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Explosives detection by sniffer dogs following strenuous physical activity ☆

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Abstract

Reduced olfactory efficiency in sniffer dogs results mainly from overheating, and causes physiological and behavioural resources to be diverted from concentration on the assigned task and applied instead to methods of body cooling. Dogs do not possess sweat glands, and panting is the main means of cooling the body. Since a dog can either sniff or pant, but can never perform both actions simultaneously, panting causes a decrease in sniffing rate.

In various military operations dogs are required to detect explosives under severe physical conditions. In such situations, the dog's high body temperature elicits rapid panting already at the very beginning of the search task. As a result, its concentration and olfactory ability are diminished from the outset.

In the current study we examined the ability of dogs to detect small explosives charges in two situations: (1) while relaxed and therefore only lightly panting; and (2) following exercise on a treadmill and therefore heavily panting. The results revealed an inverse ratio between rate of panting and efficiency of the dog's olfactory work, with increased panting resulting in a significant decrease in explosives detection. The decline in efficiency was also expressed in longer duration of search period. However, we also found that dogs are able to adjust to working under severe physiological conditions derived from extreme physical activity. Such adjustment can reduce the dog's limitations under strenuous conditions and can be taught by suitable training.

Keywords: Dog; Treadmill; Explosives; Adjustment; Sniffing; Panting

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1. Introduction

Although dogs have long been used around the world for security purposes, the exploitation of their well-developed sense of smell for such purposes is relatively new. Use of their olfactory ability has expanded over the last century and is currently widespread. ''Sniffer dogs'' are employed for a variety of security (military and police) as well as civilian purposes, such as to search for live or dead persons in open field areas, or for survivors buried beneath ruins at disaster areas (Komar, 1999), as well as to detect explosives (e.g. Phillips, 1971; Phillips et al., 1974; Lovett, 1992), drugs (Adams and Johnson, 1994) or smuggled agriculture products (Eastwood, 1990), in arson investigations (Gialamas, 1996; Kurz et al., 1994), or in search for termites, screwworms (Welch, 1990), cows in estrus (Hawk et al., 1984; Jezierski, 1992), melanomas (Williams and Pembroke, 1989), and for many other uses. Despite the wide potential, however, most working ''sniffer'' dogs around the world are used for explosives detection, due to the international problem of terrorism.

The anatomy and physiology of the canine olfactory system have been studied in depth and are well documented. The dog perceives odours by sniffing, during which air is inhaled through the nostrils in short aspirations while the mouth remains closed (Neuhaus, 1981). Sniffing may be advantageous compared to normal breathing because it presumably creates more turbulent gas flow in the air passage and thus reduces the diffusion distance from fresh air to receptors in the nose (Neuhaus, 1981; Steen et al., 1996). Laing (1983) showed that sniffing improves the sensitivity to odours compared with even air flow. Other studies have shown that larger than normal flow rates of air through the nose enhance odour perception (Le Magnen, 1945; Rehn, 1978). Sobel et al. (1998), based on Le Magnen (1945) and Laing (1983), emphasised the importance of sniffing to olfaction: ''the sensation and perception of smell are largely dependent on sniffing, which is an active stage of stimulus transport and therefore an integral component of mammalian olfaction''.

Since dogs do not possess sweat glands, panting is the main means of cooling the body. Panting consists of rapid respiration in order to regulate body temperature by increasing the evaporation of water from the respiratory tract (Crawford, 1962). During panting most of the air passes through the mouth (Schmidt-Nielsen et al., 1970). Since the dog can either sniff or pant, but can never perform both actions simultaneously, panting causes a decrease in sniffing rate, and a consequent decrease in olfaction efficiency. As a result of overheating, therefore, physiological and behavioural resources are diverted from attention and concentration on the assigned task and applied instead to conscious or unconscious ways of body cooling.

In various military operations, dogs are required to detect explosives under severe physical conditions. In such situations, the dog's high body temperature elicits rapid panting already at the very beginning of the search task, and its concentration and olfactory ability are diminished from the outset.

Despite the extensive use of dogs for the detection of various odour substances, the effects of prolonged or extreme physical activity on the olfactory acuity and detection ability of dogs actively searching for odours in the field, have not been investigated.

In the current study we examined the ability of dogs to detect small explosive charges under contrasting physiological conditions: when calm and relaxed; or following strenuous physical activity elicited by running on a treadmill. We examined the possibility of improving the dogs' performance by training them to adjust to the energetic requirements of the assignment.

2. Materials and methods

2.1. Animals

The current study tested six sniffer dogs (four Belgian Malinois and two Labrador retrievers) trained for explosives' detection.

2.2. Explosives and containers

Samples of C4 explosive (30 g) were placed in a wide variety 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 either filled with a wide range of odour sources (such as soil, sugar, coffee, and bread) or left empty. These controls ensured that the dogs were detecting the odour of the explosive and not other odours including human odours accidentally adhering to the containers.

2.3. Experimental locations

2.3.1. Indoors

The indoor test was performed in a gym (8 m × 4.5 m) equipped with fitness apparatus. The purpose of the indoor search was to standardise conditions, without the variables of wind, temperature or distracting odours that are present outdoors.

2.3.2. Outdoors

The outdoor tests were performed in a field track (125 m length, 4 m width). Outdoor testing simulated the dogs' ability to detect explosives under operational conditions, including a variety of external stimuli and greater physical exertion.

2.4. Equipment

Monitoring and video apparatus: a unique listening apparatus was used to monitor the dogs' sniffing and panting during the search. The video was used for post-factum analysis of the dog's behaviour. The listening 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 on a video camera (Sony, E-65). Audio signals were analysed using a computer software program developed especially for the purpose of this study, which counts sniffing and panting performed by the dogs while searching (detailed manuscript in preparation). Use of a microphone attached to a dog's head in order to record and analyse sniffing was first described by Thesen et al. (1993). The dogs were exercised on a treadmill, Trotter 685, adjustable slope, digital display enables control of speed, slope, length, duration of running and calories expended; environmental temperature was measured with a digital temperature and humidity gauge, ±1 °C and ±3% accuracy; wind speed was measured with Windmeter, Davis Wind Wizard; body temperature was rectally monitored with digital thermometer HF365 Philips; pulse was measured by placing a finger on the dog's femoral artery and counting pulses for 60 s; counter and stopwatch were used in order to gauge breathing rate before and after exercise.

2.5. Experimental set-up

2.5.1. Preparations prior to the examination

The dogs were exercised on the treadmill almost daily for 2 months prior to onset of experiment in order to improve their physical condition prior to, rather than during the experimental period. Fitness was assessed by measuring breathing rate, body temperature and pulse before and immediately after 20 min treadmill running. When these physiological parameters of fitness had achieved stability, we began the experiment.

2.5.2. Experimental procedure

The study was divided into two experiments: (1) indoors (inside the gym); and (2) outdoors (along the track). Both indoor and outdoor experiments were run for a total of 12 days each, one session per day. In both experiments each dog was sent to search twice during each session: first, when calm ("calm search"), and again, immediately following exercise ("strenuous search").

This order ensured maximum calm for the calm search, which was carried out while the dog was lightly panting, immediately upon arrival at the area. The strenuous search was performed while the dog was heavily panting after 20 min of running on the treadmill (9 km/h at a 12% grade).

One container of explosive was hidden in the indoor gym; and three explosives and two dummy containers were hidden along the outdoor track. The containers were hidden out of sight of both the dogs and the handlers, 5 min before each search. Prior to each search previous containers were removed and replaced by new containers which were hidden in different sites. Each dog was tested for only one session per day in order to reduce the possibility of remembering explosives' location from a previous session (even though the explosives were hidden in new places each time). All dogs worked off-leash both indoors and outdoors. Temperature, humidity and wind speed and direction were measured prior to each search; temperature ranged between 25 and 30 °C and relative humidity ranged between 50 and 70%.

The examined parameters were: (1) percentage of explosives' detection; (2) percentage of control (dummy) signing; (3) search duration (s): indoors, measured from onset of search until finding the target; outdoors, measured from onset of search until finding of the third explosive; (4) sniffing and panting frequency (measured as average frequency per 10 s of search (indoors) or per 60 s of search (outdoors); and (5) pulse, body temperature and breathing rate were measured daily before and after exercise.

2.5.2.1. Definitions. "Breathing rate": frequency of breathing by the dog immediately before and after exercise on the treadmill, measured manually using a counter and stopwatch. "Panting frequency": frequency of panting by the dog while searching for the explosives, measured by the computerised software that identifies and separates panting from sniffing and other noises. "Sniffing frequency": frequency of sniffing by the dog while searching for the explosives, measured by the computerised software that identifies and separates sniffing from panting and other noises. "Sniffer dogs": dogs used for the detection of different odorous materials.

2.6. Statistical analysis

The data were analysed using the Statistica Software. The exact type of analysis was dependent upon the question being asked. In all cases the percentage detection data were transformed using an arcsine transformation (Winer, 1962). Table's data represent means values ± S.E.

3. Results

3.1. Physiological parameters before and after strenuous activity

Following 8 weeks training on the treadmill all the dogs reached a stable physiological state. They were then tested, once a day, before and after 20 min treadmill activity. A significant difference was revealed in their physiological responses before and after treadmill activity, throughout the experimental period (Table 1).

3.2. Experiment 1: controlled environment (indoor)

The indoor test was simple since only one target was hidden and all searches ended upon detection. Thus, all dogs detected the explosive whether before or after exercise. However, exercise significantly affected all other variables—search duration, sniffing and panting (Fig. 1).

Table 1
Physiology parameters measured before and after physical activity

	Before activity	After activity	*P*-value
Breathing (per 1 min)	212.94 ± 6.68	337.65 ± 9.95	<0.01
Body temperature (C°)	38.11 ± 0.02	39.62 ± 0.11	<0.01
Pulse (per 1 min)	103.45 ± 1.6	130.74 ± 3.56	<0.01

Physiological parameters measured before and after strenuous activity. Average breathing rate, body temperature, and pulse (mean ± S.E.) before and after 20 min of exercise on treadmill. Sample size for each parameter ranged between 10 and 20 measurements (one measurement per day) for each dog ($N = 6$) before activity, and between 6 and 10 measurements for each dog ($N = 6$) after activity. Statistical analysis: two-tailed paired *T*-test.

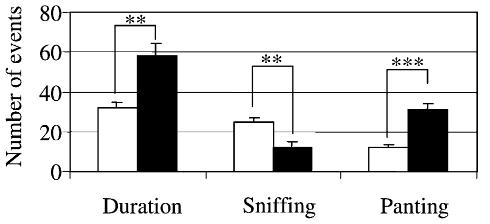

Fig. 1. Mean values of search duration (s), sniffing frequency and panting frequency (per 10 s) before (white) and after (black) strenuous activity (indoor). $^{**}P < 0.01$, $^{***}P < 0.001$; *y*-axis represents number of events of each parameter according to its measurement values.

3.3. Experiment 2: uncontrolled environment (along a field track)

3.3.1. Dogs' performances before versus after activity

3.3.1.1. Search duration. Search duration before treadmill activity was significantly shorter than after activity (286.27 ± 17.03, 356.29 ± 6.95 s, respectively; paired *T*-test $P < 0.01$, for daily sessions data see Fig. 2a).

3.3.1.2. Detection percentage. Detection percentage before treadmill activity was significantly higher than after activity ($91.46\% \pm 2.56$, $80.94\% \pm 3.78$, respectively; paired *T*-test $P < 0.05$, for daily sessions data see Fig. 2b).

3.3.1.3. Sniffing and panting frequency. Sniffing frequency was greater before than after treadmill activity (88.4 ± 9.9 and 67.6 ± 8.6, respectively; $P = 0.12$, the differences were not significant due to the individual variation, for daily sessions data see Fig. 2c). An increase in panting frequency was found after strenuous activity (143.1 ± 10.13 and 164.6 ± 12, respectively; $P = 0.26$, for daily sessions data see Fig. 2d).

3.3.2. Effect of order of explosives' location along the track

In both sets of sessions, before as well as after strenuous activity, the dogs found the third explosive more frequently than the first two explosives, which were hidden closer to the beginning of the track. The difference was significant however, only after strenuous activity (see Table 2). A significant difference was found between the second and third explosive as

Table 2
Detection percentage during outdoor strenuous searches of the first, second and third explosives according to location along the track, for the entire experimental period (i.e. how many explosives of each type (first, second and third) were found by the dogs)

Explosive locations	Before activity (%)	After activity (%)
First	84.79	68.02
Second	90.04	77.52
Third	100	96.81
One way ANOVA (*P*-value)	0.15	0.005

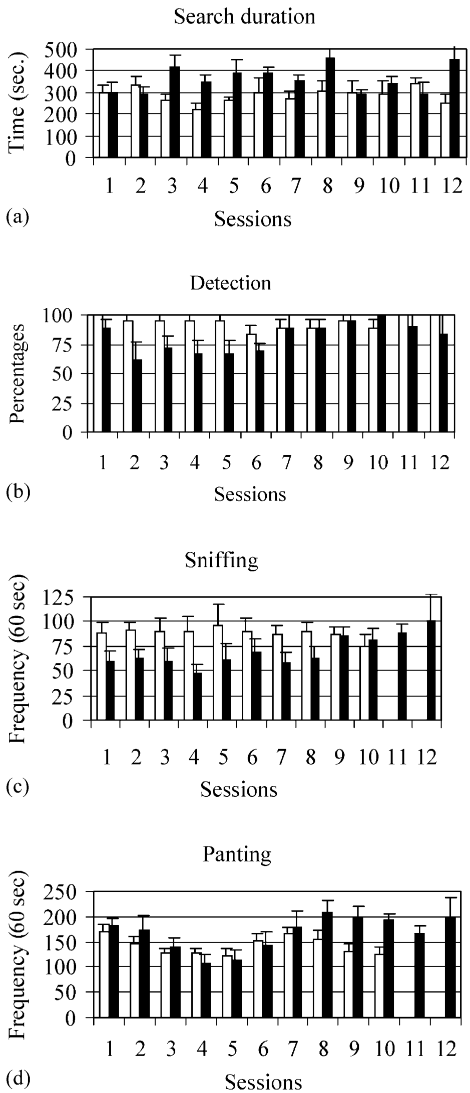

Fig. 2. Mean results for behavioural variables over the 12 sessions; search duration, detection percentage, sniffing and panting frequency, before (white) and after (black) strenuous activity (outdoor).

well as between the first and third explosive (paired T-test, $P = 0.03$ and 0.01, respectively); i.e. the greater success in detecting the third explosive appears to account for the difference.

To determine whether these findings were due to an increase in sniffing frequency toward the end of the search, the session was divided into three equal time segments and the sniffing and panting frequency were measured in each segment. Before strenuous activity, we found a slight increase in panting frequency, from beginning to end of the track (one

Table 3
Panting and sniffing frequency before and after physical activity

Track sections	Panting		Sniffing	
	Before activity	After activity	Before activity	After activity
First	243.6 ± 26.6	342.4 ± 30.6	150.35 ± 17.98	130.8 ± 17.3
Second	256.2 ± 24.7	330.9 ± 28.8	144.9 ± 13.7	137.3 ± 17.9
Third	259.0 ± 25.1	325.4 ± 26.5	147.4 ± 15.9	138.1 ± 16.8
One way ANOVA (*F*, *P* values)	0.1, 0.90	0.09, 0.91	0.02, 0.97	0.05, 0.94

Data show average number of pants and sniffs in the first, second and third segments of the search track.

way ANOVA $P = 0.9$, $F = 0.1$), and a slight decrease after strenuous activity occurred from beginning to end of track (one way ANOVA $P = 0.91$, $F = 0.09$). In both cases, the difference lay between the first and second segments (see Table 3). However, there was almost no change in sniffing frequency along the three segments before strenuous activity (one way ANOVA $P = 0.97$, $F = 0.02$), or after such activity (one way ANOVA $P = 0.94$, $F = 0.05$), although there was a marked difference between the first and second sections in each case (Table 3).

In order to examine changes in dogs' performances throughout the entire period of the experiment (days 1–12), we divided the experimental period into two parts (sessions 1–6, and sessions 7–12).

3.3.3. Comparison of dogs' performances in the two parts of the experimental period

The results show improved detection after physical activity, with time elapsed from onset to end of experimental period (67.13% ± 6.76, 93.33% ± 3.33, respectively; $P = 0.01$). This was not accompanied by a parallel improvement in search duration but did correlate with a parallel increase in both sniffing and panting (Table 4).

In order to determine whether the increase in detection percentage in the second part of the experiment (sessions 7–12) was due to an improvement in the dogs' physical fitness, we examined their physiological parameters immediately following exercise at the beginning and end of the experimental period (Table 5). No improvement in the dogs' fitness over time was shown.

Table 4
Detection performance parameters in first (sessions 1–6) and second (sessions 7–12) part of experimental period, after physical activity

Measured parameters	First part	Second part	*P*-value
Detection percentage	67.13% ± 6.76	93.33% ± 3.33	<0.01
Search duration (s)	347.1 ± 11.3	365.3 ± 16.9	>0.05
Sniffing frequency	58.79 ± 9.9	85.76 ± 15.32	<0.05
Panting frequency	145.05 ± 17.5	218.12 ± 30.4	<0.05

Detection percentages (%), search duration (s), sniffing and panting frequency (average per 1 min), at the first part (sessions 1–6) and second part (sessions 7–12) of the experimental period, after physical activity. Statistical analysis: two-tailed paired *T*-test.

Table 5
Fitness assessment parameters measured after activity, at the beginning and end of experimental period

Fitness parameters	Beginning	End	*P*-value
Pulse	128.6 ± 4.1	131.0 ± 4.3	0.66
Breathing rate	341.5 ± 13.5	339.2 ± 8.9	0.84
Body temperature	39.5 ± 0.1	39.7 ± 0.09	0.33

Statistical analysis: two-tailed paired *T*-test.

4. Discussion

Despite the extensive use of detector dogs and the well-recognised importance of sniffing for the detection and identification of odours, few studies have investigated the variables affecting sniffing behaviour in dogs. The effects of a variety of physiological and environmental variables on the dogs' detection abilities are thus barely understood.

The present study examined whether, and to what extent, sniffing and panting frequency alter the dogs' olfaction acuity, and consequently affect their ability to detect explosives. We also examined the dogs' ability to increase detection efficiency as a result of adjusting to working under severe physical conditions.

A direct correlation was found between rate of sniffing and efficiency of olfaction. Following extreme physical activity an inverse ratio between a decrease in sniffing frequency and increase in panting rate, resulted in reduced explosives detection. The decline in efficiency was also expressed in longer duration of search period (Fig. 3). Similar results were found when highly trained police tracking dogs were given the task of determining the correct direction of human footprints. Under "normal circumstances", without additional exercise, the dogs found the correct direction with 90–100% accuracy (Steen and Wilsson, 1990; Thesen et al., 1993); whereas Carr et al. (1993) found that after brief exercise in a gym, dogs' performed at only 68% accuracy. Thesen et al. (1993) recognised three phases in olfactory tracking dogs' behaviour: searching, deciding and tracking. They found that during the deciding phase, which is the most difficult one, during which the dogs have to determine the direction of the track, the duration of sniffing was three-fold longer than during the other two phases. The importance of sniffing and its

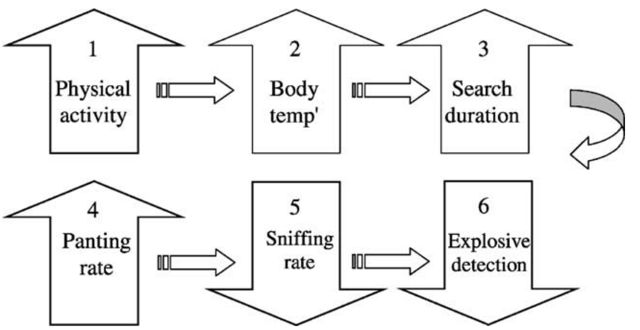

Fig. 3. Flow chart: the effect of strenuous activity on dog's detection ability.

quantity has also been emphasised by Youngentob et al. (1987) following a quantitative analysis of sniffing strategies in rats: "by taking increasingly larger numbers of sniffs and sampling for a longer period of time, the animals may have attempted to increase the total quantity of odourant reaching and interacting with the receptor epithelium as the task became more difficult".

4.1. Effect of order of explosives' location along the track

We also found that throughout the entire experimental period, the dogs detected the third explosive in higher proportion than the two explosives hidden closer to the beginning of the track. We hypothesised that such improved detection was due to a combination of two effects: a slight increase in sniffing frequency as a result of recovery time following treadmill exercise, together with a strong incentive to end the search and return to rest as the dogs had become familiar with the track and knew when they were about to reach the end. Clarke and Trowill (1971) have shown that when rats anticipate or receive positive hypothalamic stimulation their rate of sniffing increases. In the present study, anticipation of resting upon finding the final explosive might have acted as positive reinforcement, eliciting motivation that induced elevated sniffing frequency toward the end of the track. A slight increase in sniffing frequency toward the end of the search (between Sections 2 and 3) also occurred in searches performed before physical activity, although a reduction in sniffing was actually expected due to the increase in panting frequency as a consequence of search effort. This finding suggests the possibility that the dogs might have been concentrating more attention on obtaining the olfactory cues required in order to detect the last explosive along the track. Goldberg et al. (1981) have shown that dogs switch between three patterns of panting according to the demand for respiratory evaporation: (1) inhalation and exhalation through nose; (2) inhalation through nose, exhalation through nose and mouth; and (3) inhalation through nose and mouth, exhalation through nose and mouth. They found that the proportion of time that the dog used pattern (3) rather than pattern (2) increased as temperature and/or speed of exercise were increased. It is possible that in the current study, the partial recovery with time elapsed after the treadmill exercise enabled the dog to employ pattern (2) more frequently than pattern (3), i.e. inhaling solely through the nose, thus binding more odour molecules to the receptors, leading to increase in detection percentages.

4.2. Dogs performances in the first versus second part of experimental period

Examining the daily results revealed an improvement in detection percentages in the second part of the experimental period (last six sessions) compared to the first six sessions. Such improvement might have derived from either one or a combination of several of the following factors: (1) increased motivation as a result of the dog's developing acquaintance with the assignment; (2) improvement in dog's physical condition, enabling less panting and more frequent sniffing; and (3) dog's mental adjustment to work under severe physical conditions, enabling improved attention and concentration, leading to more frequent sniffing and resulting in improved detection. Since there is a direct relation between degree of motivation and dog's pace (e.g. Blokland and Raaijmakers, 1993), any motivational improvement would have been expressed in a shortened search duration. However, since search duration did not decrease throughout the experimental period, improved motivation is unlikely to have underlain the increase in detection percentage. Furthermore, the long period of preparation prior to the beginning of the experiment led to a high familiarity with the experimental procedure, and thus decreased the possibility for further improvement in motivation as a result of greater acquaintance with the assignment. An improvement in the dogs' physical fitness toward the end of the experimental period should have been reflected in a decrease in either breathing rate (e.g. Bernasconi et al., 1995; Bonsignore et al., 1998), search duration (i.e. less exhausted and therefore moving faster) or pulse. Clark et al. (1991) evaluated the effect of various confinement conditions on dogs' physical fitness by measuring heart rate during treadmill exercise. They found that the type of confinement condition for dogs had a modest effect on submaximal exercise heart rates; heart rate of dogs maintained in small cages were higher than those of dogs maintained in outside pens and runs, indicating decreased fitness in dogs maintained in the small cages. Tipton et al. (1974) and Bove et al. (1979) have also shown that trained dogs had lower exercise heart rate than non-trained dogs. No significant decrease was found in the values of any of these parameters throughout the current experimental period. Thus, it is unlikely that there was an improvement in the dogs' physical condition. Therefore, the improved detection percentage in the second part of the experiment cannot be explained by improved fitness either. Consequently, sniffing and panting were analysed to examine whether more concentrated attention had generated the improvement. Examination of sniffing and panting frequency in the first versus second part of the experimental period revealed a significant increase in both behaviours in the second part of the experiment in comparison to the first part. Increase in sniffing frequency, despite the parallel increase in panting frequency, indicates that the dogs made a special effort to perform sniffing in order to enhance perception of odour cues. Since this increase was not accompanied by improved physical fitness or greater motivation, the improved performance in the second part of the experiment appears to have resulted from the dogs' ability to adjust themselves to working under severe physiological conditions associated with extreme physical activity. Such adjustment, expressed by the increasing sniffing frequency, can improve a dog's work under strenuous conditions and can be taught by suitable training.

In conclusion, the major findings of the current study indicate that there is an inverse ratio between the degree of physical activity and the probability of detection, i.e. the greater the physical demands the lower the rate and efficacy of sniffing, and consequent reduction in probability of finding the explosives. Despite this, however, an improvement occurred in explosives' detection toward the end of every search as well as for the entire experimental period. In both cases, it seems that the dogs had learned to work under severe physical conditions and were able to increase concentration on detecting the olfactory cues. Consequently, it is both possible and essential to properly train the dogs in order to achieve optimum adjustment to working under extreme physical conditions.

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