interactive chase game in a shared virtual environment using species-unique interfaces. Related, Noz and An (2011) developed a digital iPad game of cat and mouse that facilitated both human–cat and cat only interactions. Lee et al. (2006) introduced a multimodal interaction system to support remote connectedness between humans and animals, demonstrating the benefits of virtual tactile sensation between humans and poultry. Chickens were fitted with vests that delivered "strokes" based on computer signals initiated by their human companions. Similarly, humans could wear vests, stroke a physical analog of a chicken, and in return experience their companion's "peck".

Dogs in particular have been a focus of ACI research. Early work included Rover@Home, an application that allowed humans and dogs to interact over the Internet (Resner, 2001). Beyond providing pet owners with the ability to see and hear their dogs, Rover@Home further exploited "clicker-training," a well-established dog training technique, so that pet owners could remotely dispense treats to their companions. Combining training with amusement, Wingrave et al. (2010) investigated the role of serious gaming technologies in encouraging pet owners to spend more time with their companions.

Human–dog interspecies awareness and communication have been other common threads of ACI research. Mankoff et al. (2005) developed an interspecies social awareness system, PAWS-ABILITIES. The system was built using a dog-centered design approach, and provided bidirectional pack awareness and engagement between pet owner and dog. Golbeck and Neustaedter (2012) and Neustaedter and Golbeck (2013) explored and evaluated the use of pet-based video chat systems to facilitate remote monitoring and correspondence between pet owners and their dogs. Wearable technologies have been developed to assist remote verbal communication between owners and companions (Lemasson et al., 2013), and in-person communication between working dogs and handlers (Jackson et al., 2013). In the latter, the authors found that working dogs could successfully activate wearable electronics based on biting, tugging, and nose gestures to correspond with handlers.

Finally, proposed a decade ago by Gips et al. (2005), SNIF is a proof-of-concept social networking architecture built into dog collars to enhance between-dog, owner–dog, and owner–owner communication. Not surprisingly, the SNIF concept has gained traction in recent years. Dogbook, an online social network established in 2008, has a growing membership with some 3.5 million dogs and 5 million dog lovers. The Dogbook community can share photos, earn badges, and check-in at dog parks, coffee shops, or even fire hydrants.

Human–pet–computer interaction (HPCI) shares similar objectives to ACI, such as fostering human–pet relationships, promoting healthy livelihoods, and regarding the well being of pets in technology use. However, HPCI places additional emphasis on understanding how technology can be designed and used to engage healthy human–pet interactions and relationships, which requires innovative approaches to meeting the needs of dynamic, intimate companionships. Because the focus of HPCI is at the intersection of engagement between human and pet, technology design requires taking a bonded-user approach capable of not just tracking pet attributes and relaying them to pet owners in meaningful and interesting ways, but also inspiring new awareness or positive change in human–pet relationships. Pets are not simply "usees" (Baumer, 2015) of technologies designed to entertain or reduce the anxiety of their pet owners. Rather, technology serves as a supplemental link meant to enhance the bond between pets and their owners. HPCI, then, contributes to and fits narrowly within the growing ACI discipline.

Related to the aims of HPCI is work by Paasovaara et al. (2011), Paldanius et al. (2011), Mancini et al. (2012) and Ladha et al. (2013). Paasovaara et al. (2011) developed the Paw Tracker concept, which allows pet owners to track their dogs' activities and follow their conditions in real-time. Taking a social media approach, Paw Tracker uses mobile and Internet technologies, and combines sensor and video feed data to deepen pet owners' understandings of their dogs. The authors found that dog owners not only wanted to know what their pets were doing while they were away, but were interested in how the technology could potentially discover reasons for barking and other misbehavior.

More broadly, Paldanius et al. (2011) explored the growing interest around pets and technology, and presented two case studies on hunter–dog and pet owner–dog interactions to assess peoples' needs and expectations from dog-specific technologies. Of particular interest, the authors found that technologies designed for pet owners needed to do more than ease daily pet care practices and provide new pet knowledge, but should also support dog owners in building relationships with their companions.

Taking a qualitative exploratory approach, Mancini et al. (2012) investigated how dog tracking in domestic settings reconfigures human–dog relationships. The authors found that tracking practices altered human–dog interactions by enabling pet owners to better understand, care for, and protect their companions.

Lastly, Ladha et al. (2013) developed a robust collar-worn activity sensor capable of identifying up to 17 canine-specific behaviors with approximately 70% reliability. Such behaviors included barking, chewing, pawing, and sniffing. The authors hypothesized that such high-level canine monitoring could promote both health and well-being for domestic and service dogs alike by advancing pet owners' awareness and understanding of their pets.

All four of these works emphasize how technology should be designed and used to engage positive human–canine interaction and foster animal welfare. As ubiquitous computing and the "quantified everything" movement continue gaining mainstream traction, so arise unforeseen implications for the users, as well as concerns that technological nature is replacing the natural (Kahn et al., 2009). In a speculative design study on the reaction of companion animal owners to near-future prototypes used to quantify and better understand pet welfare, Lawson et al. (2015) found that while pet owners had strong interest in leveraging technology to better understand their pets physiological characteristics and emotional needs, they expressed little concern for how any of it worked. The authors cautioned that technology designed incognizant of scientific research in animal behavior has the potential to undermine or harm human–pet relationships; confuse or worsen pet owners' understandings of their companions; and, cause new human–human conflicts among pet owners, citizens, and veterinary practitioners. The need for a niche area within the ACI community dedicated to understanding the role of computers in supplementing the coevolved, complex bond between humans and companion animals is quite timely.

We contribute to this growing body of work in HPCI and ACI by exploring the effects of integrating wearable technology, personal data collection on one's dog, and casual information visualization on pet owner–dog relationships. More specifically, we aim to address the following interlinked questions: How does allowing pet owners to track and visualize the caloric inputs/outputs and movement (steps) of their pet dogs (a) encourage owners to take a more caring and aware role in their companions' daily health and activity needs, (b) promote healthy and more engaged relationships between them, and (c) increase pet owners' understandings of and motivation to alter their dogs' lifestyles?

To explore these questions we introduce *CompanionViz*, a personal interactive visualization that relays exercise and nutritional information of dogs to their owners in intuitive and reflective ways. We hypothesize that by providing pet owners with quantifiable awareness of their dogs' health and exercise using casual visual representations, pet owner–dog bonds will strengthen, thus promoting healthier lifestyles for both.

3. CompanionViz prototype

In this section, we describe the components of the *CompanionViz* web application. First, we introduce our pilot participant, a four-year-old dachshund, and explain the step and calorie data collection process. We then review how these data were visually transformed, and the rationale behind our design choices.

3.1. Quantifying the other

Step and calorie data were collected for Maggie, a four-year-old longhaired dachshund, for the duration of two and a half months. A fitbit Ultra pedometer/wellness monitor (version 4.14) was clipped on to Maggie's collar to record movement in steps, caloric expenditure, and activity level. This device was chosen over other models due to ease of attachment, high charge retention, affordability, and mainstream brand awareness. Whilst canine-specific tracking devices, such as Fitbark and Whistle, are gaining consumer awareness, these devices cost more and appeal to a smaller, more refined user group. Thus, the potential for technology adoption is lower.

Maggie's age, height, weight, and caloric inputs were uploaded daily to the fitbit dashboard. Because the fitbit application assumes age in human years and calculates caloric expenditure accordingly, Maggie's age in canine years was adjusted to human years following guidelines published most recently by the American Kennel Club (2015). Her height was measured from level ground to the top of her shoulder blades while standing on all four legs. Inputting this information into the fitbit application resulted in a better estimate of stride length, allowing step counts to be recorded more accurately. Caloric intake was estimated based on the nutrition facts associated with dog and any other food consumed. Once uploaded, these data then transferred automatically to a live spreadsheet via the fitbit API, which the *CompanionViz* application accessed directly for creating visual data depictions.

3.2. CompanionViz implementation and design

CompanionViz is an interactive web visualization built using the D3.js JavaScript library (Bostock et al., 2011). D3 is an open-source library that allows users to manipulate documents based on data, using HTML, SVG, and CSS, while conforming to web standards. The personal visualization integrates data collected by fitbit devices, and consists of two main components: (1) Overview: Calendar and (2) Focus+Context: TimeLine. The Calendar provides pet owners with a daily gauge on their dogs' input to output caloric ratio, and allows owners to explore weekly, monthly, or yearly patterns in their dogs' health. The TimeLine depicts temporal patterns in both exercise and nutrition, and provides multiscale interaction. Pet owners can focus the TimeLine on specific time intervals by creating a brush in the lower context TimeLine. Caloric ratio and steps are plotted continuously and scaled on opposite axes. Fig. 1 depicts Maggie's *CompanionViz* for early 2014.

For calorie data, color is used as both a learning and reward mechanism. Input to output calsoric ratio data are represented in shades of red and green in both the Calendar and TimeLine. Deep shades of red convey days in which calorie expenditure is lacking, either from an exercise deficiency or excessive eating. Deep shades of green reflect days in which calorie output is greater. Colorbrewer, an online resource for selecting logical color schemes for thematic data, guided our use of color (Harrower and Brewer, 2003). Bertin (1983) describes the three perceptual dimensions of color (hue, saturation, and lightness) as visual variables, or graphical building blocks. Color works as a 'sign vehicle' and evokes emotions. Our intent is that shades of red will encourage fitness and health, while shades of green will resonate with health and fitness success. The threshold between "healthy" and "unhealthy" ratios is relative, can be modified to meet individual pet needs, and would benefit from veterinary guidance. In the use cases reported in our study, we established a threshold in between 1 and 1.4 activity to consumed calories, which captured the variation in values on either side of the threshold most intuitively.

For activity data, steps are represented only in the TimeLine. These data serve two purposes. First, their presence (or lackthereof) informs pet owners on their dogs' daily activity, and can be related to the position of peaks and troughs in the caloric ratio data plotted above. Second, pet owners can zoom to intraday step intervals using the focus interaction of the TimeLine (create a brush in the small timeline at bottom of the visualization) to view steps disaggregated to a resolution as fine as five-minute intervals. Fig. 2 illustrates the temporal zoom functionality. Multiscale interaction is useful for understanding dog movement patterns when pet owners are not home.

In summary, we designed *CompanionViz* to enhance pet owners' understandings of their dogs' health and exercise needs, and to strengthen relationships between them through the use of personal visualizations. Color and multiscale visualization techniques are used as reward and learning mechanisms.

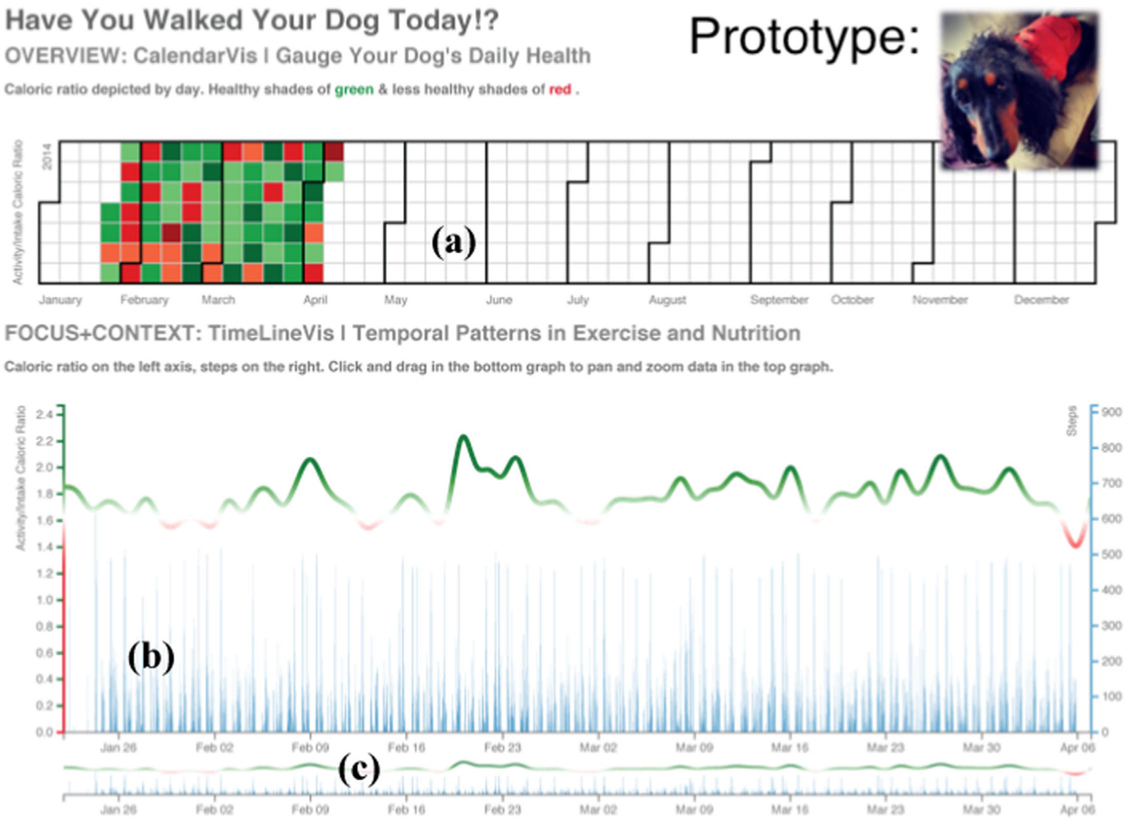

Fig. 1. CompanionViz Prototype. (a) Overview: Calendar, (b) Focus Timeline, and (c) Context Timeline.

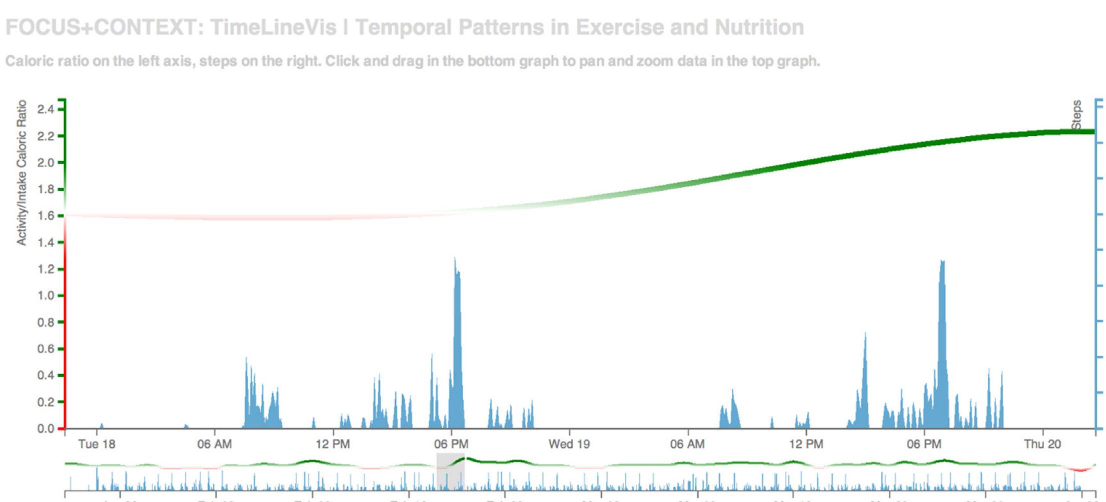

Fig. 2. TimeLine focused on Feb. 18–19.

4. Evaluation

This section begins with results from a twelve-participant survey designed to gauge initial interest in our prototype and research goals. Based on positive feedback from the survey responses, we deployed one field study, consisting of three participant groups (pet owner and canine) and lasting the duration of one and a half weeks. The one and a half weeks encompassed an introductory phase in which pet owners completed a survey and fitbit devices were calibrated for their dogs; seven days of pet tracking, diary entries and photograph uploads; and, an exit phase where pet owners were presented with their canines' *CompanionViz* and asked to complete a concluding questionnaire. This section provides an overview of study design and participants, documents insights gathered from the three studies, and discusses to what extent the studies support our research hypotheses.

4.1. Survey|Gauging interest in CompanionViz

To evaluate initial interest in our research aims and visualization prototype, we conducted a survey consisting of two main parts. The first part included a mix of multiple choice, short answer, and likert scale questions that asked participants general questions about HPCI concepts, fitness, and perceptions of health. Example questions included: *On a scale of 1–5, (1 being the least and 5 being the most) how much of your exercise is spent with your* *pet?; Are you curious about your dog's activity when you are not home with your pet? (yes, no, indifferent); On a scale of 1–5 (1 being completely unmotivated and 5 being completely motivated), how would placing a fitness and health monitoring device on your pet dog influence your motivation to exercise?.*

The second part of the survey provided participants with a URL link to *CompanionViz*, together with an explanation on what the application depicted and how it worked. Participants had the opportunity to explore and evaluate the interactive visualization, and were then asked multiple choice and short answer questions to assess their understanding of the application, as well as to provided feedback on the effectiveness and utility of *CompanionViz*. Example questions from this part of the survey included: *Would visualizing your pet's data encourage you to exercise more frequently and/or intensely? (yes, no, indifferent); How does the color in which Maggie's caloric data are presented affect your perception of her fitness level?; What features would your ideal app for human–dog–computer interaction have?.*

We recruited 12 participants. First order participants were colleagues and friends who then asked others they knew who owned dogs to participate. Participants owned between one and four dogs that ranged in sizes from toy to extra large.

Participants' time spent exercising with their dogs followed a right-skewed distribution, with pet owners spending relatively more of their exercise time without their dogs. The majority of respondents felt that their dogs did not need them to get their exercise needs, while one-third of participants felt strongly the opposite. Almost all respondents felt that exercising with a pet encouraged owners to exercise more often. However, feelings on whether or not tracking the fitness/health of pet dogs would influence human exercise habits were entirely mixed. Three-quarters of participants were curious about their dogs' activities when not at home.

After visiting the *CompanionViz* prototype, two-thirds of participants felt that they would exercise more frequently and intensely, given being able to visualize their pets' data. Moreover, all participants were effectively able to interpret Maggie's data, and commented on being able to easily understand the use of color in the interface. One participant suggested that the visualization provided the necessary tools to keep pets healthy.

The Calendar and TimeLine components were equally preferred; however, the Calendar was noted as being easier to interpret. Participants found it useful being able to compare patterns in the Calendar, both between and within particular weeks and months. One respondent commented on the utility of being able to compare trends in caloric data by certain days of the week by reviewing patterns in the Calendar by row.

Participants found the focus brush initially confusing, but enjoyed being able to explore temporal patterns at multiple scales once oriented to the functionality. Finally, participants suggested making the design more personable, which we implemented by integrating photos of human–dog interactions at the bottom of the timeline.

4.2. CompanionViz use cases|Participants & design

Study participants included: Harvey, an olde english bulldog, owned by a married female speech therapist; Zoey, a border collie, owned by a single female before-and-afterschool teacher; and, Tokala, a jack russel-border collie mix, owned by a married female before-and-afterschool teacher. Each *CompanionViz* use case entailed an introductory survey, seven daily diary entry forms for each tracking day, and a concluding questionnaire. Table 1 provides summary statistics for each dog, including age, weight, height, daily mean step count, daily mean calories in, and daily mean calories out for the seven-day tracking period of the study.

Table 1
Summary statistics by dog for 7-day tracking period.

	Harvey	Zoey	Tokala
Age (yr)	2.7	7	10
Weight (kg)	29.48	18.14	22.68
Height (cm)	58.42	60.96	50.8
Daily Mean Step Count	7007	9767	6538
Daily Mean Calories In	1572	900	850
Daily Mean Calories Out	1910	1503	1386

The introductory survey was used to acquaint pet owners with our research objectives, our prototype visualization, and most importantly, to acquire information about their dogs, so we could accurately configure the fitbit devices. We followed the same configuration approach as outlined in Section 3.1 for our pilot participant, Maggie. Devices were calibrated based on each dog's age (translated into human years), weight, and height. Pet owners provided specifics on what their dogs ate and drank, and how much on an average day. This information was used to input caloric intake.

The dogs wore the devices clipped to their collars for seven days. On each day, pet owners were required to submit diary entries. Diary entries consisted of open-ended questions asking pet owners about their daily experiences with their dogs and our study, as well as requested pet owners to upload photographs from their daily interactions with their dogs. At the end of the seven days, the dogs' fitbit data were input into *CompanionViz*, and shared with pet owners (Figs. 3–5). Lastly, the three pet owners completed a concluding questionnaire that asked open-ended questions about their overall experiences participating in the study, as well as on the visualizations.

Overall, our field studies generated three introductory surveys each containing responses to 45 questions of multiple choice, likert scale, and short answer types; 21 diary entries each containing responses to six open-ended questions; 53 photographs of pet owner–dog interactions including textual and temporal context; and three concluding questionnaires each with responses to 10 open-ended questions. We conducted thematic analysis of the collected data and iteratively refined the emerged themes (presented below) until saturation was reached.

4.3. Insight gathering

The seven-day tracking period, consisting also of daily diary questions and photograph upload requirements, was used to strongly engage pet owners in critically thinking about their daily interactions with their dogs. Three questions in particular, on all seven of the daily diary entries, sought to address our main research objectives. First, *How did knowing that your dog's activity and calorie data were being tracked affect your interactions and exercise with your dog?* Second, *How will today's reflections of your dog's activity and health affect tomorrow's interactions with your dog?* Third, *How did the process of monitoring your dog's activity and health affect your relationship with your dog?* Other more open-ended questions, asking pet owners to reflect on their daily interactions with their pets or to comment on the context of their uploaded photographs, aimed to capture more indirect inferences on the effects of HPCI on the participants.

In the case of Harvey, the process of monitoring his activity and health positively affected the relationship between him and his owner. When asked to reflect on the impact the personal data collection and visualization process had on the relationship between Harvey and his owner, his owner responded:

> "We spent more time being active than on a typical day, which is his favorite thing to do with me. I perceived Harvey as

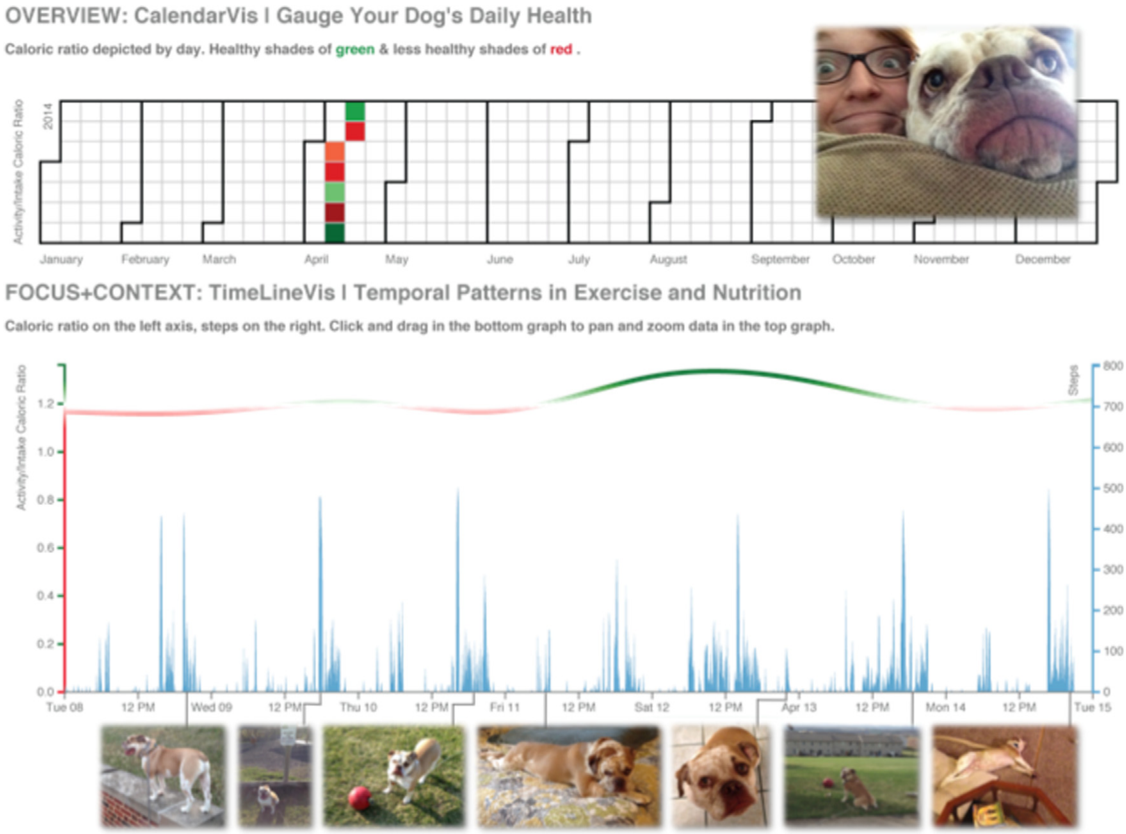

Fig. 3. Harvey's *CompanionViz*.

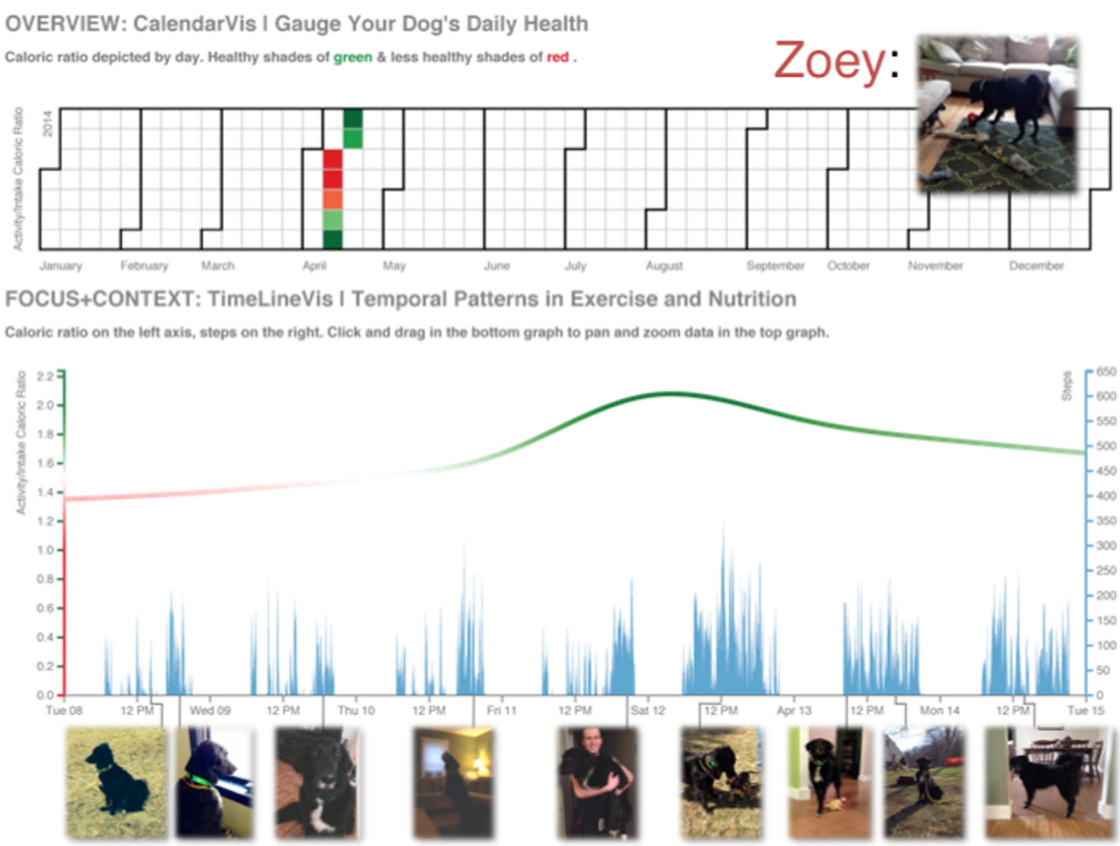

Fig. 4. Zoey's *CompanionViz*.

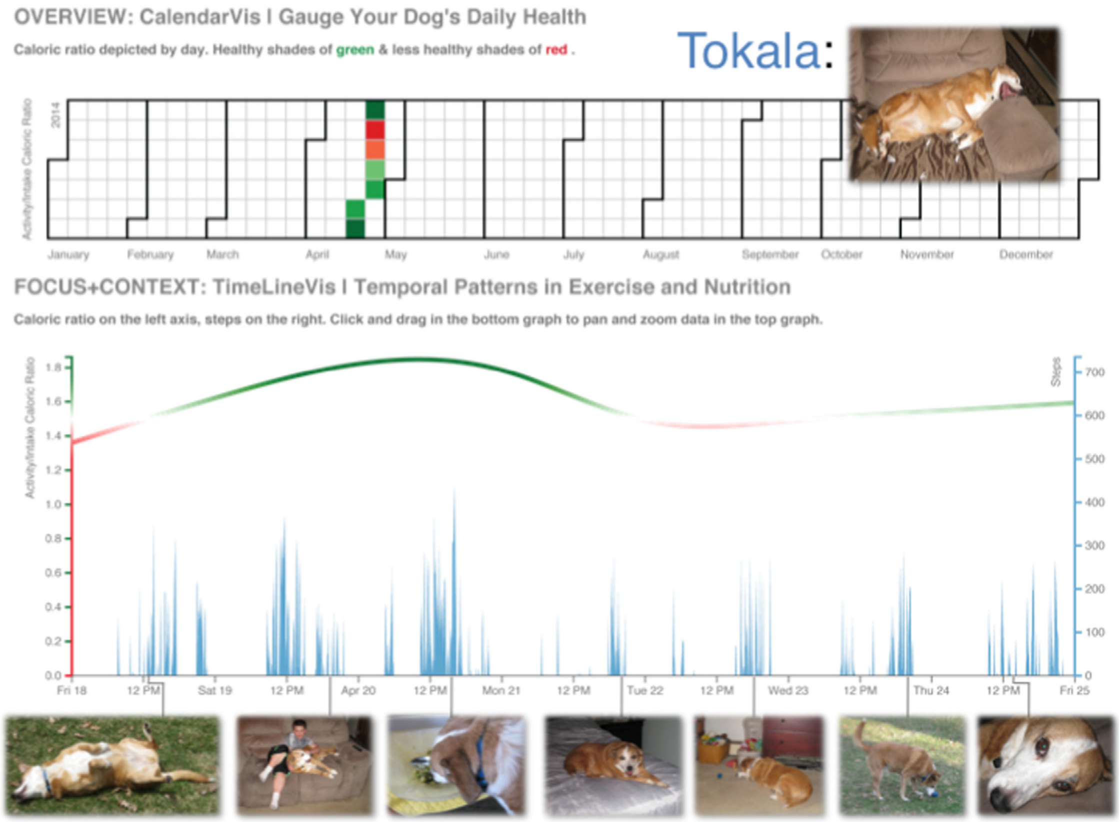

Fig. 5. Tokala's *CompanionViz*.

appreciating our relationship more. Then later in the evening he was much more tired, and wanted to cuddle with me, which is my favorite thing to do with him, so I gained more from that interaction."

Harvey's owner further noted paying more attention to what he was doing all day, and being "more 'in tuned' with his needs." Prominent themes that emerged from the study were **motivation**, **guilt**, and **increased awareness**. In knowing that Harvey's activity and caloric intake were being tracked, his owner mentioned taking him for extra walks, engaging in more toy play, and thinking more about the food scraps she fed him. One day she commented, "I normally try to avoid the dog park at busy times, as he has been aggressive with large groups of other dogs in the past. Even though I knew it was a busy time, I walked him to the dog park to check, and when it was not very crowded, we stayed to play fetch for a little while."

Harvey's owner discussed how she would feel more guilty knowing that there would be "hard evidence" if they were lazy. One day she said, "I was so shocked that the previous day's results said that he took in more than he exerted, so I sort of made it my mission to do better today with it." When asked how today's reflections on Harvey's activity and health would affect tomorrow's interactions with Harvey, his owner's response on the first day of the tracking period was, "When I am in a situation where I have the option of getting Harvey to be active or passive, I will likely choose to make him be active." One day, Harvey's owner noted wanting to make a greater effort to walk Harvey further the next day, because the rain had detoured them from getting out of the house the current day. After an exercise intensive day, she expressed concern for Harvey's health:

> "Hopefully he will be well rested tomorrow and we will be able to do a little more. Now that I have thought about how much activity he had yesterday though, I think that I may be more careful not to over exercise him."

Personal data collection and visualization mediated through HPCI benefited the relationship between Harvey and his owner, and enhanced his owner's awareness of Harvey's physical and mental needs.

Emergent themes from the Zoey study were again **increased awareness** and **motivation**, but also **curiosity**. Early in the study, Zoey's owner commented on continuously checking Zoey's step count and comparing her results from day-to-day:

> "I found myself checking her step count every few hours just to see how much she actually moves around when I'm not home to witness it. If I would notice that she isn't getting enough exercise I would be sure to make some changes."

Personal data collection and visualization together with HPCI provided Zoey's owner with the ability to evaluate Zoey's movement habits and needs, and to assess potential changes she could make to her and Zoey's routines if Zoey was not getting enough exercise. On one occasion her owner stated: "We made more of an effort to get her moving today to see how much of a difference it would make." On another day, Zoey's owner engaged in extra play sessions with Zoey to see the difference that particular activities would make on her data. She stated, "I was surprised how much a couple extra play sessions affected the amount of steps she took." Her owner was even more surprised to find that Zoey's step count was highest on days she had to work, revealing just how much Zoey paces when left home alone:

> "She had a lower number of steps today despite the fact that we were home and outside all day. This compared to yesterday's huge number of steps tells me that she paces a lot when we are not home."

On the fifth day of the study, Zoey had a considerably higher step count, and her owner mentioned trying to feed her more that evening. Also during the study week, a new puppy was introduced into Zoey's family, and her owner reflected, "It will be interesting to see how her activity fluctuates with a playmate in the picture". The quantification and visualization of Zoey's personal characteristics afforded her owner new understandings of Zoey's movement and new insights on family dynamics, as well as fostered more interactions between them.

In the Tokala study, the effects of HPCI were weaker. **Curiosity** was again an emergent theme, but the actual process of monitoring Tokala's activity and caloric intake seemed to minimally alter the interactions and relationship between him and his owner. For example, when asked how today's reflections on Tokala's activity and health would influence the following day's interactions with him, Tokala's owner responded, "I may try to take him for a walk, but more so because it is to be a nice day and I have time." In this instance, weather and available time proved to be more influential factors on daily interactions, as compared to increased awareness of Tokala's activity and caloric intake. When asked to comment on how the monitoring process affected their relationship, Tokala's owner replied, "It did not. I love having my dog with me and he is like a little shadow. Wherever I am, he must also be." However, Tokala's owner did comment on being pleased to see that Tokala "was burning as many calories as he was consuming." She further expressed curiosity in learning more about Tokala's activities when she was not home:

> "It will be interesting to see how/if the data changes starting tomorrow. I have been off work due to the long holiday weekend since Tokala began wearing the fitbit. I will be back to work tomorrow. We will not interact at all during the day, but I am curious to see if he is active or naps when I am gone. My husband gets home much earlier than I do, and I often wonder if Tokala even wakes up from his nap when my husband gets home, and if they play together when I am not there."

So while the monitoring process did not alter the relationship between Tokala and his owner, it did provide a mediated platform for the family members to have a nuanced dialog of interactions.

5. Discussion

The field study consisting of three use cases of *CompanionViz* generally supported our research hypothesis; that by providing pet owners with quantifiable awareness of their dogs' health and exercise habits using personal visual representations, pet owner–dog bonds would strengthen. For example, concluding responses on the usefulness and value of our study from the owners of Harvey and Zoey included:

> "It made for a good bonding experience for us and the dog, and we have also enjoyed looking back at the photos we took for the daily journal… In the first two days I felt very motivated to give him as much activity as possible. It was almost like a competition with myself to see how many calories he could burn."
>
> "I want to try to get Zoey to eat more during the day since she burns so many calories… It was obvious from the visualization that Zoey takes a lot more steps when we are not home. I know she paces when she's alone, but I did not realize how much!"

Even in the case of Tokala, in which the monitoring process appeared to have minimal effect on the pet–owner dog relationship, his owner concluded:

> "Giving owners a visualization could positively benefit both owners and their pets. If owners are able to see how many (or few) steps their pet takes in a day versus their food consumption, they may be inclined to up the exercise or limit food, thereby reducing pet obesity (and possibly their own)."

However, it was clear that the value and usefulness of the study varied between cases. Interestingly, the study appeared most useful to Harvey, the youngest participant, while the study was least valuable to Tokala, the oldest participant. For Zoey, the middle-aged participant, dog breed revealed being an interesting factor; in that border collies are known to pace, but Zoey's owner gained new awareness on just how much, particularly when Zoey was home alone. Age and breed of dog, as well as the length of established relationship time between dog and owner may play a vital role in narrowing the target population for dog tracking, *CompanionViz*, and HPCI more broadly.

Better understanding owner–dog and other family relationship dynamics will also further inform the needs and desires of various relevant target populations. Harvey and Zoey, for example, belonged to younger pet owners (mid 20s) who did not have kids; whereas, Tokala belonged to a 35-year-old married woman with a child in the family. In the cases of Harvey and Zoey, *CompanionViz* provided their owners with new insights on the dogs' activity and health, as well as positively affected their companionships. In the case of Tokala, *CompanionViz* served as a mediated platform for family members to interact and better understand one another when not together.

Some relevant near-term additions to *CompanionViz* might include: ability to customize pet profiles and add more than one pet (or pet owners) to the display; track dog specific attributes, such as barking and tail-wagging; integrate photographs, memoirs, or social media dynamically to the timeline; summarize and re-organize temporal patterns; and integrate place using GPS sensors and maps. Devices designed specifically for dogs, such as Fitbark, Whistle, or the activity collars devised by Ladha et al. (2013), could provide other unique application addition opportunities. fitbits, like all other human activity monitoring sensors, are known to contain systematic and other types of errors, and these types of sensors are not designed specifically for canine use (Consolvo et al., 2006, 2008). However, our study showed that common users are not as concerned about the step-level accuracy but rather repurposed it for other means, essentially using estimates as baseline assessments to gauge their pet's activity levels. In this context, affordable, highly assessable, off-the-shelf sensors, such as fitbits, are applicable to a wide-range of user groups. Future iterations of *CompanionViz* plan to support a wider-range of sensors to meet the needs of both common and expert user groups.

A clearer understanding of the future development of HPCI applications will benefit from further-reaching surveys designed to assess the varying desires of the dog-owning population. While one group may want a competitive visualization, others may prefer a more clinical design. After deciding on a, or multiple, direction(s), it would be most effective to take a longer-term ethnographic approach to understanding the target population. Field studies lasting the duration of a week and a half are suspect to Hawthorne and novelty effects, and cannot inform all of the potential needs or motivations of pet owners in remaining engaged in HPCI. Seasonality, for example, can affect activity levels for humans and dogs alike, thus potentially impacting the day-to-day and continued use of HPCI applications. More importantly, the limited study duration restricts our ability to provide insight on the long-term impacts on pet–owner health and relationships. Lengthier studies would provide opportunities for designing HPCI applications better suited for very specific needs, and measuring the effects of the technology on pets more directly. For example, if the design of an HPCI application aimed to address the needs of fitness-competitive pet owners, pet owners may want a gamified experience that allows for the overlay and comparison of their activity levels with their pets. The design approach, however, would be much different if the HPCI application targeted pet health awareness. In this scenario, performing case studies, diaries, and interviews with veterinarians, as well as average/elderly pet owners may be relevant. Yet, it remains unclear whether such applications could effectively detect early signs of pet illness, prompting correspondence between pet owners and their veterinarians to mitigate health concerns. In a worse case scenario, these technologies could harm human–pet relationships, confuse pet owners' understandings of their companions, and cause unforeseen human–human conflicts among pet owners, citizens, and veterinary practitioners (Lawson et al., 2015). In any case, technology design and implementation will benefit most from interdisciplinary collaboration among the ACI, HCI, and animal behavioral science communities. As the QS movement expands into the realm of the "quantified everything", it is more important now than ever that the design of these technologies is grounded in science that aims to transform the quantified into the qualified, better understood, healthier, happier self and other.

6. Conclusion

In summary, HPCI is an emerging subarea in the ACI discipline that when integrated with QS and QO concepts has the potential to enrich the interactions and communications with our loved ones (beyond self, beyond pets, beyond others). The potential sociality that is engendered beyond strictly HPCI from personal activity traces warrants emphasis. After all, QO is about the possibilities of using quantified data of others in our daily routines, and making our interactions more meaningful with those who matter to us (e.g., children, elders, pets, and other loved ones). HPCI is simply one instantiation of such potential that focuses specifically on pets.

Pet owner–canine companionships have much to gain from HPCI. While trends in pet ownership increase, so, too, do pet obesity rates. QS and QO activities, combined with casual personal visualizations, afford opportunities for advancing the health of pet owners and their beloved dogs, as well as the understanding and communication between them. We introduced *CompanionViz* to not just illustrate these opportunities, but to initiate exploration into the needs of various pet owner–dog relationships.

Acknowledgments

We are grateful to the pet owner and dog participants for their time and invaluable feedback on our study. We also thank the Penn State Department of Information Systems Technology for providing fitbit devices for use in the study. This work was supported by the National Science Foundation under IGERT Award #DGE-1144860, Big Data Social Science, and Pennsylvania State University.

References

American Pet Products Association. ⟨http://www.americanpetproducts.org/press_industrytrends.asp⟩.
American Kennel Club (AKC), 2015. How to Calculate Dog Years to Human Years. ⟨http://www.akc.org/learn/family-dog/how-to-calculate-dog-years-to-human-years/⟩.
Association for Pet Obesity Prevention. ⟨http://www.petobesityprevention.org⟩.
Baumer, E.P.S., 2015. Usees. In: Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems. International Conference on Human Computer Interaction with Mobile Devices and Services. ACM. New York, NY, USA, pp. 231–240.
Bertin, J., 1983. Semiology of Graphics: Diagrams Networks Maps. Univ. of Wisconsin Press, Madison, WI, USA.
Bostock, M., Ogievetsky, V., Heer, J., 2011. D^3 data-driven documents. In: Proceedings of IEEE Transactions on Visualization and Computer Graphics, vol. 12, pp. 2301–2309.
Cheok, A.D., Tan, R.T.K.C., Peiris, R.L., Fernando, O.N.N., Soon, J.T.K., Wijesena, I.J.P., Sen, J.Y.P., 2011. Metazoa ludens: mixed reality interactions and play for small pets and humans. In: Proceedings of IEEE Transactions on Systems, Man and Cybernetics, Part A: Systems and Humans, vol. 41, pp. 876–891.
Colorbrewer: Color Advice for Cartography. ⟨http://colorbrewer2.org/⟩.
Consolvo, S., McDonald, D.W., Toscos, T., Chen, M.Y., Froehlich, J., Harrison, B., Klasnja, P., et al., 2008. Activity sensing in the wild: a field trial of ubifit garden. In: Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems. ACM. New York, NY, USA, pp. 1797–1806.
Consolvo, S., Everitt, K., Smith, I., Landay, J.A., 2006. Design requirements for technologies that encourage physical activity. In: Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems. ACM. New York, NY, USA, pp. 457–466.
Dogbook: Facebook for Dogs. ⟨https://apps.facebook.com/dogbook/⟩.
Fitbark|Your Dog's Activity Monitor. ⟨https://www.fitbark.com/⟩.
fitbit. ⟨http://www.fitbit.com⟩.
Fox, S., Duggan, M., 2013. Tracking for Health. Pew Research Center's Internet & American Life Project.
Gips, J., Fields, N., Liang, P., Pilpré, A., 2005. Snif: Social Networking in Fur. In: Proceedings of CHI '05 Extended Abstracts on Human Factors in Computing Systems. ACM. New York, NY, USA, pp. 1391–1394.
Golbeck, J., Neustaedter, C., 2012. Pet video chat: monitoring and interacting with dogs over distance. In: Proceedings of CHI '12 Extended Abstracts on Human Factors in Computing Systems. ACM. New York, NY, USA, pp. 211–220.
Harrower, M., Brewer, C.A., 2003. Colorbrewer.org: an online tool for selecting colour schemes for maps. Cartogr. J. 40, 27–37.
Humane Society of the United States. ⟨http://www.humanesociety.org/issues/pet_overpopulation/facts/pet_ownership_statistics.html⟩.
Jackson, M.M., Zeagler, C., Valentin, G., Martin, A., Martin, V., Delawalla, A., Blount, W., Eiring, S., Hollis, R., Kshirsagar, Y., Starner, T., 2013. Facilitating interactions for dogs with occupations: wearable dog-activated interfaces. In: Proceedings of the 2013 International Symposium on Wearable Computers. ACM. New York, NY, USA, pp. 81–88.
Kahn, P.H., Severson, R.L., Ruckert, J.H., 2009. The human relation with nature and technological nature. Curr. Dir. Psychol. Sci. 18 (1), 37–42.
Ladha, C., Hammerla, N., Hughes, E., Olivier, P., Plötz, T., 2013. Dog's life: wearable activity recognition for dogs. In: Proceedings of the 2013 ACM International Joint Conference on Pervasive and Ubiquitous Computing. ACM. New York, NY, USA, pp. 415–418.
Lawson, S., Kirman, B., Linehan, C., Feltwell, T., Hopkins, L., 2015. Problematising upstream technology through speculative design: the case of quantified cats and dogs. In: Proceedings of the 2015 ACM Conference on Human Factors in Computer Systems (CHI). ACM. New York, NY, USA, pp. 2663–2672.
Lee, P., Cheok, D., James, S., Debra, L., Jie, W., Farbiz, F., 2006. A mobile pet wearable computer and mixed reality system for human-poultry interaction through the internet. Personal Ubiquitous Computing 10, 301–317.
Lemasson, G., Pesty, S., Duhaut, D., 2013. Increasing communication between a man and a dog. In: Proceedings of the IEEE 4th International Conference on Cognitive Infocommunications. IEEE Press. Budapest, Hungary, pp. 145–148.
Mancini, C., 2011. Animal-Computer Interaction: a manifesto. Interactions 18, 69–73.
Mancini, C., Van Der Linden, J., Bryan, J., Stuart, A., 2012. Exploring interspecies sensemaking: dog tracking semiotics and multispecies ethnography. In: Proceedings of the 2012 ACM Conference on Ubiquitous Computing. ACM. New York, NY, USA, pp. 143–152.
Mankoff, D., Dey, A., Mankoff, J., Mankoff, K., 2005. Supporting interspecies social awareness: using peripheral displays for distributed pack awareness. In: Proceedings of the 18th Annual ACM Symposium on User Interface Software and Technology. ACM. New York, NY, USA, pp. 253–258.
Neustaedter, C., Golbeck, J., 2013. Exploring pet video chat: the remote awareness and interaction needs of families with dogs and cats. In: Proceedings of the 2013 Conference on Computer Supported Cooperative Work. ACM. New York, NY, USA, pp. 1549–1554.
Noz, F., An, J., 2011. Cat cat revolution: an interspecies gaming experience. In: Proceedings of ACM SIGCHI Conference on Human Factors in Computing Systems. ACM. New York, NY, USA, pp. 2661–2664.
Paasovaara, S., Paldanius, M., Saarinen, P., Häkkilä, J., Väänänen-Vainio-Mattila, K., 2011. The secret life of my dog: design and evaluation of paw tracker concept. In: Proceedings of the 13th International Conference on Human Computer Interaction with Mobile Devices and Services. ACM. New York, NY, USA, pp. 231–240.
Paldanius, M., Kärkkäinen, T., Väänänen-Vainio-Mattila, K., Juhlin, O., Häkkilä, J., 2011. Communication technology for human-dog interaction: exploration of dog owners' experiences and expectations. In: Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems. ACM. New York, NY, USA, pp. 2641–2650.
Pousman, Z., Stasko, J.T., 2007. Casual information visualization: depictions of data in everyday life. In: Proceedings of IEEE Transactions on Visualization and Computer Graphics, vol. 13, pp. 1145–1152.

Resner, B.I., 2001. Rover@ Home: Computer Mediated Remote Interaction between Humans and Dogs (Doctoral dissertation). Massachusetts Institute of Technology, Cambridge, Massachusetts.

Swan, M., 2013. The quantified self: fundamental disruption in big data science and biological discovery. Big Data 1, 85–99.

Whistle: Activity Monitor and GPS Pet Tracker for Dogs. ⟨https://www.whistle.com/⟩.

Wingrave, C.A., Rose, J., Langston, T., Laviola Jr., J.J., 2010. Early explorations of cat: canine amusement and training. In: Proceedings of CHI '10 Extended Abstracts on Human Factors in Computing Systems. ACM. New York, NY, USA, pp. 2661–2670.