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Domination of olfaction over vision in explosives detection by dogs☆

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Abstract

This study examines the relative contribution of the senses of sight and smell to detection of explosives in dogs. Six sniffer dogs were required to detect explosives in a controlled (indoors) and uncontrolled (field track) environment, under both virtually dark (very low light intensity) and full light conditions. Detection percentages, search duration, and sniffing and panting frequencies were measured.

Olfaction was shown to be the main sense used by the dogs for detection not only when vision was possible but difficult, in very low light intensity, but also in full light. Furthermore, neither the presence nor the virtual absence of light was demonstrated to differentially affect the dogs' detection ability.

The results of the current study are of considerable importance for operational application. Many security organisations use sniffer dogs for detection of various substances. The possibility of using the same dog for both day and night operations offers a cost-effective reduction in number of dogs required as well as manpower needed to train them. Furthermore, understanding the search mechanism of security dog breeds that have not been selectively bred for odour searches, will enable more efficient training, leading to improved performances.

Keywords: Dog; Vision; Olfaction; Lighting; Explosives

1. Introduction

Hunting dogs require their senses of both smell and sight in order to track their prey. The canine visual system has adapted to exploit a particular ecological niche by enhancing

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visual performance under low light conditions while still retaining good function under a wide array of lighting conditions, including daylight (Miller and Murphy, 1995). Although little work has been done on motion-detecting abilities in dogs, it is probable that the perception of movement is a critical aspect of canine vision (Duke-Elder, 1958) and that dogs, like people, are much more sensitive to moving objects than they are to stationary ones (Miller and Murphy, 1995). The dominant photoreceptors in dogs, the rods, are particularly well suited to detecting motion and shape (for review see Miller and Murphy, 1995). However, the significant advantage of canine vision remains mostly unexploited when searching for a stationary object, e.g. explosives, drugs, etc. In contrast to vision, olfaction is not considered to be affected by object mobility or lighting conditions. Thus, it would be reasonable to expect that dogs will rely mostly on their sense of smell for explosives detection. Despite the extensive use of dogs for a wide variety of olfaction tasks, however, the relative contribution of olfaction and vision in dogs during search has never been investigated. It is well established that dogs have extremely sensitive noses. In fact, behavioural experiments have shown that the olfactory capability of the dog for detecting certain odours is at least 100 times greater than that of man (e.g. Moulton, 1960). Over the years, dogs have been selectively bred in order to produce specialized breeds suitable for different tasks. The breeds classified as scent hounds were bred for their ability to hunt and track using olfactory cues. The breeds classified as sight hounds were bred to hunt using mostly visual cues. The toy breeds were bred primarily on the basis of appearance, size and temperament (Issel-Tarver and Rine, 1996). Genetic research on 26 breeds of dogs has provided evidence that in spite of differential selection on the basis of olfactory acuity in scent hounds, sight hounds and toy breeds, the number of olfactory receptor genes per subfamily has remained stable (Issel-Tarver and Rine, 1996). The researchers hypothesized that selection on the basis of olfactory ability has primarily had an effect on the total number of olfactory neurons, the diversity of subfamilies and the level of expression of the olfactory receptor genes. Such differences in neuron numbers may evolve to global changes in sensitivity to odorants (Issel-Tarver and Rine, 1996).

Many security organisations use sniffer dogs for detection of various substances. The majority of those substances are usually stationary and sometimes partially or wholly concealed. Thus, scent hounds would appear to be the most suitable breeds for those purposes. However, most organisations use a variety of breeds (sometimes even taken from dog shelters, Weiss and Greenberg, 1997), rather than selectively bred scent hounds. A study of the search mechanism in the former would greatly contribute to more efficient training, in turn leading to improved performance. It would be natural to expect that dogs not specifically bred for scent work would employ both vision and olfaction when searching for explosives. Indeed, since they are trained to search for a partially visual odour target, it is important to determine whether, following training, they continue to use both senses or shift entirely to olfaction. Moreover, some sniffer dogs are narrowly trained for detection under specific situations and lighting conditions. In light of the above, the current study was designed to examine the relative contribution of the senses of sight and smell in dogs searching for partially concealed explosives. We examined the ability of dogs to detect stationary odourous objects in full light in comparison to very low light intensity (dim light), under both controlled and uncontrolled (natural) conditions.

2. Materials and methods

2.1. Animals

We tested six sniffer dogs (four Belgian Malinois and two Labrador retrievers) trained for explosives' detection. The dogs were trained to detect explosive material placed in four types of containers identical to those used in the experimental set-up (see below).

2.2. Explosives and containers

Individual 30 g quantities of C4 explosive were placed in four types of containers (glass salt shakers with metal lid, plastic soap-holders, small metal cans and wooden boxes) in order to ensure that the dogs were detecting explosives odour rather than container odour.

Identical control (dummy) containers were filled with either a wide range of odour sources (such as soil, sugar, coffee, and bread) or left empty. Again, this ensured that the dogs were detecting the odour of the explosive and not relating to other odours accidentally attached to the container such as human odours caused by handling the containers.

2.3. Experimental locations

(1) Indoors: A 9 m × 6 m furnished auditorium. The purpose of the indoor search was to maintain as "sterile" conditions as possible, without the wind or temperature effects or the different distraction odours that are found outdoors. Furthermore, working indoors enabled both light and dim light testing to be carried out during daytime, thus avoiding a possible differential effect of diurnal or nocturnal activity. Furniture arrangement was changed daily prior to onset of experiment.
(2) Outdoors: A 2400 m soft limestone field track, divided into six equal (400 m) sections. Outdoor testing enabled examination of the dogs' ability to detect explosives under conditions more similar to actual operational situations, including external stimuli and greater extent of physical effort required from the dogs. In order to avoid odour contamination, each dog searched a separate, and only one, section of the track each day, once during light and once during darkness.

2.4. Environmental conditions

Controlled environment (indoors): Both light and dim light trials were carried out at the same hours during daytime, thus avoiding a possible effect of temperature as well as diurnal or nocturnal activity.

Uncontrolled environment (field track): Light trials were carried out under a daytime environmental temperature that was higher than during the dark trials, which were carried out in the evening (17.9 and 15.7 °C, respectively, two-tailed t-test, $P = 0.0002$).

2.5. Lighting conditions

Light: Indoor testing was carried out with open windows in full daylight. Outdoor testing was carried out in full daylight.

Dark (dim light): Indoor testing was carried out during daytime with lights off and fully closed shutters (a narrow strip of dim light passing beneath the door enabled the observer to navigate the room cleanly). Light intensity ranged from ca. 0.17–0.7 lx.

Outdoor testing was carried out in the evening, after dark, for 11 consecutive days from full moonlight to no moonlight (27 December 1999 to 6 January 2000).

2.6. Equipment

Monitoring and video apparatus: A unique listening apparatus was developed for this study enabling us to monitor the dog's sniffing and panting during the search, for post-factum analysis. The apparatus comprised a tiny wireless microphone and transmitter (Audio Technica 2000) attached to a head harness. The transmitted audio signals were picked up by a receiver and recorded by a video camera (Sony, E-65). Audio signal analysis was performed using a special computer software that counts sniffing and panting performed by the dogs while searching. This software was developed especially for the purpose of this study (detailed manuscript in preparation). The use of a microphone attached to a dog's head in order to record and analyse sniffing was first used by Thesen et al. (1993). Surrounding temperature and relative humidity were measured by digital temperature and humidity gauge, $\pm 1\,^{\circ}\mathrm{C}$ and $\pm 3\%$ accuracy. Wind speed was measured using Windmeter, Davis Wind Wizard. Light intensity was measured by PROFISIX light detector (Gossen).

2.7. Experimental set-up

Indoors: One container of explosive was hidden (but partially visible upon approach) inside the auditorium 3 min before the search began. The dog then entered, and immediately sat and waited at the search start point in the auditorium for 3 min, in order to adapt to the lighting conditions (light or dim light). The dog then started its search for the explosive and continued until finding it. The dog performed the search independently, while its handler remained at the start point. Each dog performed between 12 and 16 trials in light conditions and between 14 and 17 trials in dim light. The exact same procedure was carried out for both light and dim light sessions.

Outdoors: Unobserved by either handler or dog, five explosives and three dummy containers were scattered along the particular 400 m section of the track to be searched. The containers were carefully thrown from a moving car in order to prevent human footprint odour cues. Each dog searched a separate section of the track in order to prevent odour cues between dogs. The dogs searched independently, with the handler following behind from a distance of 50–70 m. The handler ensured that the dog was searching both sides of the track by directing it to left and right from a distance. The dog returned to the handler upon command for reward or to be sent to re-search an insufficiently investigated section. Each dog performed between six and seven trials in light conditions and between five and six trials in darkness.

Prior to each search all old containers were removed and new containers were hidden in order to avoid odour contamination, each time in different places. The partially hidden containers could generally be seen upon closer approach. Each dog performed only one session per day, thus minimizing its ability to remember a possible explosive's location from a previous session. All dogs worked off-leash indoors as well as outdoors. Temperature, humidity and wind speed and direction were measured prior to each search.

2.8. Detection indication

The dogs were trained to sit next to the detected explosive, bark and point to it with their nose. In order to reconfirm the explosive's location, the handler would ask the dog to point to it again, before approaching the dog and rewarding it with food and praise, followed by dismissing it.

The following parameters were measured: (1) explosives' detection percentage; (2) control (dummy) signing percentage; (3) search duration; and (4) sniffing and panting frequency (indoors—measured as average frequency per 5 s search; outdoors—measured as average frequency per 60 s search).

2.9. Statistical analysis

The data were analysed using the Statistica Software. The exact type of analysis depended upon the question being asked. In all cases the percentage detection data were transformed using an arcsine transformation (Winer, 1962). Averages present ± S.E.

3. Results

3.1. Indoor search

In order to examine whether time elapsed from onset to end of experimental period influenced the dogs' performance as a result of their increasing familiarity with the assignment, we examined search duration required to complete the assignment between days. No differences in search duration (time) were found between days in either light or dim light sessions (one-way ANOVA, $F(15, 65) = 1.31$, $P < 0.2$ and $F(15, 58) = 1.55$, $P < 0.12$, respectively).

Indeed, no differences were found under either light or dim light conditions in all of the measured parameters of performance (explosives' detection percentage, search duration, and sniffing and panting frequency) (Fig. 1).

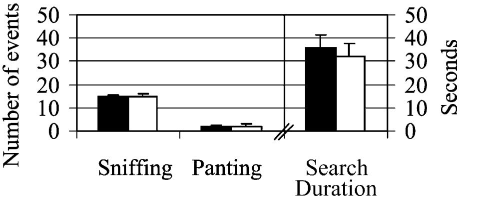

Fig. 1. Sniffing and panting frequency (per 1 min) and search duration (s) during indoor search in light (white) and dark (black).

3.1.1. Olfactory detection indication

On a few occasions, as a result of over-enthusiasm, the dog sat upon detecting the explosive but then moved it from its hiding-place and dropped it on the floor next to it. When this occurred, upon the handler requesting reconfirmation of the explosive's location, the dog first returned to sniff the site where the explosive had originally been hidden and then sniffed the floor in decreasing circles until reaching the odour source, even though it was totally uncovered and could be clearly seen by the handler and researcher.

3.2. Outdoor search

In order to examine whether time elapsed from onset to end of experimental period influenced performance as a result of the dogs' increasing familiarity with the assignment, we examined search duration required to complete the assignment between days. No difference was found (one-way ANOVA, d.f. $= 6, f = 1.03, P = 0.4$). We thus present all days as one statistical group. In addition, since each dog searched daily for five explosives, we examined effect of location order (first to fifth) of explosives along the track. Although the fifth explosive was found faster then the others, the difference was not significant (one-way ANOVA, d.f. $= 4, f = 1.8, P = 0.11$). Thus, we present all explosives as one statistical group.

Dogs' performances differed significantly between trials in dark and light. For trials in dark, search duration was shorter (106.62 ± 13.18 and 118.06 ± 12.15 s, respectively, $P = 0.04$), sniffing frequency increased (138.57 ± 11.76 and 98.05 ± 7.2, respectively, $P = 0.01$) and panting frequency decreased (82.51 ± 8.63 and 110.50 ± 7.71, respectively, $P = 0.05$) in comparison to trials in light. However, no significant difference was found in actual detection percentages between trials in dark and light (87.78 and 93.83%, respectively, $P = 0.18$; Fig. 2). During dark trials three dogs presented slight obedience problems (failing to follow fully their handler's orders), and one dog showed severe obedience problems, resulting in hasty, non-thorough searches. This explains the slightly lower (non-significant) detection percentages during dark trials. Despite this problem, however, we did not find any difference in detection percentages between dark and light trials in any of the dogs, with the exception of the dog showing severe obedience problems.

3.3. Control (dummy) signing

Throughout the entire experiment although the dogs approached most of the control containers they did not sign any of them during light sessions (out of 72 or 84 hidden

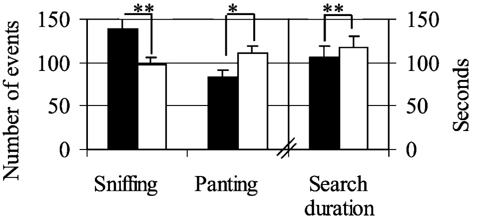

Fig. 2. Sniffing and panting frequency (per 1 min) and search duration (s) during outdoor search in light (white) and dark (black).

control containers, according to number of trials performed by each dog) and signed only two (out of 60 or 72) control containers during dark sessions. This finding indicates the dogs' high level of reliability.

4. Discussion

As part of the procedure prior to the experiment, the dogs had been trained to find explosive materials hidden in one of four small differently shaped containers. Therefore when the dogs began the present experiment they already had experience in detecting explosive materials (olfactory cue) hidden in containers whose shape was known to them (visual cue).

The purpose of this study was to compare the relative contribution of olfaction and vision in the detection of odorous objects. The experiment was designed to distinguish between use of the two sensory modalities. In order to isolate vision, the experiment should preferably have been conducted under total darkness, with the use of infra-red detection equipment. However, since this was not possible, we used a darkened room with very low light intensity (dim light).

Because the canine retina contains a predominance of rods (Kemp and Jacobson, 1992) and also has a reflecting layer (tapetum lucidum) (Lesiuk and Breakevelt, 1983), the dog's ability to see in low intensity light is greater than that in humans (Walls, 1963; Miller and Murphy, 1995). Therefore we cannot rule out that during the dim light phase of the experiment the dogs were using visual cues not apparent to the human eye. Nevertheless, under such dim light (0.17–0.7 lx), even dogs have visual detection limits, especially in identifying stationary objects.

In the indoor experiment, the environmental temperature was the same under both light and dim light test conditions; consequently the dogs were exposed to the same physiological load, and exhibited the same rate of panting under both conditions. We could thus measure and compare the true rate of sniffing required for the dogs to detect the explosive material without interference of the increased panting that occurs during outdoor daylight testing as a result of higher environmental temperature. All other parameters measured (frequency of sniffing, duration of search and detection success) were also the same under light and dim light conditions.

Based on these findings we have good reason to conclude that the dogs did not use the visual channel to search for the explosive either in the light or the dim light conditions. As noted, the containers in which the explosives were hidden were familiar to the dogs from previous training. Although the containers were hidden so as not to be visible from a distance, they could be seen upon closer approach to the site. However, even when the container was clearly visible from the position where the dog was standing, rather than approach it directly the animal would continue to search in a typical olfactory search pattern. If the dog had been cueing in on visual cues, one would expect that once it had identified the target it would make a direct approach. Thus, if using visual identification it should have approached the container faster under the light over the dim light intensity conditions, resulting in a shorter duration of search. In fact, however, the duration to finding the target was the same under the two lighting conditions.

Furthermore, our conclusion is reinforced by the cases in which the dog actually touched and moved the target, and was then called upon to reconfirm the explosive's location. Rather than indicate its new position on the floor where the dog had dropped it (and where it could now be clearly seen by the handler and the dog itself), the dog instead first returned to sniff the site where the explosive had been originally hidden and then sniffed the floor in circles of decreasing size until reaching the odour source once more, now in its new position. Thus, in cases in which the dogs could have used both olfaction and vision, they chose to use only olfaction.

Lavenex and Schenk (1998) found that rats too are able to locate a unique position as accurately in darkness as when given access to visuospatial information. They hypothesised that the olfactory traces complement the use of other orientation mechanisms, such as path integration or the reliance on visuospatial information. However, had those researchers also analysed the differences in sniffing frequencies between light and dark sessions, this would have contributed to a fuller understanding of the search mechanism used by the rats under the two lighting conditions. In order to prove olfactory complement, increased sniffing frequency during darkness in comparison to light would have had to be shown. We suggest here, based on the findings of the current study, that in dogs no complement is needed during dark searches since these animals, in any case, rely solely on their sense of smell to detect the explosives.

Logically, if a dog "normally/naturally" utilises both senses (olfaction and vision), for detection, it would be reasonable to presume compensation by the non-restricted sense (olfaction) in cases when the other sense (vision) is restricted. However, no difference in sniffing frequency was found between full light and very low light intensity conditions during the indoor test.

The differences found between dark and light performances in the field track searches resulted from the different environmental conditions during evening and daytime trials. Stavert et al. (1982), using a refrigerated enclosure treadmill apparatus, showed that a dog's respiratory frequency decreases as surrounding air temperature decreases. The lower evening temperature in the current study may have enabled the reduction found in panting, consequently allowing more frequent sniffing during the evening search. The slight decrease in overall detection percentage and search duration during dark testing was due to one dog that consistently showed obedience problems in the dark trials. This explains why, despite the increased sniffing frequency in the dark trials, we do not show a parallel increase in detection percentages.

In conclusion, neither presence nor virtual absence of light was shown to have had any significant effect on the dogs' detection ability under all the experimental conditions. Even during daytime, when performing a search for a partially concealed immobile target under light conditions, the dogs mostly relied on their sense of smell and hardly at all on their vision, even when visual data became available upon closer approach. The entirely olfactory search carried out by the dogs during reconfirmation of target location, indicates the continued dominance of olfaction over vision even when the animals are re-searching for a target in open view.

The results of the present research have both academic and, particularly, operational significance. The academic importance of this study lies in the finding that dogs appear to rely solely on their sense of smell for immobile odour detection, although they have the ability to use vision too. Thus, a dog's performance in controlled conditions is shown to be as accurate in very low light intensity as it is in full light. Because many security organisations use sniffer dogs for detection of various substances, the possibility of operating the same dog for both day and night operations, rather than specialised separate training, offers a cost-effective reduction in the number of dogs required as well as the manpower needed to train them. Furthermore, since most dog breeds used by security organisations for odour target detection are not selectively bred for scent search, understanding the search mechanism in such breeds will enable more efficient training, in turn leading to improved performance.

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