Sensing the Shape of Canine Responses to Cancer

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ABSTRACT

We conducted a short study investigating the pressure patterns produced by cancer detection dogs via a canine-centered interface while searching samples of amyl acetate. We advance previous work by providing further insights into the potential of the approach for supporting and partly automating the practice of cancer detection with dogs.

Author Keywords

Animal-computer interaction, cancer detection with dogs, interaction patterns, olfactory responses

ACM Classification Keywords

H.5.2. User interfaces

INTRODUCTION

Early diagnosis can vastly improve cancer prognosis, but some relatively common cancers are surprisingly difficult to diagnose. While noninvasive diagnostic procedures may lack sufficient specificity [5], invasive procedures may cause significant side effects without necessarily being conclusive [2]. The novel practice of cancer detection with dogs aims to improve early cancer diagnosis via noninvasive means. Following the emergence of anecdotal evidence in the early '00 [6], the science of cancer detection with dogs has been steadily progressing [7] and the British National Health Service (NHS) has recently begun to support related clinical trials, a clear indication that the practice is entering mainstream medicine.

Cancer detection dogs are trained to sniff biological samples and to signal when they recognize the presence of cancer cells. To help trainers interpret their signals, the dogs are taught to signal using stereotypical behaviors (e.g. sitting down in front of a positive sample). However, such a conventional signaling system appears to interfere with the dogs' performance. Thus we developed a canine-centered interface to enable the dogs to express themselves more naturally via their spontaneous sniffing behavior [3].

The research presented here builds on our previous work

and further investigates the potential of the approach, and how canine-computer interactions can better support canine-human communication during detection. We conducted a short controlled study using samples containing varying concentrations of amyl acetate in mineral oil, using pressure sensors to measure the interaction of two different dogs with different samples over a number of repetitions. Our findings indicate that features we previously identified in the pressure patterns produced by the dogs during detection recur under different experimental conditions. The findings also suggest possible correlations between fine-grained variations in the features and chemical concentration levels in the samples. Finally, the findings seem to question whether consistency in the dogs' responses achieved through training might come at the expense of their confidence during detection work. These findings, and the resulting early map of 'pressure patterns', further contribute towards the development of an automatic system for interpreting dogs' responses to biological samples via a canine-centered interface [3].

BACKGROUND

The theory underpinning cancer detection with dogs is that cancer tissue releases organic volatile compounds into body fluids, such as urine, sweat or breath; these compounds have a specific odor signature that the dogs can be trained to recognize [6]. As the chemical they are detecting is currently unknown, cancer detection with dogs offers a unique means of testing for cancer and trials show that the practice has significant potential as a form of secondary screening in early diagnosis. The approach has shown ever-increasing levels of accuracy [7], to an extent that cannot currently be achieved by 'electronic noses' emulating dogs' olfactory system.

Training dogs for cancer detection work requires teaching them to recognize the odor of cancer cells and to clearly communicate when they find them in a sample. However, the signaling conventions (e.g. sitting down in front of a 'positive' sample, i.e. one containing cancer cells) they are taught for human convenience impose limitations on the dogs' detection work [3]: they only enable the dogs to express binary responses, while differences between samples might be more nuanced; they differ from the way dogs express interest in salient odors, thus perturbing canine-human communication during the detection work.

The canine-centered interface we developed to enable the dogs to express themselves in more nuanced and natural ways [3], was a modified version of the stand used to

present samples to the dogs, integrating a pressure sensor and data logger to record the dogs' interaction with each sample. Consistent with others' findings on sniffing behavior during cancer detection [1], we found variations in the pressure patterns produced by the dogs' interaction with the samples: these differed distinctly for positive and negative samples, with intermediate patterns possibly associated with samples whose content was uncertain. We also identified features characterizing different pressure patterns for positive, negative and possibly in-between samples, although these seemed to vary between dogs. We wanted to further investigate the viability of this approach by addressing the following questions:

- How and to what extent do dogs' individual differences influence their interaction patterns with the samples that they investigate?
- Do features previously identified in interaction patterns still present under different conditions, e.g. different setups or sample chemical?
- Are there finer-grained correlations between the concentration of volatiles in the samples and the pressure patterns produced by the dogs?
- Is the dogs' response to the olfactory stimulus expressed by their interaction with the sample more informative than their conventional signaling behavior?

THE STUDY

We run a study in Medical Detection Dogs' training center [3], working with two male dogs - a border collie and a springer spaniel cross (hereafter Dog1 and Dog2).
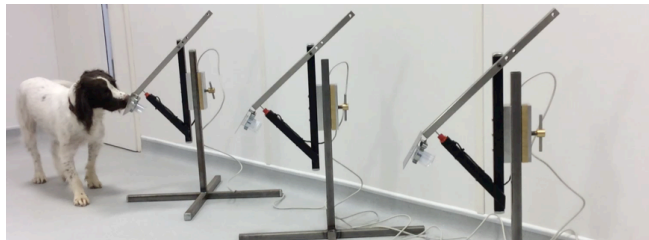
Figure 1. Dog using our canine cancer detection interface

Methodology

We used the canine interface previously developed [3]. This consisted of a frame and, pivoted at the top, an arm connected to a perforated plate through which the dogs could smell the sample; behind the plate, a conductive polymer potentiometer was used to record the pressure exerted by the dogs during their interaction with the sample (Fig 1). We used our own software to visualize the interaction over time in the form of a graph. This time, instead of working with one stand at a time, we used a stand line-up with samples suspended on three stands presenting randomly ordered samples (one positive + two negative, or all negative). Also, instead of using biological samples, which makes it difficult to control the concentration of volatiles in each sample, the dogs were trained to detect amyl acetate; thus we used varying concentrations of amyl acetate (1/1million, 1/20million, 1/50million and 1/1billion

for positives; 0 for negatives) in mineral oil. At each run (a pass along all samples), the dogs approached the line at one end leaving at the other end. We examine 2 sessions (1 per dog) of respectively 9 (Dog1) and 12 (Dog2) runs. The sessions were video-recorded and our qualitative analysis compared the sensor data against the video data.

Findings

Individual differences and consistencies

As we found previously [3], our data indicates that there is a difference in each dog's interaction with the samples, depending on whether these were positive or negative, although the difference is more consistent for Dog2. At the same time, the interaction of each dog with the samples was highly individual, resulting in a distinctive *touchprint*, with more consistent traits for Dog2. Figure 2 shows graphs produced by Dog1 and Dog2 during different runs, with the positive sample (1/20million in both cases) at position 3 (grey) and the control samples at positions 1 (blue) and 2 (orange). Both dogs indicated the target sample.
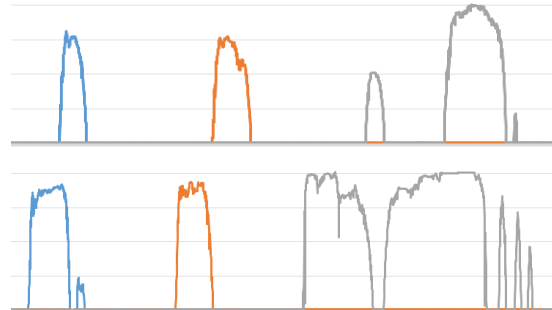
Figure 2. Graphs produced by Dog1 (above) and Dog2 (below). Grey graph corresponds to positive sample.

These individual differences might be due to different physical, breed or personality traits, resulting in individual responses to training. Dog2's spontaneous response to the sample was usually clearly related to the sample's content; however, his trained response appeared to be less consistent (e.g. he might indicate a positive by very briefly lowering his rear or by standing very still close to the sample). In contrast, Dog1's trained response was very consistent (he clearly indicated by sitting firmly and raising his head in a 'nod'); however, his response to the samples was more subtle and variable. Figure 3 exemplifies how the spikes on Dog1's graphs are generally narrower, with slightly wider, taller and possibly repetitive, indicating a more hesitant or less engaged interaction. This suggests that trained, and training for, signaling behavior might affect the dogs' spontaneous response to salient odors.
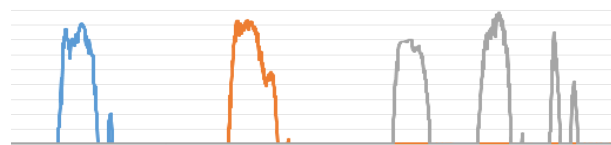
Figure 3. Dog1's response at concentration 1/1billion, with positive sample correctly identified at position 3 (grey graph).

Recurrence of key features in interaction patterns

The data shows that for Dog2 it is possible to identify certain features in the patterns produced whilst sniffing different samples. For a negative sample, the dog sniffs briefly once or twice, and quickly moves on dismissing the sample; this usually results in a compact, narrow, single-peaked spike (Fig. 2, blue and orange lower graph). For a positive sample, the interaction is longer and more complex, with the graph showing similar shape each time; this results in a wider, broken-up area under multiple peaks (Fig. 2, grey lower graph). Here, the first spike appears to be similar to the shape of a negative sample; a wider mound follows, in turn followed by several narrow spikes of diminishing amplitude. Although we previously worked under different experimental conditions (different dogs, single stand, biological samples), the features we observed this time are consistent with those we had identified [3], respectively: 1) an entry feature (denoting a first approach to and check of the sample); 2) a main feature (denoting a more focused and prolonged investigation presumably as the dog recognizes an odor of interest); 3) an exit feature (denoting the bounces of the plate on the sensor once the former is finally released). While in Dog2 the interaction with the samples is more prolonged, the consistency of qualitative features observed across different experimental conditions suggests that these features generalize.
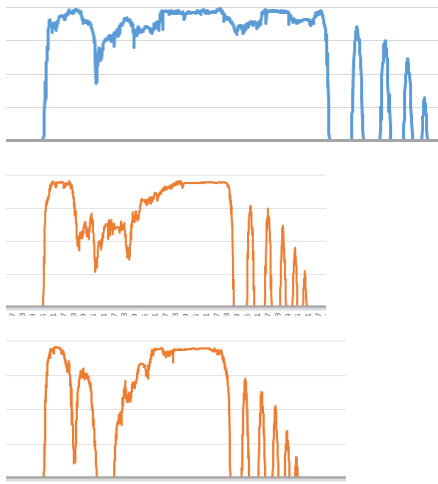

Figure 4. Graphs produced by Dog2 sniffing positive samples in different runs, respectively at concentration 1/20million (top), 1/50million (middle), and 1/1billion (bottom).

Concentration and pressure patterns

Our data indicates that, at least for Dog2, the shape of the entry, main and exit features characterizing the dog's interaction with positive samples vary with the target odor's concentration. Figure 4 exemplifies how, at concentration 1/20million, there is almost a continuum between entry and main feature; at concentration 1/50million, the entry feature is clearly distinguishable with the transition to the main feature being rather 'broken up', as though the dog had hesitated while proceeding with the 'main investigation'; at

concentration 1/1billion, there is a complete separation between the entry and main feature, with a broken entry feature, as though the dog might be about to treat the sample as negative only to decide a moment later that a 'main investigation' was warranted after all. A step forward from our previous work [3], this finding suggests that it may be possible to use certain variations in entry and main features as finer grained indicators of the strength of the dog's response to positive samples; this may then correlate with the dog's level of certainty during detection.

While the patterns illustrated in Figure 4 denote *true positives*, Figure 5 exemplifies a *false positive*. The graph was produced by Dog2 while searching a line-up with two negatives in position 1 (blue) and 2 (orange), and one positive in position 3 (grey). The negative sample in position 2 was later thought by the trainers to have possibly become contaminated with cells from a positive sample during previous runs. During the run, Dog2 began indicating in front of position 2, but not receiving confirmation from the trainer (always provided via the sound of a clicker), he moved on to position 3 where he finally made a full indication (i.e. sitting down in front of the sample), consistent with the pattern in the graph (grey). Although Dog2 seemed headed towards making a full indication at position 2, the graph (orange) shows that his response to the sample was more hesitant, with repetitions of narrow and lower spikes over a comparatively significant length of time. Thus, for Dog2, a significantly broken up graphical configuration might denote uncertainty. This suggests that the pressure patterns produced during detection could also be used to distinguish between true and false positives.
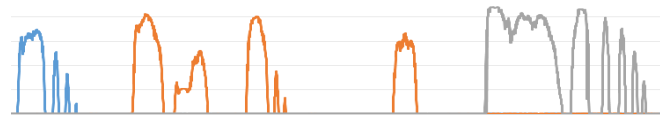
Figure 5. Graph produced by Dog2, showing a false positive indication at position 2 (orange).

Interaction signals vs performed indication

A comparison between the graph in Figure 5 and the corresponding video recording highlights how the former provides a richer picture than that provided by the dog's trained behavior: although Dog2's trained response was similar to that presented in response to a positive sample, his spontaneous interaction with it seems to tell a different story. Another example of discrepancy between trained and spontaneous response, was provided by Dog1's attempt to find a positive sample at concentration 1/1billion. Dog1 seemed unable to find the sample, which was at position 2. At the third attempt, the graph in Figure 6 shows that, having cleared position 1 and 2, he responded to the sample at position 3, even though this was incorrect. This known phenomenon results from the dog becoming frustrated when failing to find his target and, after a few runs, indicating at the last chance (i.e. the last position in the line-

up). This was not detectable from Dog1's trained behavior, but is visible in the graph. This further supports the hypothesis that the dogs' pressure patterns enable a subtler interpretation of the dogs' responses.

Figure 6. Graph produced by Dog1, while searching for the target (1/1/billion), following other failed attempts.

DISCUSSION

Our findings are consistent with our earlier hypothesis that the pressure patterns resulting from the interaction of cancer detection dogs with biological samples can provide a reliable indication of the dogs' interest and possibly confidence in their detection of the target odor [3]. Even under different experimental conditions, we still found that the features in the pressure patterns previously identified recur, although the patterns themselves may present significant individual differences. However, by increasing the complexity of the experimental set-up, we were also able to gain further insights into the characteristics of the detection process.
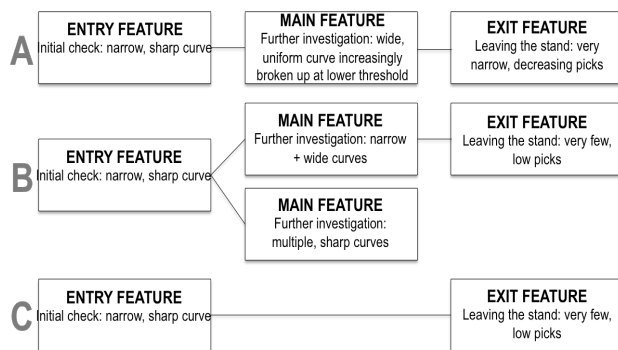
Figure 7. Range of possible responses from Dog2's data.

Firstly, by using amyl acetate instead of biological samples, we were able to control the concentration of the chemical that the dogs had previously been trained to recognize as salient; this enabled us to observe that the features denoting positive samples appear to present differently at different levels of concentration; we also observed different features between true positives and false positives. Based on the graphs produced by Dog2, Figure 7 illustrates three types of curve: **A** seems to indicate a true positive and **C** a negative; **B** appeared with the contaminated sample. The consistency of this pattern suggests that the graphs' features can be used to determine the difference between true and false positives. This could further inform the development of learning algorithms for the automatic detection and interpretation of the dogs' responses, as we previously envisaged [3].

Secondly, the use of a three-stand line-up instead of a single stand, made more apparent possible interferences between the dogs' trained and spontaneous response to the samples; in particular, we found inconsistencies between the dogs' trained (e.g. sitting down) and spontaneous (i.e. pressure patterns) responses to samples; we even found that consistency in the dogs' trained responses might come at the expense of their confidence. Would Dog1 have responded to the stimulus more vigorously before his training? It may be possible to assess the dogs' responses to a naturally salient odor (e.g. food) as a control; in turn this could help calibrate the abovementioned algorithms for individual dogs.

CONCLUSIONS

Our short study builds on and advances our previous work on the viability of using sensor data from the interaction of cancer detection dogs with biological samples, in order to develop a canine-centered system that can better support the work of the dogs and improve the reliability of the practice. Varying some experimental conditions with respect to previous work further highlighted the potential of the approach and provided further insights towards the partial automation of the process. Going forward, we plan to expand the number and diversity of participants, and continue to modify training and experimental conditions to further test out hypotheses and inform learning algorithms towards the development of an automated system.

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