Re-Centering Multispecies Practices: A Canine Interface for Cancer Detection Dogs

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ABSTRACT

We report on participatory design research where interaction designers, and canine behavioral specialists, together with their cancer detection dogs, teamed up to better support the dogs' life-saving work. We discuss interspecies communication challenges in cancer detection training, requiring the dogs to use human signaling conventions that perturb their detection work. We describe our effort to develop a technology that could resolve those challenges, and how in the process our design focus gradually shifted from a human-centered to a canine-centered interaction model. The resulting interface, based on *honest signaling,* re-centers cancer detection practices on the dogs themselves, enabling them to better express their potential as cancer detection workers; it also provides a model for re-thinking human-computer interactions.

Author Keywords

Cancer detection with dogs, interspecies communication, honest signaling, canine-centered interfaces, ACI

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

Dogs' olfactory apparatus is vastly more sophisticated than that of humans [13], thus for millennia dogs have been tasked with a wide range of scent-based activities (e.g. searching for stranded individuals during rescue operations, sniffing drugs or explosives during policing or military patrols, pinpointing invasive species during conservation efforts). A relatively recent practice consists of training dogs to detect and alert to the odor of human disease. Within this trend, an application pioneered by British charity Medical Detection Dogs (MDD) [16] is cancer detection. The charity trains dogs to recognize the odor of volatile organic compounds from cancer cells (e.g. bladder cancer, prostate cancer) in biological samples (e.g. urine, sweat, breath), and to signal back to their trainers when they identify the odor marker they are trained to recognize.

To communicate with their trainers, the dogs are conditioned to exhibit stereotyped behaviors (e.g. sitting down in front of positive samples). But while signaling conventions aim to disambiguate the dogs' response to a sample for the benefit of the trainers, the conventions' arbitrariness limits the signal's reliability. The dogs need to 'translate' their spontaneous response to an olfactory stimulus into an arbitrary behavior, which is alien to any signaling behavior they have evolved as a species. Secondly, the conventions only afford the dogs the 'utterance' of binary messages (i.e. 'this is a positive sample' or 'this is a negative sample'), with no provisions for expressing nuances in between; however, this may not be sufficient to describe the samples. Indeed, often the dogs' behavior deviates from the signaling conventions they have been trained to use, leaving the trainers with the problem of interpreting the meaning of such deviations.

The research presented here seeks to provide both detection dogs and human trainers with alternative means of communication. We report on the collaboration between The Open University's Animal-Computer Interaction Laboratory and MDD on a multispecies participatory design project. Over the past 24 months, we explored the possibility of developing an interactive technology enabling the dogs to better communicate with their trainers, while enabling the trainers to better understand the dogs. We describe the communication challenges faced by dogs and trainers and the design process that led to prototyping a canine cancer detection interface; we explain how the interaction model for our system gradually moved from being human-centered to being canine-centered, and how the latter is directly informed by the dogs' spontaneous behavior. Preliminary data suggests that our canine-centered interface enables the dogs to express degrees of certainty during the detection process, as opposed to the binary options afforded by conventional signaling protocols.

To our knowledge, this is the first study to address communication issues within the practice of cancer

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detection with dogs, and provides the first computing prototype to support this process. Consistent with the aims of the emerging discipline of Animal-Computer Interaction (ACI) [10], our research re-centers cancer detection training and practice on the dogs themselves, as the most important agents in the process. This promises to increase the dogs' signaling reliability and precision, while enabling trainers to measure the dogs' spontaneous responses; thus this also increases the potential of cancer detection with dogs as a medical application. Beyond ACI and cancer detection, however, we propose that our approach, based on what animal communication scientists term *honest signaling* [14], could provide a useful interaction model for HCI applications; particularly, this could be relevant when an interaction method might need to produce reliable signals and when detecting the subtleties of such signals might be important.

BACKGROUND

Cancer detection by dogs: from anecdote to science

While being relatively common, some forms of cancer (e.g. prostate cancer) are particularly difficult and dangerous to diagnose. For one thing, non-invasive tests can be highly inaccurate (e.g. up to 75% false-positives for the Prostate Specific Antigen blood test used to diagnose prostate cancer [26]). For another thing, while being more accurate, results from available invasive tests are still not conclusive (e.g. up to 33% false negatives for needle biopsy, also used to diagnose prostate cancer [5]); additionally, the test procedures themselves can have serious side effects (e.g. a large needle has to go through rectum, bladder and prostate both ways, thus contaminating the surrounding tissue with bacteria and cancer cells). There is therefore significant interest in finding accurate, non-invasive tests for the early diagnosis of cancers that are relatively common but still difficult to diagnose. In this respect, clinical trials [17] are increasingly highlighting the potential of cancer detection by dogs.

Following anecdotes of dogs reportedly detecting cancer in their human companions [20], in the early '00s researchers begun to conduct clinical trials of olfactory detection of human cancer by dogs. In the first study [31], six dogs were trained to discriminate between urine from bladder cancer patients and urine from diseased and healthy controls; they were then asked to select one bladder cancer urine sample from six controls during a double-blind trial in which neither dogs or trainers knew the content of the samples; as a group the dogs had a success rate of 41%, with 54% for the most successful dog, against the 14% expected by chance. In more recent bladder cancer discrimination trials [30], thanks to improvements in experimental design, the dogs reached a performance of 73%. The latest (still unpublished) findings from ongoing work by MDD indicate that their dogs now achieve higher levels of accuracy in their detection, with one particular dog achieving a reliability of over 90% (on bladder and prostate cancer). This is consistent with findings from other research reporting sensitivities of over 90% for prostate [4], colorectal [1,27] and lung cancer [6]. While these statistics are encouraging, enhancements in cancer detection practices would help further increase the accuracy of such non-invasive cancer screening procedures.

Although the chemical composition of the odor detected by the dogs is not known, the findings of these studies indicate the presence of volatile compounds responsible for a distinct odor signature, originating in cancer tissue, and excreted or secreted through bodily fluids. The work of the dogs has thus informed research into the development of 'electronic noses' for the early diagnose of cancer (e.g. using a gas sensor array coupled with a pattern recognition algorithm [28]). At the moment, the success rate of these devices (65%) is still significantly lower than the success rate of the dogs, but a better understanding of how the dogs work and what they find could significantly contribute to the improvement of such sensors. Enabling cancer detection dogs to work more reliably and expressively could also contribute to the development of such electronic noses by allowing researchers to consider a range of responses, possibly indicating differences in odor signatures.

How cancer detection by dogs works

Training detection dogs in general requires sensitizing them to salient odors while, at the same time, providing them with means of signaling the presence of such odors. In both respects, the training process pivots around the effective communication between human trainer and detection dog. To teach the dogs to recognize salient odors, trainers use what is known as clicker training [21], where the distinct sound of a clicker, previously associated with a reward (e.g. food, play, depending on each dog's preference), is used to communicate to the dogs when they are exhibiting a desired behavior: initially this may be briefly looking at the source of the odor, but gradually the stakes are raised and the dogs only receive a click (plus reward) if they focus on the source of the odor for longer (see [24]). It is critical that the trainers click as soon as the dogs exhibit the desired behavior, to help them establish a connection between what they do and what the trainers want of them. The spontaneous response dogs have towards an odor they have learnt to be of interest is called *stimulus response*; this may consist of subtle behavioral changes (e.g. bodily postures and gestures). However, trainers also need the dogs to explicitly communicate back to them what they have found in a sample; thus clicker training is also used to shape the dogs' signaling behavior. This entails training the dogs to exhibit a stereotypical behavior in response to what they find (e.g. sitting down in front of a positive sample, moving away from a negative one). The behavior that the dogs learn to exhibit in order to signal back to the trainer is called *operant response*.

The operant response is purposely convention-based in order to help the trainers disambiguate the dogs' intention to signal. However, the arbitrariness of the operant response also means that the dogs have to learn to perform a behavior which is not related to their spontaneous response to the stimulus. Since the dogs have to work at very low sample concentration thresholds (part-per-trillion) and screen several samples in rapid succession, the divergence between stimulus and operant responses can lower the reliability of the dogs' signaling. Such divergence imposes on them a cognitive and physical overhead, thus introducing delays in the timing of their operant signaling; in turn this delays the clicking timing of the trainers, who are waiting for the operant signal. Such delay is confusing for the dogs, who may have correctly identified a sample but, for various reasons, may hesitate to produce the operant signal. Thus, capitalizing more on the dogs' spontaneous responses to a relevant odor would enable the dogs to communicate more directly, eliminating a perturbing element from what is a subtle process. Moreover, existing signaling conventions only allow the dogs to communicate whether an odor is present or not; there is currently no signaling convention enabling the dogs to express degrees of confidence about or interest in a detected odor, or different levels of odor strength. Therefore, when deviations in the dogs' operant response occur (e.g. hesitating when sitting down, moving away from a sample but coming back to it), trainers have to try and infer whether such deviations are meaningful and what they might mean. Recently Concha *et al.* [3] analyzed footage of scent detection training sessions and identified consistent variations in sniffing behavior. Thus, enabling cancer detection dogs to express such nuances in their stimulus response, while enabling their trainers to interpret those nuances, would increase the accuracy of the detection process.

Related work: communication technology for animals

Scientists have sought to provide other animals with means for communicating with humans for some time. Examples in recent history include Apple's Koko's Mac II, a touch-screen computer designed in the '80s to allow the famous resident of The Gorilla Foundation to communicate with researchers using lexigrams; nowadays, bonobos at the Bonobo Hope Great Ape Trust Sanctuary use a modern version of the same technology [25]. In the '90s, within studies of acoustic mimicry at Washington's National Aquarium, underwater keyboards were designed to allow dolphins to select different keys to play a range of sounds and obtain corresponding objects [22]. In these applications, the animals involved had to use arbitrary sign systems (i.e. symbols), devised by members of another species (i.e. humans) with no grounding in the animals' evolved communication systems.

In more recent ACI work, researchers developed interfaces enabling working dogs to carry out communication tasks within their professional activities. For example, Jackson et *al.* [8] developed a wearable system enabling working dogs to remotely communicate with their handler (e.g. during search and rescue); the dog's vest was equipped with sensors that the dog could learn to activate (e.g. by biting a 'pulley') to communicate different meanings (e.g. having found a stranded person). Similarly, Robinson *et al.* [24] designed a canine alarm to enable diabetes alert dogs to remotely call for help on behalf of their human companions should these become temporarily incapacitated; the dogs could trigger the alarm by pulling a 'sausage-like' input device. Both these systems were designed in accord with canine ergonomic requirements (e.g. dogs tend to manipulate things with their mouths); however, as with previous applications, these too use signaling methods in which the relation between the signal (pulling or touching a device) and their effect (calling for human attention) is arbitrary (albeit contextually derived from existing practices). For dogs operating 'in the wild', in life-or-death situations (e.g. search and rescue, diabetes alert), the use of signaling conventions (that they would otherwise not use) to signal discrete events reduces the chances of ambiguous signaling or misinterpretation [24]. However, as discussed, for a dog operating in a focused laboratory setting, the use of such arbitrary signals is not necessarily needed or desirable. Our research aimed to afford the dogs ways of communicating with their trainers by means more grounded in their detection work and more nuanced. In pursuing this aim, our 'design journey' has seen our focus shift from another conventional (if more nuanced), thus human-centered, signaling model to a canine-centered signaling model in which the dogs themselves define the signaling parameters.

THE PROJECT

Research set-up

Our research journey has been one of longitudinal, multidisciplinary and multispecies participatory design. The team comprises one interaction design researcher, one electronic engineer and two highly specialized dog trainers: MDD's CEO (an animal behavioral scientist - below referred to as CEO) and head of cancer training (an expert dog trainer and formerly a trainer of police dogs - below referred to as HCT). Five cancer detection dogs from MDD have participated in the work at different times. A third specialist trainer and two dogs were observed during an inspection visit to the affiliated charity MDD Italy.

We first discussed signaling issues in cancer detection in 2011, but our collaboration officially started in January 2013 and is still ongoing. During this time, we have regularly met to discuss trainers and dogs' requirements, and their mutual communication challenges; and to explore various design concepts and test different prototype versions. The interaction design researcher, regularly, and the electronic engineer, occasionally, have observed and participated in training sessions. The researcher has also served as a face-to-face interpreter and correspondence translator between MDD and MDD Italy. Below we describe cancer detection training practices and present the team's shared understanding of existing communication challenges between dogs and trainers. This defines our design space, based on the participant observations and records made by the researcher, and on the experience and records kept by the head of training and the CEO. Records include notes, photographs, videos and sensor recordings.

Figure 1. Carousel. The samples are suspended between metal screens preventing volatiles from traveling between positions.

Figure 2. Stand line-up. The samples are suspended on individual stands.

Cancer detection training and practice

The settings

MDD's premises are located in open countryside outside of Milton Keynes, UK. The place is very lively, always brimming with trainers, volunteers, and dogs of various breeds (mainly Labradors and Spaniels) and ages (from several weeks to several years); the dogs move around freely among their human colleagues, lounge on chairs and couches, rest in dedicated areas, or work their shifts. Functionally furnished, the training center boasts bespoke, state-of-the-art facilities for cancer detection by dogs. Around 6-12 dogs are normally in training at any one time, with more dogs being trained as of late. The living and working arrangements for the dogs prioritize their welfare: "*The welfare of our dogs is absolutely paramount for us, which is why we have a no-kennel policy*." (CEO). Instead of being confined in kennels, all the dogs live with highly selected foster families, who accompany them to the center in the morning and take them home at the end of their working day. Again, in the interest of the dogs' welfare and to maintain their performance levels, training schedules are designed to afford the dogs plenty of downtime: "[about ten minutes into a session] *We'll do another round* [duration for the dog about 1 minute] *and then we'll stop; he is getting tired.*" (HCT). Similarly, the dogs are ever only trained by positive reward and a lot of attention is paid to ensure that they always have what they need (e.g. water, quiet resting places, scampering outside).

The training laboratory is a clean, ample room, featuring only the training equipment: a counter and fridge to preserve sample stocks; a desk, chair and laptop computer for the trainer to input records of sessions into a dedicated database; a screen behind which the trainer can hide while the dogs investigate the samples; a small fence to contain the dogs while samples are swapped around during sessions; and the apparatus used to present the samples to the dogs. The dogs work in turns, one at a time, with usually one, but occasionally two, trainers at once. Samples are presented to the dogs on surgical stainless steel stands, which can be variously arranged as a carousel (Fig. 1) or as a line (Fig. 2). The simplest configuration consists of a single stand at the top of which an arm is secured at an angle; the arm ends with a perforated plate, behind which a small plastic pot containing the sample is clamped; the dogs sniff the sample through the hole in the plate; the combined angles of the arm and plate relative to the vertical stand are such that the plate is always parallel to the surface of the dogs' nose: "*This offers the dogs the best angle to sniff at the best of their abilities.*" (HCT); the height of the plate is adjustable to accommodate the size of different dogs.

The training process

Training protocols may vary slightly (e.g. the arrangement of the samples might differ depending on what aspect of the training is being focused on), but the structure of training sessions is always the same. Helped by an assistant (and wearing surgery gloves to avoid contaminating the samples), the trainer places the samples on the steel arms and lines them up on the counter top ready for use. For each session, the type of sample is always the same (e.g. urine); one sample is typically from a cancer patient (e.g. prostate), while the controls might be from healthy individuals or from patients presenting with conditions usually associated with that type of cancer (e.g. inflammation): "*The dogs need to learn to signal to the odor of the cancer but disregard any other confounding odors*." (CEO). Depending on the protocol, when multiple stands are used, one or two stands (e.g. first or last) might contain no sample; line-ups that are all negative are also set-up and used by the trainers. Each training session is composed of multiple *runs*; a run is one pass of the dog along all the stands in a line-up or one round on the carousel. After each run, the arms are usually disinfected and swapped around the available stands: "*The dogs can easily memorize the samples' positions*." (HCT). However, sometimes the trainers only pretend to swap the samples as another way of controlling for the dogs' responses: *"...so they do not necessarily expect to find the target* [positive] *in a different position.*" (HCT).

Once a session is set up and the trainers are ready, they retrieve the dog who is on duty from behind the fence or from outside the room. Before the session starts, the dog receives a pre-session reward (e.g. a few biscuits, brief play of ball), then the two get into a fixed position with respect to the stands' line-up, which is strategically located to provide the dog with the best possible entry point towards the samples: "*This ensures that the dog does not stop at or skip the first stand.*" (HCT). Once the two are in position, the trainer locks into eye contact with the dog, who looks up to the trainer; at the trainer's command "*Seek, seek…*", the dog moves away from the trainer and approaches the closest stand, from which to begin the screening. "*Ideally the dog moves along the stands* [sniffing each sample] *and only stops in front of the target* [positive sample] *and immediately signals by performing the operant response in a clean, confident fashion.*" (CEO). If the dog correctly identifies a positive sample or discounts a line-up of negative samples, the trainer clicks while vocally praising the dog - "*Good boy/girl!*" - and delivers the reward. However, the dogs do not always exhibit a clean, confident operant response; that is when the signaling conventions that inform the operant response break down and trainers have to start looking for more subtle other clues instead.

Limitations of operant signaling

When communication breaks down

The following examples illustrate typical breakdowns in the communication flow between dog and trainer, due to discrepancies between stimulus and operant responses, and to the difficulty for the trainer to perceive stimulus responses in time to provide useful feedback for the dog.

Head flick. This 'near-missed alert' figure, also called *check pace*, occurs when the dog approaches a positive sample, sniffs it and moves away, only to flick his head back to double check the sample before deciding to signal (e.g. sit). "*The dog has an appropriate stimulus response* [his attraction towards the sample, which brings him back] *but the operant response* [requiring him to walk away or sit] *produces an automatic behavior which diverges from the behavior that would naturally be triggered by the stimulus*; *so the dog moves away too quickly only to realize later that he needs to go back.*" (CEO). For the trainer it is difficult to spot with a naked eye that the dog has already responded to the stimulus on first approach, so "*…the trainer is not fast enough to give feedback before the conditioned response causes the dog to move on*." (CEO). In other words, it is as though the dog was more focused on performing a learnt behavior rather than on the stimulus coming from the sample, of which he becomes conscious with delay. The trainer cannot be sure that the dog has recognized the sample at the first check, so he is unable to provide reinforcement before the dog moves; as he cannot correctly focus the dog's attention in a timely fashion, the behavior is likely to recur.

Position false alert. This is a 'displaced alert' or 'delayed alert' figure which occurs frequently particularly during early training. "*The dog approaches and sniffs a positive sample but, instead of signaling in front of it, moves to the next stand and signals in front of that one instead.*" (CEO). If the dog works on a line, he does not have another chance of finding himself in front of the same sample again, so he signals in front of the best alternative, i.e. the following stand. If the dog works on a carousel, since the samples are arranged in a circle, he can hold off signaling until she is again in the correct position for doing so. "*In neither scenarios is the trainer able to click; even if he thinks he knows what's going on, the feedback would come too late with respect to the stimulus response* [which the dog would have had when first sniffing the sample but which the trainer would have not been able to detect]." (CEO). Unlike in the figure described above, in both these cases the operant response comes too late with respect to the stimulus response, once the dog has already moved on, "*…it is as though he had forgotten that he needed to signal.*" (CEO). Unable to provide feedback to the stimulus response, the trainer misses the opportunity to reinforce both stimulus and operant responses.

Look back. This is an 'uncertainty' figure, which may occur with dogs who are unsure or have a less confident personality; "*It often happens at the beginning of their training*." (HCT). The dog walks along the line and stops in front of the positive sample, but hesitates to perform the signaling behavior, which would render his interpretation of what's in the sample explicit; instead, he turns around to look at the trainer. "*If a trainer is less experienced, in earlier sessions he may have inadvertently given the sample away through his own body language or facial expressions* [which dogs can read]*…the trainer may also have clicked too quickly* [thus preempting the dog's response]." (HCT). In such circumstances, the dog may look back at the trainer for confirmation before deciding to signal. However, "*It is possible that the dog looks back at the trainer when neither of his signaling options* ['yes' and 'no'] *reflect what he finds in the sample, and therefore he is unsure what to do…'What am I supposed to do here? What do you want me to do?'*" (CEO).

Limiting the impact of operant signaling

The adoption of mechanisms, such as operant responses, helps bridge the gap between the subtlety of the dogs' responses to a stimulus and humans' difficulty to interpret such responses in real time due to their perceptual limitations. Operant training also imparts a measure of homogeneity to the dogs' working behavior thus making responses which come from very different individuals more comparable. However, in an effort to limit operant training's impact, MDD personalizes it as much as possible: "*We look at what a dog does spontaneously during their daily activities* [while not working] *and inform their operant response accordingly.*" (CEO). Thus, rather than being suppressed, the dogs' individual diversity in experience level, personality and physical constitution are reflected in their detecting styles, especially in the way they interact with the stand while sniffing a sample. For example, one of our canine participants, a light-built Coker Spaniel, touches the steel plate very gently; while another, a large Labrador, presses and licks the plate so vigorously that his nose pokes through to the other side of the hole, causing the stand to shift backwards. "*Not to risk contamination, the dogs used to be trained to not touch the plate, but not anymore*." (CEO). Being allowed to freely interact with the plate gives the dogs the best possible access to the stimulus they have been trained to recognize and are keen to detect.

Notwithstanding these allowances, there remains a need for standardization in the signaling process enabling the trainers to interpret the dogs' responses. When members of the research team first met in 2011, the only available solution was to teach the dogs to use a human convention, with the consequences we have described. The following account summarizes the main stages in the development of a different solution, and how our design concept, and related interaction model, evolved from a human-centered into canine-centered design, as we became aware of requirements we had not previously considered. The outcome so far, and the base for future developments, is an interactive technology that enables the dogs to inform and use their own signaling language, while the burden of standardizing and interpreting goes to a machine.

TOWARDS A CANINE-CENTRED INTERFACE

A design journey

When the researcher first visited MDD to find out whether the ACI Lab could support the charity's work, the answer was: "*Sometimes we have difficulty interpreting exactly what the dogs find…if we could develop something that allowed them to tell us, that would be really helpful.*" (CEO). At the time, the potential solution seemed obvious: others had developed simple 'keyboards' enabling dogs to communicate with humans and ask for things such as water, food or going out, by pressing a small range of large buttons with their paw; surely we could similarly develop some kind of 'traffic light' system allowing cancer detection dogs to 'classify' samples as positive, negative or in-between; after all, it had been shown that dogs were able to use such a device. However, as it soon became apparent, there were a number of problems with this concept. Firstly, dogs tend to interact with things with their mouth or nose rather than their paws (see [24]). Secondly, training the dogs to use a more-than-binary signaling system would be more difficult. Thirdly, the dogs would still have to use a human convention, only a more complex one. Fourthly, 'classifying' continuous quantities (the possible concentration of cancer cells) is not the same as requesting predefined objects. While the dogs might now be able to express more nuances, their overheads would increase (they would have to decide between more than two options) while the reliability of their response would decrease.

We then considered suspending next to the sample a keypad featuring soft buttons that the dogs could operate with their nose; we also considered providing several options between the positive and negative ones to better account for the continuity of cancer cells' concentration levels in the samples; we envisioned that the dogs would only be trained to use the negative and positive options, but could then be allowed to spontaneously choose any options in between (without the difficulty of training on multiple options). However, while more nuanced and ergonomic, these new concepts were also essentially human-centered, for example they presupposed that dogs would order entities and represent their ordering in the same way as humans do. We wanted to empower the dogs, but were still trying to do so from a human perspective.

Our perspective started to change when we realized that we needed to re-start our thinking from the dogs themselves, measuring their spontaneous behavior and 'translating' it into some kind of representation. We conceived a new binary signaling apparatus: to clear a sample as negative, the dogs would simply come away from it, as they would be used to do; to flag a sample as positive or possibly positive, the dogs would press with their nose on a pad placed next to the sample. A sensor behind the pad would register the pressure placed by the dogs' nose as a measure of their response and an indicator of their confidence in the positive nature of a sample. This approach was a lot friendlier to the dogs, but still required them to come away from the sample in order to interact with an unrelated object (the pad), all of which still implied an operant component.

The final shift in our design thinking came when we realized that, since sniffing was the core activity of cancer detection, it was precisely the sniffing behavior that needed to be measured. In other words, it was not the pattern of an operant response that we needed to characterize, but that of a stimulus response. As MDD's cancer detection dogs are allowed to freely interact with the metal plate behind which the sample is secured, we could turn the plate itself into a sensor and measure the pressure that the dogs exerted on it while investigating the samples. Such a solution could be seamlessly integrated within the charity's existing practices, and in principle the approach would require no operant training, relying entirely on the dogs' stimulus response. We had potentially identified a canine-centered interaction model for addressing the problem.

A canine-centered prototype

While enhancing it with sensor and computing capabilities, our canine-centered prototype minimally modified the cancer detection set-up already in use (Fig. 3). We constructed a steel frame that could be clamped to the detection stand and whose height could be adjusted vertically to suit individual dogs as required. The arm which was connected to the plate holding the sample was pivoted at the top of the frame; at the bottom, another arm was fixed at an angle securing a pressure sensor on which the first arm rested against the spring within the sensor (LM10/3M29). The sensor was a conductive polymer potentiometer that changed resistance in proportion to the movement of the shaft; it was connected to a Picolog 1216 sixteen-channel data logger, so using Pico's proprietary software the movement and its duration could be graphically represented. When the dogs sniffed the samples, touching the metal plate with their nose and/or tongue, the pressure they put on the plate while investigating the sample could thus be recorded and represented. Our assumption was that the degree and duration of this pressure, together with the resulting patterns, might be considered a measure of the dogs' interest in the sample being tested. We hypothesized a correlation between the characteristics of the graphs produced by the dogs' detection activity and the stimulus coming from the sample.

Figure 3. Cancer detection rig: the sensor is visible (in red) behind the base of the pivoted arm, above the sample.

As mentioned above, Concha *et al.* [3] recently analyzed video data of dogs' sniffing from controlled scent detection tasks; the authors found that sniffing behavior differs depending on the content of the sample being sniffed; the difference predicts whether an operant response is a true negative (the signal is negative and the sample is indeed negative), a false negative (the signal is negative but the sample is in fact positive), a true positive (the signal is positive and the sample is indeed positive), or a false positive (the signal is positive but the sample is in fact negative). In particular, the authors find that in the case of true negatives the sniffing duration is significantly shorter than in the case of false negatives, true positives and false positives; they also find that in the case of true negatives the dogs only sniffed once, while in all other cases they commonly sniffed twice. These findings seemed to confirm the potential of recording and analyzing sniffing behavior to interpret and reinforce the dogs' stimulus response.

But for this potential to be manifest, our prototype needed to undergo iterations. For example, initially the weight of the steel arm and plate on the sensor was causing measuring inconsistencies (e.g. by preventing the sensor from going back to a neutral position between swaps); so we tried different kinds of counter-weight and what finally worked best was to suitably lengthen the arm beyond the pivot. We also had to find a way of stabilizing the stand to prevent it from being pushed back by the dog and thus dispersing the pressure we wanted to record; for that we used plastic Velcro on a heavy MDF base. Moreover, the Picolog software we started with did not offer a sufficiently detailed rendering; so we moved to Picoscope, a virtual oscilloscope program providing a higher resolution representation. Initially we could hardly distinguish between positive and negative patterns; but as other interferences started to disappear, the 'voice' of the dogs started to emerge, pointing to finer-grained differences in sniffing behavior than found so far. This suggested that our approach could capture the subtleties and meaning of such behavior with unprecedented accuracy.

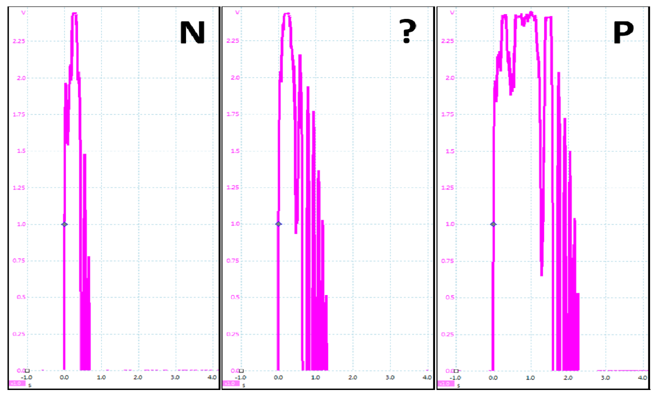

Figure 4. Pressure data produced by one dog while sniffing a negative (N), positive (P) and possibly intermediate (?) sample.

Preliminary test results

While, as mentioned, different dogs have different detecting styles due to individual physical and psychological characteristics, and training experience, early testing showed consistent patterns for individual dogs. The testing setup entailed running training sessions to a standard protocol, with the trainers offering random sequences of samples for the dogs to assess one at a time. The researcher recorded the dogs' input and examined the resulting visualizations, comparing different samples within sessions and the same samples between sessions. Figure 4 exemplifies the graphs produced by one of the dogs (the large, energetic Labrador) whilst investigating three different samples. Firstly, the length of time the dog spent pressing the plate of the negative sample (left) is considerably shorter compared to that spent pressing the plate of the positive sample (right); similarly, the amount of pressure he placed on the plate of the negative sample is considerably smaller than that placed on the plate of the positive sample. This suggests that the dog put more energy and invested more interest in investigating the positive sample, while quickly dismissing the negative sample. The middle graph appears to indicate an interest which is higher than that shown in the negative sample, but lower than that shown in the positive sample. Although this particular sample had been classed as negative, the dog repeatedly produced a comparatively similar middle pattern across different runs. It is possible that the sample had become contaminated (something which may occasionally happen); but it could also be that not all negative or positive samples are equally so.

These findings are consistent with those of Concha *et al.* [3], with the advantage that continuously recorded pressure data enables us to capture more detail about the dogs' interaction with the samples. In particular, the composition of the resulting graphs appears to be somewhat modular, where different 'modules' are present (almost identical or partly altered) or absent depending on whether the sample is negative, positive, or 'in-between' . The characteristics of these modules suggest how the dog's stimulus response might express itself. The first 'component' of the graph is an *entry* feature, which corresponds to the first high pick, marking the dog's first decisive contact with the plate. In the positive sample this first feature is followed by a *main* feature consisting of a wider curve and (what would be) a higher pick. This is in turn followed by a smaller *secondary* feature consisting of a narrower curve over a lower pick. Finally, there is a succession of much smaller, decreasing picks making up an *exit* feature. The main and secondary features appear to mark a more in-depth investigation of the sample, while the exit feature corresponds to the bounces of the arm on the sensor once the dog has left the stand, and it appears to indicate the amount of energy the dog put into investigating the sample. The graph of the negative sample appears to only show the entry feature and a minimal exit feature, suggesting that the dog only quickly checked the sample before dismissing it. But the graph of the middle sample, shows another, albeit small, feature prior to the exit feature, which suggests that he double-checked before dismissing. In different contextual conditions (e.g. different dogs, locations, days) the patterns of graphs produced by the same samples appear to vary, but they appear to do so in a consistent fashion. These variations could thus be computationally neutralized.

DISCUSSION

Re-centering practices: honest signaling interfaces

The pressure data produced by the dogs when investigating different samples highlights the complexity and nuances of their responses to salient stimuli, and shows why the signaling conventions used in operant training may cause problems for the dogs. To make up for humans' perceptual shortcomings and meet their interpretational needs, the dogs are required to express themselves obviously and explicitly. Clicker training is how humans close the communication gap between them and the dogs, providing the latter with means to express themselves obviously and explicitly. However, as a relatively crude medium, the clicker only allows the trainers to teach the dogs signals that are too simple to reflect the nuances of the reality they might otherwise be able to detect and convey. Additionally, because the signals taught in operant conditioning are purely conventional, their relation to their meaning is entirely arbitrary. Even when signaling stereotypes are based on the dogs' daily spontaneous behaviors, they still need to be taken out of their original context and their meaning re-established by convention within cancer detection practice. Although the dogs can obviously learn the re-contextualized meaning of those behaviors (now turned into cancer detection signals), what they learn remains - so to speak - a 'foreign' language, ungrounded in their evolved modalities of expression and communication.

In his semiotics theory, Peirce [19] distinguishes *symbols*, *icons* and *indexes*, based on the relation that each type of sign has to its meaning: symbols are the most abstract of all, being related to their referent (meaning) entirely by convention (e.g. mathematical symbols); icons are less abstract, being to some extent isomorphic to their referent (e.g. portrait); indices are the most grounded in their production context, being produced by or concomitantly with the referent (e.g. footprint). More specifically, in their dissertation on animal signals, Maynard Smith and Harper [14] define indexes as "*signals whose intensity is casually related to the quality being signaled, and which cannot be faked*", also referred to by Enquist [7] as "*performance-based signals*". Animals, including humans, communicate using a range of signals, many of which can (at least in principle) be used to deceive or simply misused. However, indexes are difficult to fake or suppress, thus they constitute more reliable indicators of that which they signify and are considered to be *honest signals*. Lie detectors are typical examples of how honest signals (e.g. subtle bodily and facial motions) are used to verify the reliability of other, more arbitrary signals (i.e. spoken language).

While a dog's operant response is an arbitrary signal the dog has learnt to use, his stimulus response is an honest signal of what he is actually detecting, which is what makes it more reliable; because, unlike arbitrary signals, honest signals cannot be abstracted from their production source. At the same time, such honest signal is the dog's evolved response to a stimulus, so it does not need to be learnt, which avoids having to negotiate a difficult interspecies communication gap. The design of our canine cancer detection system aims to capture and interpret the honest signals which a dog produces during the detection process to make them accessible to their human trainers. Our system shifts the focus from what humans are capable of reading in dogs to what dogs are capable of expressing on their own terms, thus re-centering detection practices on the dogs themselves. As a part of this re-centering process, the burden of reconciling interspecies communication divergences shifts from the dogs (and trainers) to the technology. On this trajectory, we are beginning to develop learning algorithms to automatically calibrate, interpret and reinforce individual dogs' detecting behavior, aiming to eliminate human and operant biases from the training process. Of course, there still are issues of reliability; but these shift from the communication mechanisms at the core of cancer detection to the technology itself, and we expect that they will improve as the technology matures. Elsewhere, Mancini *et al.* [12] highlight the role of *indexical semiosis* in technology-mediated interspecies interactions. Our work with cancer detection dogs shows how a design approach based on honest signaling can indeed re-configure interspecies co-operative interactions to everyone's advantage.

From individual to universal design

ACI is an emerging discipline whose aims include: studying the interaction between animals and technology in naturalistic settings; developing user-centered technology that can support animals in different ways; and informing user-centered approaches to the design of technology intended for animals, enabling them to participate in the design process as stakeholders and contributors [10]. However, the kind of interspecies communication barriers discussed above mean that designing *for* and *with* animals [24] is a non-trivial challenge. A range of approaches borrowed from HCI [23,24], anthropology [12,29] or animal behavioral science [2,9], have so far been explored to overcome existing barriers, at least to an extent. Perhaps the greatest issue remains that of who is in control when we work or design for and with non-human animals. All design processes are embedded in wider social contexts and the reality of, for example, working dogs is that choices are made for them as to what roles they have and how they need to carry out their tasks within those roles. However, we propose that indexical approaches to the design of interspecies communication technologies have the potential to reconfigure human-animal working relations by allowing the animals' individual 'voice' to emerge. Similarly, we propose that favoring the development of indexical systems over symbolic systems has the potential to better contribute to the development of animal-centered approaches and applications in ACI.

However, we suggest that interaction design approaches based on honest signaling could also lead to better interaction models within HCI. Pentland [18] and colleagues explored how honest signals, such as body language, could be computationally captured to represent subtle interactional dynamics to support social awareness. We suggest that honest signaling can play an important role also as a model for designing input mechanisms in specific. For example, a doctor who is using a touch screen interface to review and assess CT scans might use a type of finger swipe to move through the images; the system could infer his level of confidence during diagnosis (a reflection implicit knowledge) by measuring different pressure patterns in the swipe (instead of ignoring weaker swipes or differences between them). Over the decades, computing interactions have greatly evolved from purely symbolic (e.g. text-based) models; and current tangible interfaces tend to be informed by interaction models that are both isomorphic (iconic) and indexical (e.g. the swipe of parting fingers on a screen represents the user's wish to enlarge an image). With more recent advances in sensor technology and computational models, at least for certain applications, there is an opportunity to explore indexical interaction models based on honest signaling which could allow the user to gradually inform his own 'interactional language', instead of learning interactional conventions predefined by others. Mancini [11] argues that looking at HCI from an ACI perspective has the potential to enable designers to improve user-computer interactions by identifying more universal interaction models while better accounting user diversity (regardless of species). We propose that indexical interfaces based on honest signals provide an example of how ACI could contribute to the advancement of HCI towards interaction models and applications that are more individually defined and, by the same token, more universally accessible.

CONCLUSIONS

We have discussed how the conventional signaling behavior that cancer detection dogs have to use to bridge interspecies communication barriers with their trainers interferes with their detection work. We have shown how a simple computing device whose indexical interaction model is based on honest signals can allow the dogs to express the nuances of their responses to biological samples containing cancer cells. We propose that such an approach can re-center detection practices on the dogs themselves better supporting their life-saving work, enabling them participate in the re-definition of social practices of which they are part and at the very center of which they operate. Similarly, our research highlights how ACI research could lead to the exploration of computing interactions that are at the same time more individual and universal.

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