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Forensic Science International Proficiencies of Mantrailing Dogs in Law Enforcement and Legal Contexts, Prospects for the Future, Boundaries, and Possibilities -a review

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Proficiencies of Mantrailing Dogs in Law Enforcement and Legal Contexts, Prospects for the Future, Boundaries, and Possibilities - a review --Manuscript Draft--

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Abstract:	<p>The use of dogs for search and tracking of individuals has a long history and the results of dog deployments often find their way into courtrooms. Consequently, it is not surprising that both scientific discourse and media outlets are rife with contentious debates surrounding the reliability and even the fundamental feasibility of such results. Intriguingly, there exists a limited number of studies explicitly addressing the subject of mantrailing. Some of these studies have yet to be integrated into the ongoing discourse. In this review, we present an extensive overview of the existing body of research concerning the detection and tracking of human scent trails using mantrailing dogs. These studies illuminate the fact that certain practical observations and assumptions related to mantrailing currently lack comprehensive scientific explanations. As such, a substantial amount of further research is warranted to bridge these knowledge gaps effectively.</p>
Suggested Reviewers:	Lisa Harvey, PhD Department Chair, Victor Valley College Lisa.Harvey@vvc.edu recognized expert on this subject Paola A. Prada-Tiedemann, PhD Assistant Professor, Texas Tech University Paola.Tiedemann@ttu.edu recognized expert on this subject
Opposed Reviewers:	

Dear editors,

1
2 Enclosed with this communication is a manuscript submitted for your esteemed consideration
3 for publication in **Forensic Science International**.
4

5 For some time now, a scientific discourse has been ongoing regarding the performance
6 capabilities of mantrailing dogs in human scent tracking [1-5]. This debate has been stimulated
7 by the utilization of dog-generated results as evidence in legal proceedings. It is noteworthy
8 that only a limited number of studies have explicitly delved into the subject of mantrailing, and
9 not all of these studies have been incorporated into the ongoing discourse. In response to this,
10 the enclosed manuscript offers a comprehensive overview of the current state of research,
11 encompassing pertinent findings pertaining to human scent, canine behavior, mantrailing dog
12 training, and practical insights associated with mantrailing.
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15 We believe that Forensic Science International is exceptionally well-suited for the
16 dissemination of our research findings, given the journal's extensive readership within the field
17 of forensic science.
18

19 We sincerely appreciate your consideration of this manuscript.
20

21 Yours sincerely,
22

23
24 Leif Woidtke
25 On behalf of the authors"
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- 31
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Title:

Proficiencies of Mantrailing Dogs in Law Enforcement and Legal Contexts, Prospects for the Future, Boundaries, and Possibilities - a review

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Highlights

A scientific discourse continues regarding the performance capabilities of mantrailing dogs in tracking human scent trails.

There exists a limited number of studies explicitly addressing the subject of mantrailing.

Some studies suggest, that mantrailing dogs are capable of detecting and following even several days aged human scent trails.

Some practical observations and assumptions related to mantrailing currently lack comprehensive scientific explanation.

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1 Introduction

The use of dogs for search and tracking of individuals has a long history: „*Importantly, the tradition of using Bloodhounds as mantrailers in Britain is shown as having begun at least before 1300.*“[1]. Building on this, modern law enforcement agencies also utilize these abilities [2]. Unlike substance-based searches, such as for drugs or explosives, dogs search for the human scent trail, which is inherently invisible and difficult to visualize through technical means. Additionally, it is currently unknown which components of the human scent dogs utilize for individual scent tracking. However, despite not being fully elucidated, there is evidence suggesting that each person has a unique body odor, as individual as a fingerprint [3]. We have previously presented the fact that the results of dog deployments often find their way into courtrooms [4]. Therefore, it is not surprising that both in the media [5, 6] and in scientific discourse [7-15], there are controversial arguments regarding the reliability or even the fundamental possibility of such results.

Cut to the chase at Ensminger: “*The prosecution cannot rely solely on anecdotes regarding the dog’s capabilities. Instead, a foundation must be laid from academic or scientific sources regarding (a) how long scent remains on an object or at a location; (b) whether every person has a scent that is so unique that it provides an accurate basis for scent identification, such that it can be analogized to human DNA; (c) whether a particular breed of dog is characterized by acute powers of scent and discrimination; and (d) the adequacy of the certification procedures for scent identifications.*” [16, p. 89 referring California v. Willis, 115 Cal.App.4th 379, 9 Cal.Rptr. 3d 235 (Ct. App. 2004).].

The scientific interest in the abilities of dogs has continued to grow in recent years, as reflected in relevant anthologies [16-21], e.g. and yet a systematic literature search conducted in 2012 using relevant databases and combining the search terms "scent," "detection," and "dog" yielded only 31 studies, and in 2015, it yielded only 87 [22, 23]. However, the explicit topic of mantrailing has been minimally researched, and there are only a few known research works that address it. Only one of the mentioned 87 studies specifically focused on the tracking method of "trailing" [24]. A search conducted in the Web of Science database in August 2018 using the term "Mantrailing" yielded only two results from a dataset of 63,550,997 entries [25], and as of May 2023, there were just nine.

The following overview presents the theoretical explanations, existing research, and practical experiences related to mantrailing and human scent discrimination.

2 Human Scent

The discourse regarding the existence of a personal, unique scent for each individual has been ongoing for a long time. As early as 1923, Löhner postulated that one should assume an individual variation and a biochemical individual specificity, particularly with regard to the human individual scent [26]. Based on his research, Löhner concluded that the individual scent of the same person can exhibit temporal changes, which are determined, among other factors, by food intake, as well as the consumption of substances and medications. These changes are primarily attributed to the secretion of sweat and sebaceous glands, as well as the activity of bacteria. Löhner also identified external factors, primarily personal hygiene and cleanliness, which can influence these processes to varying degrees [27].

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1 Menzel and Menzel, after conducting numerous experiments with their dogs, were also
2 convinced of the individuality, or as they formulated it, the inherent scent of each individual.
3 According to their understanding, three physiological processes contribute to the formation of
4 this personal scent: skin respiration, sweat secretion, and the secretion of skin sebum. They
5 consider the continuous release of skin secretions as the most significant source of permanent
6 odor emission. Additionally, Menzel and Menzel explicitly mention the constant shedding of a
7 multitude of skin flakes as another potential source of odor [28].

8 2.1 Origin 9

10 All humans constantly emit a variety of volatile organic compounds (VOCs). Gas
11 chromatography-mass spectrometry (GS-MS) studies showed that human scent secreted from
12 eccrine glands in the palms of the hands [29] consists of a combination of volatile components
13 produced from the skin [30-33] and differing in ratio from person to person, along with some
14 compounds that are specific to certain individuals. This combination contributes to the
15 individuality and uniqueness of human scents [30, 34-40] at a precise given time. Curran et al.
16 described human scent as a combination of VOCs and ultimately defined them as the most
17 abundant VOCs in the headspace of a scent sample [41]. Recent improvements in analysis
18 techniques, including sampling by solid-phase microextraction (SPME) coupled to GC-MS, has
19 led to the identification of hundreds of different volatile molecules, including hydrocarbons,
20 heterocyclic and sulfur-containing compounds, ketones, aldehydes, alcohols, acids and esters,
21 that have been shown to be involved in the composition of human scent (see Cuzuel et al.,
22 2017 for review). Samples obtained from hands, hair, saliva, fingernails, various regions of the
23 skin, breath, underarm perspiration, blood, or urine were examined [30, 31, 33, 34, 38, 43, 44].
24 For a review of VOCs associated with human skin, see, e.g., Dormont et al., 2013, for a review
25 which have dealt with human scent in forensics see Peters et al, 2023. This complex organic
26 volatile mixture actually results from the summation of various types of chemical compound,
27 which have been classified in three categories according to their origin. The primary scent,
28 corresponding to the genetic part of the human volatile organic compound (VOC), is
29 determined by the highly polymorphic major histocompatibility complex (MHC) [37, 46-48]
30 which binds to specific peptides and is emitted by glands [37]. In addition, the primary scent
31 is also determined by the degradation of the MHC-peptide complex by the bacterial flora
32 present on the skin surface, resulting in the production of volatile and odoriferous metabolites
33 [46, 49, 50]. There are several explanatory approaches as to how the MHC could influence
34 odor formation. For instance, MHC molecules or fragments thereof could themselves serve as
35 odorants; however, these proteins are not volatile like certain odors. On the other hand, MHC
36 molecules may bind to an allele-specific subgroup of peptides, and the volatile metabolites of
37 these peptides could be the source of odors. Another consideration is that MHC molecules
38 may act as carriers of odorants, whereby peptide-presenting structures are converted into
39 volatile transport molecules during the breakdown of MHC molecules, to which the volatile
40 odorant binds. A fourth explanation is that there may also be MHC-specific selective bacterial
41 colonization [37, 51-54]. It is known that extrinsic disturbances, such as diseases or nutrition,
42 alter the skin microbiota [55]. The gut microbiome also changes due to diseases or nutrition
43 [56]. Recent studies have observed a connection between the gut microbiome and that of the
44 skin, known as the gut-skin axis, and individual health [57, 58]. Extrinsic factors such as
45 hygiene practices, lifestyle, and the environment influence the abundance and composition of
46 microorganisms on the skin [59]. The survival abilities of respective microorganisms are closely
47 linked to the specific environmental conditions on the skin, including pH, temperature, and
48 moisture [60, 61]. Furthermore, it is known that the longitudinal stability is associated with
49 specific areas of the skin. Sebum-rich areas (e.g., forehead or back) exhibit the highest
50 stability, while dry areas such as the palms and forearms show the greatest temporal variability
51 [62]. The secondary scent results from occasional endogenous production of volatile odorant
52 markers by an individual on a particular diet or in a particular physiological state: e.g., spicy or
53 medical diet, menstrual cycle, emotional state, health status, etc. [63-67]. The third component
54 of human scent comes from exogenous contaminants such as cosmetics (e.g., skin care
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products, fragrances, shampoos, detergents) or volatile odorant molecules present in the environment (e.g., tobacco smoke, odors coming from outside).

In a forensic context, the vast majority of crimes are associated with physical aggression, which involves transfer of biological materials. It is therefore obviously important to develop and validate chemical analysis techniques able to determine the individual VOC profile with the highest precision, representing a unique chemical signature that can be seen as a biometric measurement. In particular, determining the VOCs that are genetically programmed for each individual (primary scent) is an important challenge if human scent is to be considered as a constant and reproducible biometric measure [35, 68-70].

Despite considerable progress in analytical techniques to identify the quantitative and qualitative composition of the complex VOC mixture of human scent, precise determination of the compounds present in the primary, secondary and tertiary scent remains totally out of reach. Yet, very interestingly, while analytic techniques struggle to isolate the primary component from the secondary and tertiary components [68], rigorously trained dogs have been found to be able to perform this task very easily [71-73]. This also applies to identical twins' individual scents [73, 74].

2.2 Dispersal and Deposition

The scent trail originates on the body and contains all the body's scent plus all scents carried on or attached to the body and consists of chemical clues but the specific chemicals used by the dogs to follow the trail are unknown. Consequently, trail scent sources are broadly classified as gases, liquids, or solids and are discussed below in these phases [75, 76]. Volatilization and respiration release gases from the body into the surrounding air. Gases in the scent trail can also include those produced by volatilization from shed particles (liquids and solids) while the particles are in the air and when they are on or attached to surfaces along the trail. Clothing and footwear are secondary sources of scent since they absorb gases, secretions, and particles from the body. Liquids include particles from respiration, perspiration, speaking, sneezing, coughing, and spittle although the last four are not produced continuously and only contribute intermittently to the scent trail. These particles vary in size from aerosols to visible droplets and are likely to contain skin flakes and gases. The aerosols can evaporate while in the air and on the ground leaving skin particles, microbes, and VOCs. Solid particles include shed skin flakes, hair, and those from any extraneous source on the body (e.g. explosives) [77] which may vary in size from sub-micron to visible. When a person moves, the rubbing action produced by footwear and clothing increases the number of solid particles released by the body [78].

An understanding of the human scent trail requires information on how the scent is dispersed from the body and on how the scent is deposited or attached to surfaces on the trail. In addition to the obvious transfer of scent through touch, there are also other ways of "transporting" it into the environment. The constant shedding of a large number of skin flakes is explicitly mentioned as a possible source of the human scent trail [28, 79]. The skin is the largest organ of the human body. Depending on body size, it covers up to approximately two square meters of body surface area [80] and continually renews its outer layer. For this purpose, new cells called keratinocytes are constantly formed in the basal layer (stratum basale). These keratinocytes push the overlying cells through the layers of the epidermis until they reach the outermost layer called the stratum corneum. During this process, the keratinocytes undergo a transformation that ultimately leads to the formation of flattened, nucleus-free corneocytes. This process takes approximately 28 days [81]. Once at the surface, these corneocytes are shed through desquamation. Individual or cohesive detached cells are described as "rafts" [79]. Up to 10 grams of these corneocytes, which have a thickness of 0.5-3 μ m and a diameter of 30-40 μ m, are shed daily [82-84]. Shedding rates for skin flakes vary significantly among individuals, depend strongly on the size range considered, and on the level of activity. The

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1 values range from 667 to 23148 cells per second [62, 79, 85-88]. Nevertheless, the possible
2 error rate of the measurement procedure of 20 to 30% should mentioned [89]. Desquamation
3 is promoted by external influence on the skin, such as occurs during walking, but also by friction
4 over the skin [83]. Whyte and Hejab (2007) found the rate for particles $\geq 0.5 \mu\text{m}$ exceeds two
5 million per minute and a moving person produces millions of particles per minute. Furthermore,
6 a number of bacteria or microcolonies are reported to be present on the shed skin cells/rafts
7 [79, 90-94]. These range from 2 to over 1000, with the number of bacteria at the lower end of
8 the scale and relatively sparsely distributed compared to the entire skin surface area [62]. Taxa
9 that are found exclusively on human skin range in size from $1.1\mu\text{m}$ to $9\mu\text{m}$ [95, 96]. The
10 dispersion per minute of microbe carrying particles averaged 2,400 but can exceed 10,000
11 [97]. Osterkamp (2021) calculated that, depending on the assumptions, particle densities on
12 the trail can reach 1 particle per cm^2 but only on the order of 1 in 1000 carry microbes.

15 VOCs and particles may be trapped or adsorbed on vegetation (grass, weeds) and other
16 surfaces (soils, asphalt, concrete), and in voids above the ground surface (e.g. leaf litter). The
17 particles would continue to emit VOCs which form tiny discrete plumes that move downwind
18 [79]. Changes in wind direction and turbulence near the surface would produce multiple plumes
19 and eventually result in a small cloud of VOCs associated with each particle [76]. These VOCs
20 may attach to surfaces, especially organic surfaces, depending on conditions [98]. Neglecting
21 intermittent processes, the human thermal boundary layer and plume, respiration, body
22 movement which produces bellows action of clothing and footwear, and wind appear to be
23 primarily responsible for dispersal of scent from the body. When air temperatures are colder
24 than skin temperature (average $\sim 33 \text{ }^\circ\text{C}$), air in contact with the skin becomes warmer and
25 lighter which causes it to flow upward in a thin boundary layer along the body surface from the
26 feet to the head [78, 99]. This rising thermal boundary layer exists with clothing with some
27 exceptions (e.g. rain gear, cold weather clothing). Its maximum thickness is about 0.2 m and
28 maximum velocity about 0.3 m/s. The volumetric flow rate can range from 20 – 35 l/s to 70 –
29 80 l/s, depending on environmental conditions [100]. As early as 1969, Lewis et al., 1969
30 described this airflow, which starts at the feet and continues from there along the body to above
31 the head, where it forms a cloud and then passes into the ambient air. This airflow around the
32 body contains 30-400% more microorganisms than the ambient air. Larger particles (greater
33 than $50 \mu\text{m}$ in diameter) are likely to fall to the bottom, but smaller particles are entrained and
34 move upward with the airflow.

37 Most clothing is permeable to gases and particles which allows them to be incorporated into
38 the boundary layer although with reduced numbers. Since the layer transits the body from feet
39 to head, it incorporates scent from every part of the body including VOCs, skin flakes, aerosols,
40 and other similar sized liquid and solid particles. This flow can carry particles, which are
41 repelled from the body and have approximately the density of water, up to a diameter of $80\mu\text{m}$
42 [78]. Here it should be taken into account that depending on the particle shape and size, the
43 surface area of attack differs for different forces. The larger the surface area, the stronger the
44 potential for uplift until a certain size is reached where gravity dominates. This threshold is
45 seen to be around $100\mu\text{m}$ [102]. Desquamated human skin cells account for the majority of
46 particles within the thermal cloud and flow surrounding humans [100]. Consequently, when the
47 boundary layer separates from the body at the top of the head it becomes the human thermal
48 plume which carries scent from every part of the body. In still air, the plume extends up to
49 about 2 m above the body. A light horizontal wind, $<1 \text{ m/s}$, is enough to tilt the plume above
50 the head significantly [99] or destroy it completely [103]. The distribution of the particles is
51 influenced by the wake created during walking. Thus, there is a recirculation zone in the upper
52 part of the wake flow, from the head to the legs. This recirculation zone ends at the legs, as it
53 is divided by a flow generated by the counter-rotating motion of the legs. At the same time,
54 due to the forward motion behind the body, a downwash is generated. The interaction with the
55 recirculation flow causes the air suction to widen laterally behind the lower torso and legs. In
56 this process, the highest concentrations of evenly distributed contaminants are found behind
57 the shoulders and legs [104, 105]. In still air, the released particles descend about 2 to 5cm
58 per second, depending on their size [106]. Boundary layer collection of all scent on the body,

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1 it's incorporation into the plume, and deposition on the trail, indicates that the scent trail
2 contains scent from every part of the body.

3 Schlieren studies of the boundary layer [107] show that exhaled air through the nose and
4 mouth can penetrate the layer but may be partially incorporated into it. This contributes gases
5 and particles from respiration to the layer which would be incorporated into the thermal plume.
6 For air temperatures warmer than the skin temperature, air in contact with the skin would cool
7 and the flow would be reversed and carry scent to the ground [76]. Much of this scent would
8 be deposited on the ground and other surfaces (e.g. vegetation) close to the trail. This may be
9 an important consideration for trails made in hot weather but there is no information available
10 for this reverse human thermal boundary layer and plume. It has been demonstrated [77, 78]
11 that the bellows action of clothing and footwear can eject gases and particles from shirt collars
12 and cuffs and the bottoms of pant legs and tops of footwear. While some of the ejected
13 materials are incorporated into the boundary layer, pant legs and footwear have the potential
14 for depositing scent directly on surfaces along the trail [76]. This scent would not be from every
15 part of the body. If there is no wind, the human thermal plume carrying scent above the head
16 of a standing person would slowly settle around the person and be deposited on the ground
17 and other nearby surfaces. However, more information is needed, especially the effects of
18 windspeed and direction relative to the trail. The wake provides a process by which trail scent
19 can be deposited or trapped on surfaces and linger in the air along the trail. Continued
20 production of VOCs by bacteria on particles provides a process which can increase the density
21 of scent along the trail. The effects of wind on the boundary layer are to disrupt it on the
22 windward side and to create turbulence on the downwind side.

23 For a briskly walking person with no wind, the plume forms a turbulent wake with eddies behind
24 the person [108]. The eddies in the wake are carried downward behind the person and would
25 contact the ground and other surfaces along the trail. For wind parallel to the trail, the wake
26 would still cause deposition of scent along the trail at a location depending on the velocity of
27 the wind relative to the trail layer. For wind at an angle to the trail, the characteristics of the
28 wake would be modified but the wake would still be likely to cause deposition of scent on the
29 ground although at some distance from the trail. Particles would be deposited on surfaces
30 along the trail and downwind of it. The presence of secretions on skin flakes may make them
31 "sticky" so they would tend to adhere to surfaces and each other. Particles and VOCs may be
32 trapped in dense vegetation (grass, weeds), pores of surface soils and hard surfaces (asphalt,
33 concrete), and in the interstices of leaf litter. When deposited or trapped on surfaces, particles
34 continue to emit VOCs which form tiny discrete plumes that move downwind [79]. Changes in
35 wind direction and turbulence near the surface would produce multiple plumes and eventually
36 result in a tiny cloud of VOCs associated with each particle [75]. The VOCs may attach to
37 surfaces depending on conditions. A similar behavior of pheromones of the light brown apple
38 moth (*Epiphyas postvittana*) has been described [98]. The distribution (partitioning) of VOCs
39 on trail surfaces depends on surface temperatures, surface characteristics, and other factors
40 [109]. VOCs move to soil particle surfaces at low soil moisture contents but can be released
41 by high humidity or light rain. VOCs move to vegetation at lower ambient temperatures and to
42 the atmosphere at higher ambient temperatures. This indicates there is a daily cycle in the
43 concentrations of VOCs in the air and on surfaces (Simonich, personal communication, 2011).
44 Concentrations on surfaces should be higher during the night and for surfaces in shade
45 compared to these surfaces in sunlight. Concentrations near surfaces in sunlight would be
46 strongly influenced by wind and convective instability. VOCs also partition between the gases
47 and aerosol particles [110] and would be expected to partition between the airborne VOCs and
48 skin flakes whether or not skin bacteria are present on the flakes. The implications of this for
49 trail scent are that all flakes would have VOCs on them whether or not they have bacteria. This
50 result is also predicted from different considerations by the recently introduced Permeative and
51 Aerosolized Corneocyte Model (PACM) [111]. The PACM aims to provide an answer to the
52 numerous anecdotal reports from dog handlers regarding the behavior of dogs in various
53 situations. In this context, the stability of odor and the fact that dogs can trail even when the
54 contribution of bacteria to the scent trail has been removed play a crucial role. The PACM
55 relies on VOC sources that are permeative in nature, aerosolizeable, and corneocyte particle
56 (keratin filament mesh) based, and is premised on the idea that cells detach from the body due

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1 to the skin renewal process. Furthermore, it is important to note that this process occurs over
2 a period of approximately 30 days. The different properties of corneocytes can be correlated
3 with various types of keratin molecules within the cells. Additionally, keratin filaments can form
4 a type of cytoskeleton or scaffolding that encapsulates the components (dissolved VOCs) of
5 each cell and potentially even multiple cells. The scaffold-forming keratin can also serve as a
6 nutrition source for adherent bacteria, even when the cells have detached from the body. The
7 PACM postulates that this non-uniform "net" or mesh composed of keratin-derived molecules
8 serves as the permeation medium for the chemicals contained within the corneocytes, which
9 were generated in an individual over the last 30 to 35 days. Even in the absence of bacteria,
10 the entrained components could still permeate out from inside the corneocyte. The amount
11 released is sufficient to achieve a significant signal-to-background ratio for dogs. Furthermore,
12 keratins are partially resistant to digestion by certain proteases, and insoluble in dilute acids,
13 alkalis, water, and organic solvents [111, p. 286-296]. This could explain the stability of the
14 scent in the environment.
15

16 2.3 Stability

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18 In agreement with previous studies [41, 112, 113], the data obtained in dogs suggest that
19 chemical features of human scent can persist for as long as several days [114, 115]. In
20 addition, it was shown that dogs could successfully detect human odor on objects heated to
21 800°C, and two dogs could do so even on objects heated to 900°C [116] or from cartridge
22 cases after being fired [117]. The possible stability of human scent after high thermal exposure
23 is supported by the fact that other biological material can also be recovered from objects after
24 severe heating [118] or detonation. [119].
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27 Furthermore, studies showed that dogs were able to detect and identify human scent from
28 aged samples, e.g. for samples, aged 6 weeks [28] or 2 years [120]. One study reported that
29 7-year-old scent samples led to correct identification in 8 out of 12 cases in a scent lineup
30 [121]. Reports are also available for 17-year-aged [122, p. 64] or 15-year-aged samples [42].
31 While there is very little research on the stability of human trail scent under field conditions,
32 anecdotal evidence from handlers suggests that the scent is sufficiently stable to allow trailing
33 dogs to trail a month or more after the trail was made. It has been proven that scent traces can
34 also survive on objects stored outdoors and can be detected by dogs. This was achieved with
35 objects after six and eight weeks, although with low success rates and not with significant
36 accuracy [123]. The findings of a recent study revealed that, out of a cohort of five dogs tested,
37 two demonstrated the ability to successfully match the scent article that had been aged for 64
38 weeks [124]. Scent traces of persons standing on wooden floors, concrete and asphalt
39 surfaces, sandy floors, iron surfaces and plastic could be used for successful scent
40 discrimination even after four weeks, depending on the environmental impact. The same was
41 true for a trace exposed to heavy rain for 14 days [122]. It was also possible to pick up and
42 follow a six-day-old track over about 1500m [125]. Tracks of body fluids (blood and seminal
43 fluid) deposited outdoors could be indicated after periods of up to six days. In some cases, a
44 complete DNA profile could be determined from these traces [126]. The stability of human
45 scent on scent articles has been demonstrated by subjecting them to fire, explosions, radiation,
46 chemicals, and aging [127]. The articles included two gas cans (metal and plastic), four pipe
47 bombs with different explosives, five paper sheets irradiated with about 40 kGy for one hour,
48 and four paper sheets sprayed with a ten-percent solution of sodium hypochlorite. Scent was
49 collected from all items on sterile gauze pads using the STU-100. Trailing dogs with these
50 articles were highly successful matching the scent on the pads and trailing to the correct
51 subject [127] indicating that the discriminating qualities of the scent survived being subjected
52 to conditions involving fire, explosions, radiation, and a chemical treatment. These conditions
53 would be expected to destroy skin flakes and bacteria, modify the composition of VOCs, and
54 render these scent articles useless. However, DNA has been recovered from steel fragments
55 of exploded pipe bombs [128] as well as from postblast IED containers [129] and parts of
56 fingerprints which can contain skin flakes and bacteria have been shown to survive on fired
57 cartridge cases [130-132] and DNA can be obtained [133]. Osterkamp's unpublished research
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1 has previously suggested the capability of dogs to trail from scent articles containing as few as
2 two fingerprints. It is suggested herein that partial or complete fingerprints on the bottoms of
3 the gas cans, bomb components or bomb fragments, and the undersides of the sprayed and
4 the irradiated paper sheets may have survived these conditions which would have made the
5 scent articles viable for trailing dogs. Dogs have also successfully trailed using scent articles
6 obtained from much larger explosions [24]. The PACM [111] predicts that viable scent may
7 survive the explosions as a result of permeation and aerosolization of the skin flakes.

8
9 Two studies investigated the tracking of aged trails [134, 135]. Wolf examined trails aged one
10 day, one week and one month with a length of 500m. Woidtke studied trails aged 1, 2, 3, and
11 6 months. Trails had varying lengths from 400m to several thousand meters. Both concluded
12 that the dogs were generally capable of following the trail at all tested ages (further details can
13 be found in the subsequent section on studies). In both studies, there was no chemical analysis
14 of the scent articles. In a series of tests by the German police with trails aged one month results
15 similar to those reported by Woidtke, 2020 were obtained [8].
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18 The continuous production of VOCs by residual bacteria on particles is a process that can
19 increase the odor density along the trail. However, it should be considered that this is not the
20 case in all situations. Bacteria are highly sensitive to the effects of UV radiation due to their
21 small size, short generation time, and lack of effective UV-protective pigmentation. With
22 sunlight, UV-A (wavelength 320-400 nm) and UV-B rays (280-320 nm) reach the Earth's
23 surface. The bactericidal effect of ultraviolet A light is attributed to oxidative damage to lipids,
24 proteins, and DNA, while UV-B radiation causes direct DNA damage by inducing the formation
25 of DNA lesions (photoproducts), especially pyrimidine dimers, which block DNA replication and
26 RNA transcription [136]. Additionally, bacteria are destroyed due to thermal effects [137], and
27 it can be assumed that after destruction, they do not contribute to the individual human scent
28 trail. The notion that the key stimulus for individual scent tracking by mantrailing dogs is
29 associated with the constantly shed skin cells is not invalidated by the fact that the bacteria
30 present on them cease their metabolism. Considering the aforementioned aspects, it appears
31 plausible that bacteria and their metabolic products may not contribute as a key stimulus for
32 individual scent tracking under certain conditions.
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34 This is not contradicted by the fact that individuals could be identified based on their individual
35 microbial cloud. On one hand, the cited study (Meadow et al., 2015) was a laboratory
36 experiment conducted in an enclosed space, and the personal classifiability in this study likely
37 depended on the relatively low microbial background biomass (e.g., dust) in the test chamber,
38 and these patterns were not evaluated in the presence of multiple individuals. Furthermore, in
39 a second experiment, the differentiation of individual persons relied on the detection of a
40 certain number (at least 20%) of subgroups of human-associated taxa. The second experiment
41 confirms the assumption that detectability depends on the amount of bacterial biomass emitted
42 by a person. Furthermore, it is noted that with increasing air exchange, as expected under real
43 conditions, the detectable human microbial cloud is nearly eliminated [138]. The above
44 discussion indicates that the scent trail followed by dogs likely consists of VOCs present as
45 gases and liquid and solid particles. These can be present in the air and deposited on or
46 attached to trail surfaces. It has been shown that, during sniffing, strong exhalation jets from
47 the dog's nose can remove particles from surfaces and that some of these airborne particles
48 are inhaled [99, 139]. Handler observations suggest that dogs learn to use these jets to remove
49 VOCs from surfaces and inhale them while working. This examination of the behavior of
50 particles and VOCs on trails may help to explain some of the ease and difficulties that trailing
51 dogs have when trailing under the conditions noted above. The PACM [111] appears to explain
52 some of the handler observed behaviors of trailing dogs while trailing but needs to be
53 experimentally verified.
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3 Dog Behavior

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3.1 Cognitive aspects

To understand how dogs successfully differentiate between various scents and trail the right one, it is essential to understand the social and sensory cognitive abilities that dogs possess as well as the many factors influencing dog cognition. Here we examine different aspects affecting and directing dog behavior. Dogs' cognitive abilities are a complex interplay of developmental factors, mental and sensory skills as well as perceptual abilities, personality, and motivation [140]. There have been many studies and reviews seeking to understand the underlying mechanisms that allow us to predict whether a working dog fails or succeeds in their training [141-144]. We will first delve into the sensory cognitive abilities that dogs possess that allow them to be trained in multiple different fields. We will then take a closer look at working dogs and the unique traits that make them well-fitted to work in their respective fields. In the following we seek to summarize different aspects of dogs' social and nonsocial cognitive abilities and focusing especially on what researchers have found in regard to dogs' olfactory abilities which play a vital part in mantrailing dogs. Nonsocial cognition studies mostly focus on dogs' perception of their environment, how they develop mental representations of physical stimuli in their environment, as well as what elements dogs utilize to solve a variety of different tasks. Nonsocial cognitive skills entail abilities like discrimination learning, categorization, memory, problem-solving and quantitative understanding [145]. Social cognition studies mainly focus on the aspects of dog-to-human communication, social learning, response to human cues and perspective taking. When looking at the nonsocial cognitive skills of dogs, we identified three subcategories that play an important role in the context of scent recognition and mantrailing.

Object Learning

Researchers have found that dogs are capable of object learning, building mental representations of objects – as well as people and other animals – and then integrating different characteristics of that same object by using associative learning [146]. The basis for this is the dogs' capability of object permanence, which refers to the ability of understanding that objects still exist outside of the individual field of perception [147]. This has been tested and replicated multiple times by testing dogs on a visible displacement task [148-150]. Researchers could furthermore verify that dogs reach Stage 5b of object permanence after Jean Piaget, meaning they are able to successively retrieve an object they saw being hidden in several hiding locations, not making A-not-B errors anymore. The A-not-B error manifests when dogs successively search in the last location they saw the object prior to its disappearance [151, 152]. There has been some debate whether dogs reach Stage 6 of object permanence, referring to the ability to solve an invisible displacement task where the object is hidden out of sight of the dogs and they would need to use inferential reasoning to find the target object [153-155].

In terms of object learning however, studies found that dogs can combine auditory and visual stimuli of social partners and create a mental representation of what their social partner should look like. Faragó et al. tested this by using dogs as the social stimulus. Playing an audio of a dog growling, dogs in the experiment were shown two pictures of the same dog: One picture showed the actual size of the dog while the other picture was edited to make the dog look either 30% larger or smaller. The results showed that the test dogs looked first and/or looked longer at the picture of the live-sized target dog, indicating they had matched the size of the dog with the sound of the growl [156]. A similar study was conducted by Gazit et al. (2005)

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1 based on olfactory cues: They found that dogs seemed to use odor cues to develop
2 expectations about hidden targets. This was tested by letting trained working dogs find hidden
3 explosives with unique odor signatures (PETN, TNT, C4). With baseline detection rates over
4 80% dogs were highly successful at finding the hidden location of all three odor types but
5 showed the lowest baseline performance at finding TNT through odor cues. After doing
6 repeated search trials with only TNT, the two other target scents were reintroduced, and
7 searches were performed with all odor cues again. However, TNT scent targets were
8 manipulated and found in either smaller or larger proportions than the other scent targets. After
9 having greater exposure to the TNT target scent, the dogs' search efficiency for TNT improved
10 largely but only on trials where the probability of finding TNT remained high [157]. These results
11 suggest that dogs formed expectations based on previous TNT odor cue encounters. These
12 studies highlight one vital skill for dogs working in the field of scent detection as they need to
13 rely on their olfactory skills to find hidden target objects. Another study by Bräuer & Belger
14 (2018) found that dogs match an odor trail with the corresponding object. They tested this by
15 using a violation-of-expectation paradigm where dogs (family dogs & working dogs) were
16 following a scent trail of Target A but at the end of the trail were led to Target B. Dogs showed
17 signs of "surprise" (e.g., continued search for target A) when encountering Target B instead of
18 the expected Target A, indicating they had matched the scent of Target A to the corresponding
19 object [158].
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Discrimination Learning

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27 Learning to discriminate similar stimuli is of utmost importance for working dogs in many fields
28 and especially for scent detection dogs as they need to alert their handler only to a specific
29 target odor and ignore other odors. They therefore need to be able to successfully discriminate
30 between the target odor and other scent cues. Discrimination learning furthermore is an
31 important component in dog training as many stimuli that are introduced to dogs – for example
32 human or explosives odors – first have no intrinsic biological relevance to the dog [145]. Dogs
33 are especially well suited for odor detection tasks as their sense of smell seems to be the
34 sense they rely on the most as a study of Gazit & Terkel (2003) showed. When comparing
35 whether sniffer dogs relied on their vision or olfaction for detection tasks, olfaction was the
36 main sense dogs utilized not only in very low light intensity but also when the light intensity
37 was high. The six sniffer dogs in the study were required to find explosives, both in controlled
38 indoor conditions and in uncontrolled conditions outside on a field track. Neither the presence
39 nor the absence of light affected the sniffer dogs' ability to detect the explosives which in turn
40 meant that odor detection could be carried out by the same individuals during day and night
41 [159]. Another study by Hall et al. (2013) confirmed that dogs learned an odor discrimination
42 task quicker and with more success than a visual discrimination task [160]. Williams and
43 Johnston (2002) furthermore found that dogs can be trained on recognizing multiple odors
44 without a decrease in detection performance. In their study, dogs were first trained to detect
45 one single scent. After 10 days, detection performance of the same odor was tested again,
46 and the dogs were given refresher training to bring the performance up to the required standard
47 again. After dogs received the refresher training, they were introduced to a new odor they had
48 to detect, given a 10-day rest period, and afterwards were tested on the detection of both
49 learned odors. This sequence was then repeated every 10 days, adding a new odor at each
50 new trial until dogs were trained on recognizing 10 different target odors. The authors found
51 that even with the increase of trained odors, detection performance of previously learned odors
52 did not decrease. Furthermore, training the dogs on new odor cues and giving them refresher
53 training for scent detection took less time as more scent discriminations were trained [161].
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1 Researchers also tested dogs' scent discrimination abilities within two different training
2 approaches. The first group of sniffer dogs were trained on detecting the pure target odor, the
3 second group was trained on recognizing the target scent in different odor mixtures. The dogs
4 were then tested on their detection performance with the odor in a new context: Six different
5 herbs (dandelion, basil, parsley, ribwort, St. John's wort, marjoram) were combined into
6 various mixtures with the target odor chamomile either added (positive) or not (negative). The
7 dogs were trained to show specific behaviors for each context, one behavior for when the
8 target scent was detected, one for when the target scent was missing. Test presented one
9 sample at a time. Both training approaches were successful in teaching the dogs to
10 discriminate between scents and find the target odor in any of the presented mixtures with an
11 overall sensitivity of 72% and a specificity of 84%. Dogs that were trained with the second
12 method had more success in identifying the target odor in the transfer task [162].
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16 *Spatial cognition*

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18 Spatial cognition abilities play a role in a number of different jobs that dogs serve in, e.g.
19 detection, herding, patrolling. Spatial cognitive mechanisms allow dogs to navigate and orient
20 themselves in their environment as well as track the location of objects, persons, and other
21 animals [145]. Different studies have been conducted on dogs' spatial cognition abilities,
22 examining dogs' navigation skills in different contexts and how spatial cues influence dogs'
23 search behavior as well as how search strategies might differ between dogs and how those
24 strategies influence search performance. Searching efficiency is a vital skill for dogs working
25 in odor detection jobs, whether that be in search and rescue, explosives detection or
26 mantrailing. Particularly when looking at the search strategies of dogs, there seem to be large
27 individual differences. Fabrigoule and Sagave (1992) analyzed dogs' searching performance
28 and strategy when navigating six radially distributed food sites within an open space. Across
29 trials, dogs showed high efficiency in searching the sites with only a few search omissions or
30 repeated searches. Strategies however differed: While some dogs searched more
31 sporadically, one dog started to use a circular search pattern across the sites [163]. Search
32 strategies have also been shown to be influenced by meteorological conditions. While dogs
33 are successful in finding target scents in different weather conditions [164], their strategy and
34 speed changes according to changes in humidity and air temperature [165]. Olfactory
35 orientation behaviors of trained search and rescue dogs were observed under different
36 weather conditions when searching for a hidden human target (trail aged 1-3 hours) in a natural
37 landscape. With a 93% success rate, dogs were highly successful at finding the hidden human
38 target 800m from the start location. As air temperature became cooler and more humid, dogs
39 adapted their search strategy by searching closer to the experimental trail and modifying their
40 head position and speed according to their location distance to the experimental trail. Dogs
41 ran at a quicker pace and searched with their head up when close to the trail, while their speed
42 decreased and they were more likely to search with their nose on the ground when their search
43 took them farther away from the experimental trail [165].
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52 When looking at spatial cue preferences, there seems to be some uncertainty as to how dogs
53 select in which order different baited target sites are visited. One study of Dumas & Pagé
54 (2006) found that dogs seem to randomly select which target site to visit first when they're
55 given multiple search sites to explore, and all target sites were at an equal distance from the
56 dog's starting point with only slight modifications in angular deviation [166]. However, when
57 angular deviation was higher or a different number of targets were available, dogs seemed to
58 rely on the principle of maximum divergence, meaning after visiting one (unbaited) site, they
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1 chose the target site farthest away in their next trial [167]. As of now, it is not clear whether
2 dogs use random selection or divergent selection when given the option of multiple search
3 sites and more research needs to be conducted in that area. In terms of spatial navigation,
4 research focusses mostly on which spatial cues dogs use to navigate their environment.
5 Egocentric spatial cues refer to a target location in relation to the dog's own position while
6 allocentric spatial cues are related to the target location in relation to external environmental
7 stimuli [145]. Dogs have been shown to use both egocentric and allocentric spatial cues to
8 navigate in different types of tasks [168]. During an object location task, dogs seem to prefer
9 following egocentric cues but can switch to allocentric navigation when egocentric cues were
10 no longer available or became useless [169, 170]. Christie et al. (2005) furthermore reported
11 that age plays a role in the spatial navigation of dogs [171]: Older dogs (+8 years) and young
12 dogs (6 months – 5 years) perform similarly using egocentric cues to navigate. Older dogs
13 however perform significantly poorer when using allocentric cues. Researchers furthermore
14 investigated how sex and sexual intactness influence spatial navigation skills. Sexual
15 hormones have been proven to influence spatial cognition with gonadectomy potentially
16 affecting spatial learning skills in female dogs [172]. Scandurra et al. (2018) tested the effects
17 that gonadectomy had on the spatial navigation skills of dogs and whether gonadectomized
18 dogs seemed to prefer allocentric or egocentric navigation. They first determined which
19 strategy dogs preferred in a navigation task in a plus-shaped maze. Afterwards they tested the
20 four dog groups (divided into equal groups based on sex and gonadectomy) on their non-
21 preferred strategy when their preferred strategy was no longer possible. Sex didn't seem to
22 influence the preferred strategy. However, ovariectomized females showed a strong
23 preference for egocentric navigation. There was an increase of successfully resorting to the
24 non-preferred strategy in older female dogs while there was a decrease in older male dogs.
25 Younger males seemed to be able to flexibly switch between navigation strategies [173, 174].
26 The above-mentioned areas cover some of nonsocial cognitive abilities important for odor
27 detection and focus mostly on the sensory skills of dogs. As dogs are however highly social
28 animals that interact and communicate with humans in a multitude of ways, it is of utmost
29 importance to understand which social cognitive skills influence and direct success in scent
30 detection dogs. There have been a few studies suggesting that behavioral and social learning
31 components actually play a bigger role in successfully training a working dog than sensory or
32 morphological traits [175, 176]. A job in scent detection requires dogs to successfully
33 communicate with their handler: after finding a target odor, they must be capable of indicating
34 the presence of said target odor to their handler as well as inhibit alerting their handler to non-
35 target odors. Dogs having the sensory abilities to do so still doesn't guarantee success in a
36 working dog role. Maejima et al. (2007) reports that many working dogs do not successfully
37 complete their training or do have to be withdrawn from their jobs prematurely [177]. This can
38 have several reasons, from decreased welfare due to stress, poor performance, breed to
39 personality [142]. That is why it is important to understand which social cognitive traits play a
40 role in scent detection jobs, not only to increase performance but also to identify suitable
41 selection criteria that help predict working dog success.

52 Personality – defined as a set of behavioral traits that show consistently over different contexts
53 and time – has been linked to either success or failure during training programs in odor
54 detection dogs [177]. Certain personality traits seem to enable dogs to perform better at scent
55 detection tasks while other traits inhibit them from doing so. Lazarowski et al. (2018) examined
56 the behavioral characteristics of dogs that underwent training to detect hand-carried and body-
57 worn explosives and which characteristics set successfully trained dogs apart from dogs who
58 were not able to perform the tasks required of them. 146 dogs received identical puppy training
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1 during development as well as basic odor training. After undergoing performance evaluations
2 at 3, 6, 10, and 12 months old, they were then sold for service. Dogs were categorized into
3 three groups: dogs successfully sold for body-worn explosives detection, dogs sold for
4 standard explosives detection, and dogs that failed to be sold for any type of detection job
5 (washouts). The dogs were compared in terms of performance (search-related behaviors),
6 trainability (ability to learn new skills) and environmental stimuli (reaction to novel stimuli). Dogs
7 that were successfully sold for hand-carried and body-worn explosives detection scored higher
8 in the trainability and performance sector compared to dogs sold for general explosives
9 detection and washout dogs. In the performance sector, successful candidates especially
10 scored higher in the categories of *Hunt*, *Focus*, *Possession*, *Independence*, and *Work Effort*.
11 Another interesting finding in this study was that dogs sold for general explosive detection and
12 washout dogs did not differ significantly on the performance scale but that most washout dogs
13 failed to be sold due to difficulties in the section of reaction to novel stimuli [178]. Another
14 important aspect that was found in this study was that specialized scent detection dogs scored
15 higher than the other dogs in the *Independence* subcategory. This is in line with other working
16 dog studies that have found that a certain level of autonomy is an important trait in working
17 dogs [179, 180]. While working dogs need to communicate efficiently with their handler and
18 show obedience to their handler's cues, Troiski et al. (2019) makes an important point in their
19 review: Pet dogs who tend to have a strong social bond with their humans spend more time
20 gazing at their owners which positively correlates with obedience [142]. However, pet dogs
21 have also been reported to perform worse in an independent problem-solving task than
22 working dogs, indicating that pet dogs rely more heavily on their owners to guide them during
23 novel or challenging tasks (in Troiski et al., 2019). This in turn means that to be successful in
24 their respective fields, working dogs must remain a degree of independence from their handlers
25 to be able to perform well. This however does not mean that working dogs and handlers should
26 not have a social bond at all. There are a number of studies that underline the importance of
27 dogs and their handlers being a bonded team, which not only affects dog performance but also
28 their overall welfare and arousal levels [143, 144, 181, 182]. Lefebvre et al. (2007) found a
29 correlation between the amount of time military dog handlers spent with their working dogs and
30 the dogs' behavior in terms of well-being, aggression, and obedience. Handlers who took their
31 dogs home and/or engaged in sports activities with them reported fewer biting incidents
32 compared to those who housed their dogs in military kennels. Dogs that spent more time with
33 their handlers also exhibited a higher level of obedience, and dogs living with their handlers
34 were reported to be more sociable. Furthermore, dogs practicing sport with their handlers
35 and/or living at home with their handlers showed fewer signs of impaired welfare. Dogs with
36 suspected previous mistreatment displayed a higher level of anxiety and aggression [144]. It
37 has been furthermore shown that changing a familiar handler to an unfamiliar one negatively
38 impacts dogs' detection performance and behaviors. Dogs working with their familiar handlers
39 exhibited higher detection accuracy and were also less distracted [143]. Furthermore, there is
40 evidence suggesting a connection between salivary cortisol levels of working dogs and their
41 handlers, which are used as an indicator of stress. In an experiment, the stress level of the
42 handler was found to correlate with the stress level of their dog, and this influence was
43 reciprocal. This was particularly evident when either the dog or the handler made a mistake or
44 failed a task during a performance test. The correlation of stress levels was more pronounced
45 in female handlers and their female dogs. [181]. Another study conducted by Lit et al. (2011)
46 discovered that handler beliefs influence working dog detection outcomes. In their study, they
47 examined whether dogs in scent detection tasks can be influenced by their handler's belief in
48 the presence of a target scent, and vice versa. They found that dogs were indeed influenced

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1 by their handler's belief and more frequently falsely indicated the presence of an scent when
2 their handler believed a target scent was present [180]. Numerous studies have been
3 conducted on how life experiences and temperament shape the cognitive abilities of dogs and
4 how these experiences contribute to either their success or failure in working dog roles [183-
5 185]. Foraita et al. (2021) wrote an extensive review about how environmental influences affect
6 the development of executive functions in dogs. These environmental variables include stress,
7 early life experiences, housing and training. It is beyond the scope of this article to delve deeper
8 into the different categories here. The aspect of training will be mentioned later on in more
9 depth as it actively influences working dog success or failure. Here, we will only briefly mention
10 two social learning strategies that potentially enhance dog performance: the model-rival
11 technique utilizes social stimuli to create an interest and/or curiosity for an object in the dog,
12 meaning instead of using food as a reinforcement strategy, the dog learns to perform a task
13 for an intrinsic reward, e.g., by learning the features of an object and then retrieving it
14 successfully [187]. McKinley & Young tested this by comparing learning through operant
15 conditioning and the model-rival method. They labelled different objects, e.g., all yellow toys
16 were labelled "SOCKS" and all red toys were labelled "CROSS". One trainer and one model-
17 rival were then having a conversation about one of the objects where the model-rival would
18 retrieve the object and pass it back to the trainer while naming the label of said object. They
19 found that operant conditioning and the model-rival method both had the same efficacy in
20 training dogs to retrieve certain objects [187]. However, Cracknell, Mills & Kaulfuss (2008)
21 found while replicating McKinley & Young's study and adding the component of stimulus
22 enhancement (e.g., one of the experimenters holding the object that should be retrieved) that
23 dogs learned to retrieve a named object quicker due to stimulus enhancement and not
24 necessarily possessed the complex cognitive abilities that are suggested in the model-rival
25 method [188]. Another established social learning training method is the Do as I do method
26 where dogs learn to copy the behavior of a human demonstrator on the command "Do it!".
27 After learning from a social partner, they are later able to translate and generalize what they
28 learned on to novel actions [189]. This method has also been proven to be more effective than
29 shaping/clicker training [189, 190]. In the context of social learning, the aspect of reversal
30 learning should also be mentioned. Reversal learning tests both inhibitory control and
31 behavioral flexibility. In a reversal learning task, dogs' reaction is assessed when a previously
32 correct response is no longer valid [175]. Fagnani, Bentosela & Barrera (2020) found some
33 evidence that dogs are more successful at reversal learning when in a social context, with
34 humans as a stimulus, instead of two apparatuses. They however also mentioned that their
35 results should be assessed with caution [191]. More research in this area is needed to confirm
36 these findings.

3.2 Motivation

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49 Selecting dogs that are suitable for a job in odor detection often boils down to identifying traits
50 that are correlated with a high level of success during working dog training. We previously
51 mentioned how personality plays a key part in selecting dogs to train in scent detection. Some
52 of the personality traits identified as important factors are boldness, the ability to cope with
53 stressful situations and environments as well as a strong motivation [176, 177, 179, 192, 193].
54 But how to define and quantify motivation? Motivation is defined as the force that initiates,
55 guides and drives goal-oriented behavior. Most commonly, motivation is divided into the
56 categories of internal and external motivation. While external motivation is often driven by the
57 desire to earn rewards such as food or praise, internal motivation arises from the gratification
58 that solving a task or a problem brings or the curiosity for a novel stimulus or situation [194-
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196]. Animals are motivated by both intrinsic and external factors [197]. Researchers have furthermore identified three key components to motivation: activation – which describes the decision to initiate a behavior, persistence which is the continued effort put in a task despite challenges or obstacles, and lastly intensity which describes the energy and concentration that goes into the pursuit of a goal [198, 199]. There are different methods to test motivation or “drive” in an experimental setup. Some researchers examine their experimental trials post hoc to check for motivational factors that may have been influencing behavior during the experiment. Indicators of decreased motivation could be greater latencies to begin an interaction with a test object or a delayed decision-making process [200, 201]. Other researchers make sure that the food motivation of dogs is similar, by asking owners to fast their dogs for 4 hours minimum or overnight before participation in the experiment begins [185, 202]. However, dogs should not be too hungry when given a search task: Miller & Bender (2012) found that dogs that were fed before engaging in a working memory task searched more accurately than dogs that weren’t fed. This positive effect on memory however only lasted until 30 minutes after breakfast consumption [203]. Another method is to conduct “warm-up trials” before the experiment to test which dogs are motivated to participate in the experiment: Only dogs that e.g., fetch a toy repeatedly or show high food motivation after given the opportunity to approach said rewards freely are included in the study [204-207].

In the context of motivation, it is also useful to mention the reinforcement sensitivity theory (RFT). This theory describes three major systems which influence an individual’s behavior: The Fight-Flight-Freeze System activated by aversive stimuli such as punishment or predators, the Behavioral Inhibition System activated by uncertain or conflicting stimuli and the Behavioral Approach System activated by rewards such as food, praise, or positive social interaction [208]. There are large interindividual differences in the sensitivity towards these systems that in turn result in differences in personality [209]. Thus, some stimuli are perceived as more positive or negative by different individuals due to their differences in sensitivity: some animals may experience negative activation by a certain stimulus while others are positively activated through the same stimulus [210, 211]. When selecting potentially suitable working dogs, it may prove to be helpful to assess their positive-negative activation (reward-aversion) sensitivity as dogs that score high in positive activation, or extraversion, show high levels of exploratory behavior and strong motivation when positively reinforced [192]. High levels of positive activation/motivation have also been linked to a higher chance of successfully completing working dog training [177, 179, 184, 192, 212]. Another factor worth noting in the context of motivation, is the correlation of high persistence and stereotypies. Protopopova, Hall & Wynne (2014) found that dogs with stereotypies also had a higher perseverance and persistence during an extinction task. Stereotypies indicate decreased welfare and should not go unnoticed and untreated [213]. Another study by Dalal & Hall (2019) found that persistence is associated with a decreased performance in an olfactory discrimination learning task, something that could be extremely detrimental to dogs working in scent detection [214]. Higher levels of persistence are also associated with behavioral inflexibility [215]. It is therefore important to select working dogs that show high levels of motivation and behavioral flexibility as only high persistence will not guarantee a successful working dog and may even have negative consequences in the performance sector. Thus, assessing motivation at the level of temperament is a helpful and important tool to select suitable scent detection dogs as an individual’s response to certain stimuli should allow to predict behavior over a range of contexts on a trait-level [196]. Gazit, Goldblatt & Terkel (2005) found a link between long-term reference memory and motivation in scent detection dogs. Experienced explosives detection dogs were sent to explore two similar paths, path A that always had five hidden explosives, and path B

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1 that never had any explosives hidden on it. Dogs were taken on searches on one of the two
2 paths daily. After only one search on path B, dogs showed signs of decreased motivation on
3 the subsequent searches on that path while the motivation to search remained high on path A.
4 Even when explosives were ultimately hidden on path B, motivation and performance
5 remained low. Dogs seemed to remember the path which in turn affected their search
6 performance and behavior, even when conditions changed [216]. This could pose a challenge
7 in real-life odor detection, as rewards such as finding actual explosives or identifying target
8 scents, are potentially rare and/or infrequent. Porritt et al. (2015) observed the same
9 phenomenon of performance decline as Gazit, Goldblatt & Terkel (2005) in their study.
10 Detection accuracy dropped significantly after repeated searches with no present target odor.
11 They could also verify that this was not due to the dogs forgetting the scent, but the
12 performance decline was a result of decreased motivation. Their suggested strategy to mitigate
13 these effects is to train scent detection dogs on a non-target, non-explosive scent that they will
14 periodically encounter in a working context. They hypothesized that dogs encountering the
15 non-target scent in working situations would show increased persistence. This would in turn
16 translate to higher motivation to search for target odors too. In their study, this method proved
17 to be effective as dogs encountering the non-target scent on their trials showed higher
18 motivation and increased performance in also finding target odors while dogs that encountered
19 zero targets continued to show a declined performance [217].
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3.3 Bio-psychological aspects of dog decision-making

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27 The suitability of dogs, both as individuals and specific breeds, for work in a sniffing capacity
28 strongly depends on a set of behavioral and neurobiological conditions. Brain functions that
29 strongly influence working dogs' capacities are often summarized as „executive functions“.
30 This term includes, among others, working memory, self control/inhibitory control, time
31 management, internal representation, spatial memory and other processes. In the last few
32 years, neurogenetically analyses more and more team up with behavioral data, based on
33 questionnaires or specific test situations. However, most of these publications currently relate
34 more to social behavior, attachment system etc. (see e.g. MacLean et al 2019). Only a few
35 papers address inhibitory control [218, 219], and only one recent paper [220] covers
36 differences in olfactory detection by genome screening. Personality dimensions such as
37 persistency or emotional stability can be scored by means of questionnaires as e.g. developed
38 by [221, 222], or [223]. The most wide-spread of these, also in a broad database, is the Canine
39 Behavioral Assessment & Research Questionnaire (C-BARQ). All of these could be applied to
40 find better correlates with dogs' suitability for such tasks. The importance of working memory,
41 one of the main components of executive functions, for sniffer dog work has been outlined by
42 Gadbois & Reeve, 2014. The design of line-ups for detection work by dogs might be more
43 relevant for detection probabilities than the ability of a dog to discriminate and even detect a
44 given scent, if the positive sample is positioned more towards the end of the „cafeteria“ line-up
45 than if it is positioned at the beginning. The emotional capacity of persistency or perseverance,
46 but also the cognitive bias of the dog (being optimist or pessimist, [224] could also influence
47 whether a dog detects, discriminates and then communicates a given scent. Further
48 neurobiological components influencing the quality of a sniffer dog's work are the relative
49 importance of the two sub-components in the brain reward system (liking, being the more
50 passive satisfaction with a current situation, versus wanting/seeking, constituting the active
51 strive to further improve the current situation). Gadbois & Reeve, 2014 outline this and refer to
52 more detailed literature. Recently, an extensive pathway consisting of five tracts of white matter
53 has been identified, which are connected to the occipital lobe, cortical spinal tract, limbic
54 system, piriform lobe, and entorhinal tract. This extensive white matter network, originating
55 from the olfactory bulb and forming direct connections to other cortices of the brain, appears
56 to support theoretical assumptions about how dogs integrate olfactory stimuli into their
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1 cognitive functions. Specifically, a direct connection between the olfactory bulb and the occipital lobe has been documented for the first time [225].

2 Detection work in dogs includes three, fundamentally separated tasks: „What“, „Where“, and
3 „How much“. All three relate to different parts of the memory systems, and are connected to
4 spatial orientation, motor integration. Signal detection theory, habituation-dishabituation,
5 errorless discrimination training or, as mentioned already, memory load issues in line-up tests
6 are among those biopsychological concepts that could be better integrated into the practical
7 work (see Gadbois & Reeve 2014 again). Heritabilities of suitable traits for dog work in part
8 reflect the importance that this particular trait had been assigned in domestication history.
9 Many traits in behavior, including most of the functional system of „hunting“, which we use in
10 olfactory work mostly, only have low to moderate heritabilities within breed [226]. Between
11 breeds however differences are more significant [227, 228]. Gnanadesikan et al. (2020) find
12 highest values for heritability in communication with humans and in inhibitory control. Less
13 important, in terms of heritability, are spatial/physical orientation and memory. These latter, in
14 addition to other aspects of executive function, seem to strongly depend on socialization and
15 early experience [186, 229] as well as absolute body size [219, 230, 231], with larger dogs
16 having better executive functions and being more trainable, better willing to relate to their
17 human counterparts etc.

18 Developing test situations specifically for each task or job a dog in future should be trained for
19 has only rarely successfully included cognitive aspects. Indeed, comparing tests for explosive
20 detection versus assistance dogs, would be a good outline for similar efforts [183]. From
21 among a total number of over 100 test situations the author could identify a subset most
22 suitable for each of these future jobs. Another area that more and more comes into research
23 focus is the influence of sexual hormones on spatial orientation, memory, but also
24 communication between dogs and humans. In all these areas, neutered dogs often fare worse
25 than intact ones. The wide-spread belief that neutering working dogs makes them more reliable
26 thus has to be strongly questioned [173, 232]. In summary, recent developments in cognitive
27 and neurobiology research, including genetics, could offer a huge potential to improve the work
28 of detection dogs, including mantrailing, if a better multidisciplinary understanding would arise.

3.4 Constraints on the use of sniffer dogs – biological considerations on stress and welfare

36 The concepts and definitions of what constitutes „stress“ for an individual vary between authors
37 and areas of research. In animal welfare science, the definition by Broom is one of the broadest
38 and most commonly cited. According to this, „stress is an environmental effect on the individual
39 which overtaxes its control systems and results in adverse consequences, eventually reduced
40 fitness“ (Broom 2002 p 6). According to this definition there is nothing such as „positive stress“.
41 Stress is always negative, all positive effects are termed „stimulation“ or „challenge“. This
42 distinction is highly relevant to the use of dogs in all areas of animal-assisted activities,
43 including the use of sniffer dogs. Gadbois & Reeve, 2014 repeatedly refer to dopamine-
44 controlled breeds of dogs who are the most suitable breeds for olfactory work due to their high
45 degree of motivation and perseverance (they explicitly mention Border collies, Russel terriers,
46 or Belgian malinois). The activation of the dopamine system, which is part of the mesolimbic
47 as well as prefrontal reward system in mammalian brains, is, among others, also tied to sniffing,
48 especially when combined with rhythmic activation of the skeletal musculature, such as in
49 following a trail. In this context we have to consider that dopamine, the most important
50 transmitter in the „seeking/wanting system“ in our brains, can easily cause addictive
51 processes. And addiction definitely meets the criteria of „adverse consequences“ sensu
52 Broom. Related to this, and the behavioral trait of persistency (which again is a helpful
53 precondition for focused long-term work), is also a higher probability of developing behavioral
54 disturbances, stereotypies etc. [213, 233].

55 In order to better understand the risks and possible aversive side effects of sniffer dog work
56 related to stress and dog welfare, an important distinction also has to be made between dogs
57 and their ancestors. Very often, in all areas related to dog biology, a comparison is drawn to
58 wolves. Related to our topic here, we have to get rid of the notion of wolf packs hunting for

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1 days on end, covering huge distances in pursuit of their ungulate prey. Data on feral or village
2 dogs (summarized e.g. by Gompper, 2014, Boitani et al., 2016, and other field researchers)
3 paint a totally different picture: Feral dogs spend only a few percent of their 24 hour activity
4 budget in „travelling“, mostly between resting sites and foraging areas (i.e. garbage dumps).
5 Between 50 and 80 % of their daytime activity are spent „resting“, and even the (on average)
6 about 30 min/24 hrs that are spent in vigorous high intensity locomotor activity are distributed
7 over several bouts of a few minutes each. We thus really have to limit the bouts of searching
8 and sniffing that a single dog spends on a trail to maximally 30 min (which by the way is
9 common among really responsible dog handlers anyway). However, we can understand that
10 in certain operational scenarios involving service dogs, such as search and rescue missions,
11 this may not always be feasible. A contemporary approach to dog (or other animal) welfare, as
12 outlined e.g. by Rooney & Bradshaw, 2014 contains three equally important issues: physical
13 health, psychological well-being, and expression of natural behavior. Only when taking these
14 into account pro-actively can we expect this type of work to be accepted by the general public
15 in the future.
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4 Dog Training

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21 It is assumed that dogs naturally have the ability to locate and track scents. The ability to locate
22 scents is vital for survival, whether for foraging or for reproduction to find a suitable mate [212,
23 p. 10]. In addition, there appear to be indications that the opportunity for nose work may have
24 positive effects on the emotional status of dogs, in part because it provides natural behavior
25 and autonomy. [237]. It could be argued that dogs need special training for tasks such as scent
26 discrimination, tracking, or mantrailing. Instead, it is more important to encourage the dog to
27 use its natural abilities on command and continue until the desired object is found or there is
28 no longer a scent to follow, without being distracted by other surrounding stimuli. Furthermore,
29 the signals given by the dog during a search must also be clearly recognizable and
30 interpretable by the handler. This is the only way to accurately classify a "search success",
31 especially when it comes to the invisible scent trail. Many studies have examined the criteria
32 for selecting a dog, such as ancestry [238], genetics [228, 239], or behavior (an overview in
33 Bray et al., 2021). Fundamental considerations for dog training are presented by Troisi et al.,
34 2019 and Hall et al., 2021, which includes key mechanisms of learning in dogs (classical
35 conditioning, operant conditioning, and social learning) and the relationship between the dog
36 and handler, as well as the training setting, such as the number of repetitions, positive
37 reinforcement, the use of negative samples, the location, the length of the search, and the
38 training of the handler, such as the influence of the handler on the dog through their own
39 unconscious signals or behavior and how they correctly interpret their dog's signals (Troisi et
40 al., 2019, Hall et al., 2021; a summary of individual aspects can be found in Jamieson et al.,
41 2017; for more in-depth information, see Minnhinick et al., 2016). These findings are in addition
42 to the insights into dog behavior presented above.
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47 It is important to keep in mind that the trailing dog team consists of the dog and handler. While
48 the dog does almost all of the work, the handler must contribute their small portion at critical
49 times, particularly at the start of the trail and when the trail has been lost. However, there is
50 widespread agreement among trainers and handlers that the handler is the weakest part of the
51 team. This means that the team's success and research results based on the team's
52 performance will be significantly influenced by the skills of the handler.
53

4.1 Human Scent Discrimination

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57 While discrimination is the ability to distinguish different signals in a chemically complex
58 environment, identification is the ability to recognize a signal and compare it with previously
59 stored information [240]. Research has shown that it may be possible to train dogs that have
60 not been trained for discrimination tasks to find a single (novel) odor without much effort.
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1 Twenty-four trials (target odor anise; Hall et al., 2013) or a few days (e.g., target odor amyl
2 acetate; Edwards, 2019) may be sufficient. For more complex odors, the required training
3 period may extend to several months, for example 3 months (target scent red palm weevil;
4 Suma et al., 2014), 11 months (target scent koala feces; Cristescu et al., 2015) or even 16
5 months (target scent prostate cancer from urine samples or blood from deceased individuals;
6 Cornu et al., 2011, Riezzo et al., 2014) . For dogs already familiar with olfactory search tasks,
7 this can even be achieved within a few minutes (target scent black tea; Johnen et al., 2013).
8 Often, discrimination or detection tasks are performed on dogs using substances that are not
9 biologically significant to dogs. This includes applications used by authorities, such as
10 detecting explosives or drugs. The following discussions refer exclusively to scenarios of
11 assigning the human scent trail to the person who caused it, often in forensic applications. It
12 cannot be excluded that the assignment/recognition of individual human scent has gained
13 significance during the domestication of the dog, whether because of the availability of
14 food/feed or shelter or friendly interaction. Only occasionally are there explicit statements
15 about training the dogs. Dog training usually relies on operant conditioning, however, there are
16 no proven standards for training dogs for human scent matching tasks [246]. Initially,
17 comparable basic training methods are often used, which are later varied and extended [247,
18 p. 155]. The training period usually lasts several months, for example 6 months [248], 8 months
19 [249], 12 months [250], 16 months [251] or 18-20 months [252, 253]. In a police context
20 between 6 months and two years [254]. Essential aspects of training, such as avoiding of
21 coercion, positive reinforcement, phase-wise training, conducting control trials, and referring
22 to potential sources of error, are already found in earlier literature (e.g. Menzel and Menzel,
23 1930) and are still applicable today. In the following, the basic aspects of dog training for
24 human scent discrimination will be discussed.
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27 Information varies as to the age at which training should begin. There is consensus that it
28 should not be started too early. Thus, an age starting between 8 and 17 months is reported
29 [122, 251, 253]. Regularly, training is preceded by basic obedience training. This concerns in
30 particular the compliance with the commands "down" and "sit". The known methods describe
31 a training scope of 4 - 5 days per week and an intensity of 3 to 15 repetitions. Marchal and
32 Ferry (2017) emphasize that the daily pensum should not exceed 8 runs, as this can lead to a
33 loss of motivation in the dog. The training is carried out in several phases, varying between
34 four [122, 251], five [253] or even six [249] phases. However, the phases can basically be
35 divided and summarized into the following steps:
36
37

38 1. Learn to search all the jars in the line.

39 For this purpose, all stations are filled with food and the dog is asked to put its muzzle into the
40 jars to reach the food. The food acts as positive reinforcement, supplemented by praise from
41 the handler. Already in this phase, one can put a search harness on the dog before the
42 beginning of the run, which thereby gets signal meaning. Furthermore, it is already possible to
43 place a blank scent article (gauze pad) under the food. Building on this, the difficulty can be
44 increased so that only individual stations are filled with food and the dog should show an
45 indication behavior such as "Down!" or "Sit!" at these stations. This can be supported by an
46 appropriate command and reinforced by the use of a clicker.
47
48

49 2. The dogs are presented with a familiar scent and indicate the corresponding station.

50 Initially, the dog handler's familiar scent is used. This can be on an object belonging to the
51 handler, but also on a manufactured scent sample (e.g. a gauze pad, held in the hand for
52 several minutes). Presenting the scent sample can be connected with a command, e.g. in
53 Germany with the term "Riech!". The sample is then placed in one of the jars and the others
54 filled with blank samples. The dog is asked to indicate this with a command, e.g. "Search!".
55 Positive reinforcement is also given by food or clicker. Subsequently, the difficulty is increased
56 so that the handler does not know the location of the target sample. Furthermore,
57 reinforcement with food should only occur intermittently.
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3. The dogs are presented with random scent samples and indicate the corresponding station or recognize that no corresponding sample is present.

Scent samples of persons not known to the dog are used. All stations contain scent samples. The handler does not know the location or whether a target scent is present. The dog is presented a scent article and has to indicate the matching jar. The difficulty is increased by the use of different scent samples and target scents (scent samples from different parts of the body, on different scent articles and different ages).

A transition to the next level of training only takes place when the dog can reliably indicate the respective sample and reliably recognize when there is no match in the stations. After completing the training, the dog's performance level must be maintained at this level over the entire course of the dog's working life through constant training.

4.2 Mantrailing

To the best of our knowledge, no study has specifically investigated which method promises particularly good results in the training of a mantrailing dog. In the published works that explicitly address mantrailing (see below), either no comprehensive information is provided on the specific training method used for the dogs [24, 127, 134, 255, 256], or it is stated that they have undergone an appropriate evaluation by organizations [24, 165, 256, 257] or they refer to a training methodology described elsewhere [112, 258, 259]. A somewhat more detailed description can be found in [135]. One study has focused on experiences regarding basic entry competencies in the context, without reflecting on a specific training method [260]. Requirements for teams deployed in investigative measures have been formulated [113]. Fundamental considerations can be found in the Scientific Working Group on Dogs and Orthogonal Detection Guidelines [261], and further continued in the General Guidelines for Training, Certification, and Documentation of Canine Detection Disciplines [262] and specifically in the Standard for Training and Certification of Canine Detection of Humans: An Aged Trail Using Pre-scented Canine [263]. Additionally, it should be noted that many canine organizations have established internal standards and standard operating procedures.

For the training of mantrailing dogs, a variety of concepts and methods have been established. In general, the genetic predisposition of all dogs for tracking scent trails is utilized. Depending on the intended purpose of the dog's use, different aspects are emphasized. These include, among others, the selection of the dog breed, the timing of the training onset, or the intensity of the training. Essentially, a distinction can be made between the private or recreational sector and the deployment in rescue organizations or authorities. In the latter, the training and continuing education density is more extensive, and before these dogs are deployed, passing an evaluation is mandatory. While in the recreational sector, a dog can begin training regardless of its age, for planned professional search purposes, training should commence early as a puppy. However, premature weaning from the mother or litter siblings should be avoided as they play a significant role in socialization and the dog's future behavior. The experiences gained during the socialization phase have an impact on the dogs' future social behavior [264, 265] and thus also on the operational outcome/success.

It should be noted at this point that a distinction must be made between tracking work and mantrailing, as different perspectives have been established. Therefore, a differentiation is necessary. A distinction can be found in the seminal work by Syrotuck from 1972:

„Tracking Dog: In the strict sense of the term, the dog should indicate almost each of the subject's footsteps. (...) The basic orientation of the dog is to the footsteps.

Trailing Dog: The dog is oriented to the rafts which have fallen to the ground along the person's route. The dog may well be working some distance from the actual footsteps." [79, p. 79]. This differentiation is maintained in current standards:

- tracking

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1 The propensity or learned ability of a canine to methodically follow odor/scent on the ground
2 (human/ground disturbance) by working the canine close to the pathway. Canines are not
3 typically pre-scented on an object.

- 4 • trailing

5 The propensity or learned ability of a canine to methodically follow the target scent. The canine
6 may follow a scent plume which could be either air borne or settled on the ground/vegetation.
7 The canine will use whichever technique will get them to the target the most efficiently. Canines
8 are typically pre-scented on an object [266].

9
10 Whereas in tracking the training of the dog regularly starts on soft surfaces, especially grass
11 [267, p. 56, 268, p.66] and thus the soil damage plays a major role as a key, this is not the
12 case in trailing. Particularly, for police dogs and rescue dogs care is taken not to start training
13 on soft surfaces [269]. But there are also dissenting views [270, p. 127]. From the local
14 perspective, Schweda's view is supported. This variation may be the reason for the differences
15 in performance. In both, tracking and trailing, it is assumed that the dog basically follows the
16 temporal course of the track. As mentioned, the training of tracking and trailing dog differ. In
17 addition to the considerations about particularly suitable dog breeds, which are not discussed
18 here, the question arises as to the age at which training should begin. The data described in
19 the literature for this diverge. For tracking from 6 weeks [28, p. 59], 8 weeks to seven month
20 [271, p. 105], 10-12 weeks [267, p. 49] over 4-6 months [268, pp. 60-61] up to 1-1.5 years
21 [272, p. 57]. In trailing 7 weeks [273, p. 4], 8-12 weeks [270, p. 38] or 2-3 months [274, p. 127].
22 In general, the earliest possible start is recommended for both tracking and trailing. This is also
23 in line with the findings of corresponding studies, see Bray et al., 2021 and citation therein.
24 Therefore, it is appropriate to start with the first training elements around the age of eight to
25 twelve weeks [20, p. 311, 275]. Nevertheless, it is not until the dog is older that more advanced
26 scent-tracking tasks are integrated into training. The effects of different training methods on
27 the learning success of dogs are the focus of a large number of studies. A distinction has been
28 made between aversive methods (based on negative reinforcement or positive punishment)
29 and reward-based methods (positive reinforcement and negative punishment). While there is
30 widespread agreement that aversive methods induce stress-induced behavior in animals and
31 thus have a negative impact on animal welfare, there are contradictory statements regarding
32 the effectiveness of the methods used [182, 276-279]. A recent review provides a descriptive
33 overview [280]. Regardless, there is no known study that has compared mantrailing training
34 methods and correlated mission success.

35
36 In scientific and technical literature, as well as formulated standards, the following aspects are
37 regularly presented for the training of mantrailing team: terminologies, basic knowledge of
38 cynology, fundamental understanding of the origin and distribution of the human scent trail,
39 required equipment, collecting/securing and storing scent articles, handling and "reading" the
40 dog, assessing the dog during search work, and age-appropriate training tasks [263, 274, 281-
41 290]. Exemplarily, the methodology developed by Armin Schweda is presented here [269],
42 which has been successfully applied in the training of search and rescue dogs and police dogs
43 [291, 292]. According to this approach, it is essential to enable the handlers to work with their
44 dogs detached from traditional training methods, which often rely on aversive techniques [293]
45 or extensive and exclusive use of food as reinforcement. Additionally, the dogs need to be
46 prepared for the intended operational scenarios. The training of handlers focuses primarily on
47 areas such as scent comprehension, proper "reading" of the dog, leash handling, and tactical
48 deployment, or in Schweda's words - the toolbox. Key elements of the dog training encompass
49 "bonding", concentration and focus, as well as everyday neutrality.

50 Training should ideally begin in the puppy stage, allowing the dog to be exposed to various
51 influencing factors in a controlled manner to train its stress resistance and promote
52 concentration. It should be noted that, as a general rule, dogs live with their owners. A crucial
53 element of the training is teaching the dog to willingly follow or find a person (bonding). The
54 dog should be motivated to independently seek out a stranger and, therefore, search
55 persistently and attentively. The goal is to convey to the dog that searching for a person is a
56 natural substitute (drive). Practically, this is achieved by engaging intensively with the dog to
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capture its attention and interest. It is also important to establish the connection between the left scent and its author. For example, in training, the person leaving drops a larger piece of clothing along the path. The dog follows this person, directly crossing over the item of clothing, thereby obtaining the scent of the target person once again. In the next step, the dog is taught to use its nose to find this person. The person engages with the dog and then departs, hiding behind an obstacle to create an optical barrier. This means that the dog cannot see the person and must rely solely on olfactory cues to reach the target. These exercises are then associated with a specific command, such as "Search!" or "Find!". It is important that this particular command is used exclusively in this context. The training sessions are appropriate for the puppy's age and therefore kept short to avoid overwhelming the dog and to maintain its interest in this work. Based on the individual performance level of the dog, the next step is to familiarize the puppy with a search harness that it will later wear during search operations. After mastering the basic steps, additional scent articles can be introduced into the training. The possibilities are endless, as any objects carrying human scent are suitable, regardless of their solid, liquid, or gaseous state. A scent article refers to an object that carries the scent of the target person being searched for, which is presented to the dog. The training should take place under conditions that resemble the actual operational environment. This includes considering the weather, surroundings (e.g., urban areas, streets, buildings, crowds), and the ground conditions (e.g., soil, asphalt, concrete). A fundamental aspect for successful work is a high level of everyday neutrality. In addition to getting the dog accustomed to various environments (e.g., pedestrian zones, shopping centers) and situations, the dog handler practices the obligatory rules of interaction with his dog. This does not involve traditional obedience exercises. Essentially, it is sufficient for the dog to reliably respond to commands such as "No", "Come", and "Stop". It is crucial that the dog is allowed guidance during the search work without using this "freedom" on the trail for "unrelated activities", such as chasing after cats or extensively investigating other dogs' markings. Connected to this is the concentration and focus of both the dog and the handler during the task at hand, devoting their attention exclusively to the search work for an extended period. Core elements include performance and environmental characteristics, as described by Lazarowski et al., 2018:

Performance:

Hunt, (*Dog constantly uses nose to search and investigate targets using closed-mouth search, not looking for handler guidance. Dog does not become over-excited when target odor is present and does not get discouraged when odor is not easily found*),

Focus (*Dog is able to focus on rewards/tasks. Dog notices environmental stimuli, but does not respond to distractions (i.e., urine, ambient noises)*)

Work effort (*Dog will give 100% effort on every search/task every time. Dog is eager to find target to interact with handler*)

Air scenting (*Dog is constantly using nose to find air currents, while consistently and efficiently searching air. Dog is not looking at specific targets/objects*)

as well as the one described as still to be investigated:

Distractibility: *Extent to which ongoing searching is interrupted by attention and/or attraction (not fearful or anxious) to objects, people, or other activities occurring in the environment—execution of task easily or frequently interrupted by ancillary events in surroundings, differentiated from "focus," the measurement of which is mostly related to attending to reward or immediate presence of odor, by measurement during operational style searches*

Environment:

Surfaces (*Dog will transition across any and all kinds of surfaces without any hesitation*)

People (*Dog notices people, but does not try to interact. Dog may sniff people, but does not focus on people. Does not show fear, distraction, or excitement elicited by people*)

Vehicles/urban clutter (*Dog adapts to clutter and works normally without disruption in searching behavior*)

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Acoustic startle (*Dog will notice loud stimuli, but holds ground and recovers quickly and then goes forward to investigate area*)

Excitability (*Dog is very active, excited to work, but not erratic. Dog may run through odor, but can recover and return to scent cone without giving up on task*) [178].

This also applies to the dog handler, who, in addition to mastering leash handling, must learn not to obstruct the dog's path. As the team gains more experience in completing the basic tasks, the level of difficulty is increased. This includes, for example, overlapping older and new scent trails, exclusion procedures with contaminated scent articles, negative indications, line-ups, or aged scent trails. Ultimately, the individual performance capability of the dyad dog/handler determines the timing of introducing new training content. The focus lies particularly on whether the dog has a strong bond with the "target person/victim" and shows a willingness to find people. Ultimately, the dog must understand that it is necessary to pick up the scent at the starting point, follow the scent trail, and indicate the specific person at the end of the trail. It can take approximately 24 months from the start of training with a puppy until a team reaches full operational capability [292]. This is considerably longer than the training duration for other specializations, such as patrol dogs (16 weeks), drug detection dogs (12 weeks), or explosive detection dogs (18 weeks) [294]. However, the extended training period for mantrailing dogs appears to be established. According to a survey conducted by Joyner among experienced bloodhound trainers in the USA in 2003, the training of an 8-week-old puppy to become a mantrailer takes between 3 to 24 months to achieve an entry-level. The most commonly mentioned timeframe was 6 months. Joyner concludes that the training should last approximately 6 months, with five training sessions of about 30 minutes conducted weekly [260]. Similarly, search and rescue dogs also have a comparable training duration of 12 to 18 months [295].

5 Practical findings

5.1 Human Scent Discrimination – odorology

Olfactory cues provide information about food, mates, offspring, predators, prey and pathogens [296, 297]. As detecting these compounds is essential for survival, most animals have developed a highly sophisticated olfactory system during the course of evolution [298], with thousands of volatile compounds perceived as distinct odors [296]. Among species that show remarkable olfactory detection ability, dogs have long been used in a variety of forensic areas [161, 299-302]. In particular, the ability of dogs to identify and discriminate between human odors has long been documented [303] and numerous experimental studies (see Ensminger 2012 and Jezierski 2016, 2012 for review) have shown that dogs are able to detect, memorize and identify the odor of a particular person with high specificity.

In 1972, a confidential patent for the human scent line-up was granted in the former German Democratic Republic (DDR), subsequently adopted in other countries within the so-called Eastern Bloc [122, pp. 54-55; 143-145]. The human scent identification line-up, subsequently described by Schoon and De Bruin [305] and later refined [250, 306, 307], is a task performed in the laboratory (semi controlled conditions) in which trained dogs are presented with scent collected from a crime scene ("evidence" scent, indirect, corresponding to a trace scent - TS) and are required to compare this sample to a selection of human scents ("comparison" scents, i.e. direct corresponding to a body scent BS or indirect corresponding to a trace scent TS, usually 5 or 6 in number) collected from persons not involved in the crime but also including a scent from a possible suspect ("target" scent).

A typical session trial starts when the dog is taken to the work room and presented with an open jar containing the target sample (also called the reference scent) at the starting point for 5 sec. Then the dog is allowed to search alone along the line-up on which 5 jars are presented each one containing a body scent (BS) collected from different person. Among the jars, one contained the target scent was randomly placed in the line-up with 4 other jars containing

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1 comparison scents collected from unrelated persons randomly chosen in the population (but
2 of the same status of sex, age and ethnicity). If the target scent matches the evidence scent,
3 the dog shows a typical conditioned response (usually, sitting or lying down) at the target
4 station. This behavior is obtained after an extended training procedure during which the dog
5 acquired the principles of classical matching-to-sample, in which the conditioned response to
6 a correspondence between target scent and sample is reinforced by food, whereas responses
7 to any non-identical comparisons are not reinforced (Ensminger and Jezierski, 2012 for
8 review).

9 During this training (2 years), dogs are trained to identify the primary component of an
10 individual scent present on different collection supports. In a previous study [253], we showed
11 that the comparison between the body scent (BS, direct sample) collected from a particular
12 individual and a trace scent (TS, indirect sample) collected at a different point in time (from
13 some hours to several days between collections) from an object that had been in contact with
14 the individual resulted in the identification of both scents as originating from the same person
15 with a very high level of sensitivity (see below). This suggests that dogs, when appropriately
16 trained, are able to detect, memorize and identify the particular primary VOC pattern in a
17 complex mixture constituting human scent, so as to be able to retrieve it in another radically
18 different mixture.

19 BS and TS likely consist of mixtures of various odorant compounds (body molecules +
20 distractors) present in different proportions. Moreover, the proportion of distractors in the
21 mixture affects the intensity of the targeted human odorants in the head space [308, 309] and
22 interactions between odorant molecules in a mixture influence the detection and recognition of
23 odorants in humans and in animals through activation of the olfactory sensory neurons in the
24 nasal olfactory mucosa [310, 311]. If a correct identification response depends directly on the
25 degree of perceived similarity between body molecules present in the odor sample and those
26 present in the line-up, then the difference in sensitivity suggests that the proportions of body
27 molecules and distractors differ between BS and TS mixtures and that a common specific body
28 scent feature is difficult for dogs to extract when both types of odor are used in the test. The
29 excellent sensitivity scores obtained with the use of the same kind of scent (BS in the sample
30 et BS in the line and TS in the sample and TS in the line) suggest the comparison could result
31 from configural coding; however, the sensitivity scores (true positive rate calculated with the
32 ratio: total number of hits / total number of hits + total number of misses) obtained with BS/TS
33 and TS/BS (ranging from 71% ± 3 to 74% ± 3; results obtained in 12 police dogs that performed
34 a total of 6502 trials during continuous training; Marchal et al., 2016) suggest that dogs were
35 able to extract common specific body scent information from mixtures presented in the sample
36 and in the line-up by an elemental coding process. According to Jezierski et al. (2014), high
37 detection scores should be regarded as exceptional and indeed dubious as they depend on a
38 variety of factors such as odor presentation method, odor source and, of course, individual
39 differences in dogs' olfactory detection thresholds thus suggesting that sensitivity is critically
40 dependent on the type of odor presentation during the task and specificity dependent on the
41 dog's breeding [312].

42 5.2 Mantrailing

43 Mantrailing involves the search and tracking of an individual's specific human scent trail. To
44 accomplish this, a scent article from the person in question must be provided to the dog. The
45 dogs are trained to begin trailing when the appropriate scent is present at the location being
46 checked. Otherwise, the dog will not initiate trailing. Despite the significant effort required for
47 intensive training as mentioned above, an increasing number of enthusiasts are drawn to
48 mantrailing, as it also provides suitable mental and physical stimulation for the dog. There are
49 substantial differences in training methods for handler and dog, their skills, their experience,
50 and in the local environmental conditions where they work. Consequently, handlers would not
51 agree with all of the anecdotal observations below. The following is based primarily on the
52 review of Osterkamp, 2021.

53 **Wind** - For a specific set of trailing conditions, maximum scent deposited along the trail occurs
54 when wind is in the same or opposite direction to the trail and minimum scent occurs when the

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wind is perpendicular to the trail. The dogs become more animated when trailing into the wind. Particles and VOCs that remain in the air can be transported significant distances. For a low wind speed of 1.5 m/s, they could be transported up to 15 m in 10 s downwind along the trail or at an angle to it.

Air temperatures - High air temperatures ($>30^{\circ}\text{C}$) are difficult trailing conditions. At temperatures $>38^{\circ}\text{C}$, the reverse human thermal plume may put more scent on the trail which would partially offset difficulties associated with these high temperatures. During break-up in Alaska, air temperatures above freezing cause snow and ice to melt. Some handlers report that dogs which have been trailing all winter appear to have more difficulty trailing during break-up than at colder temperatures. It may be that frozen scents that are not available during winter are released by melting but there is no information available to test this hypothesis. For air temperatures below freezing, microbial activity slows significantly. At air temperatures like those in a freezer ($<-18^{\circ}\text{C}$), microbial activity ceases, which indicates that microbes cannot be the source of trail scent at these temperatures. Handler observations in Interior Alaska indicate that trailing dogs (TDs) can trail at temperatures of -35°C . This ability to trail may occur because warm and moist exhalation jets from the dog's nose warm and dislodge VOCs and particles from surfaces which are inhaled and would produce detectable VOCs in their warm and humid noses.

Ground surface temperatures - It is more difficult for TDs to trail when the sun is shining on a surface, especially during midday when a person's shadow is less than 2 times their height. This usually makes the air near the surface unstable. It is easier for them to trail from sunset to sunrise, on surfaces in shade, and on cloudy days. This may be caused by the effects of temperature changes on the microbes and skin flakes, by the daily cycle of VOC concentrations, and/or by the effects of unstable air. Trail surfaces (soil, vegetation, rocks) at night and in shade emit long wave radiation to a clear sky that causes the surfaces to be cooler than the air. This is a stable condition that keeps the scent concentrated close to the ground. Cooler surfaces release fewer VOCs, but the net effect is to improve scenting conditions.

Humidity and Rain - Trails on very dry soil surfaces are difficult, which may be a result of VOCs partitioning to the soil particle surfaces and/or reducing the viability of microbes on the surfaces. High humidity, dew, and light rain make trailing easier for dogs, probably because moisture releases VOCs from dry soil particle surfaces and makes the microbes and skin flakes viable. Heavy rain makes trailing more difficult. If surface run-off occurs, scent can collect in favorable sites downstream such as the edges of roads, ditches, and vegetation downslope. This suggests VOCs and particles deposited or adsorbed on surfaces may be washed off the surfaces and carried away to these sites. TDs sometimes move laterally to these sites and continue trailing.

Snow - TDs can trail with at least 15 to 20 cm of new powder snow on the trail. Surface melting that freezes into a continuous ice crust and/or more than about 5 cm of wet snow that has refrozen makes trailing difficult to impossible. It appears that the type of snow, its thickness, and thermal history determine whether dogs can trail when snow has fallen on the trail, but there is no published information.

Aged trails - There are reliable reports of TDs completing trails on searches (double blind) up to a month old, but it is usually not possible to obtain independent verification. Trails aged 2 weeks or more have been reported [76, 113, 313]. These trails were heavily contaminated daily by hundreds of people and vehicles indicating that contamination is not a problem on aged trails. Similar reports can be found for aged trails up to two [314, 315] or four months [316, 317] and is confirmed by data on forensic police operations [4, 318]. Two recent studies have shown that aged trails could be followed up to one month [134] and up to six months [135] respectively, see below. There is no information on the characteristics or behavior of aged trail scent. Experiments on human scent have shown that it can be divided into three fractions according to its volatility [319]. Detector dogs could identify subjects from any of the fractions, but success rates were greatest for the lowest volatile fraction. Since the more volatile fractions are likely to be depleted over time, this suggests that TDs may be using the lowest volatile fraction of scent when following aged trails.

Vehicle trails - Numerous double blind vehicle trails performed during searches indicate that TDs can follow them. This is likely a result of vehicle ventilation systems that exhaust air

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1 containing scent from under the vehicle or from open windows. However, there is no
2 information available to evaluate the conditions and success rates for dogs attempting these
3 trails.

4 Due to their exceptional performance and diverse range of applications, such as locating
5 missing persons or linking a suspect to a crime scene, a multitude of authorities utilize this
6 investigative tool [4]. Historical evidence also confirms the use of mantrailing dogs for tracking
7 purposes[320-323]. One might expect this interest to be reflected in a plethora of scientific
8 publications on the topic of Mantrailing. However, this is not necessarily the case. The body of
9 research on the subject is rather limited and primarily consists of published works on tracking.
10 The following section presents the current state of scientific research known in relation to
11 mantrailing.

12 13 14 **6 Studies relating to mantrailing dogs**

15
16 Initial findings can be found in Romanes, who was convinced that his Terrier could track him
17 for kilometers: *„... (which I knew had a splendid nose, and could track me for miles)...”* and
18 locate his master: *„... picking up my scent, tracked my footsteps over all the zigzags I had made*
19 *until he found me...“* [303, p. 65-66]. From the results of his tests, he concluded that his dog
20 could track the trail based on the scent of his boots rather than the scent of his feet. This was
21 possible even when a strong different scent (in this case, anise oil) masked the actual scent.
22 Furthermore, he deduced from his experiments that his female dog was capable of detecting
23 his scent, regardless of the trail walked, at greater distances, specifically up to a distance of
24 200 yards. Romanes emphasized the individuality of human scent. Löhner makes the following
25 statement: "Experiments with police dogs suggest that these animals are able to recognize a
26 common individual index among the various regional odors of a human individual." In
27 summary, Löhner concludes that the individual scent refers to the characteristic personal scent
28 of an individual at a specific point in time. This scent can be perceived, even at considerable
29 spatial distances, by animals such as dogs [27, p. 28, 44]. A critical examination was carried
30 out by Konrad Most, who conducted scientific experiments with police dogs and came to the
31 conclusion that the dogs did not fully perform the tasks attributed to them [324, pp. 51-61 and
32 citation therein]. Later, Kalmus (1955) demonstrated that police dogs can reliably work on
33 individual scent tracking. Further considerations were devoted to the question of whether dogs
34 have the ability to track a human scent and determine the direction of a trail. This yielded
35 various results and success rates, such as 60.6% [325] or 87.5% [326]. Another study aimed
36 to avoid methodological shortcomings of the aforementioned studies by using an adequate
37 number of dogs (22 dogs) of the same breed (German Shepherd). As a group, the dogs were
38 not able to determine the correct direction better than expected by chance. However, eight of
39 the participating dogs were able to consistently determine the direction with success rates of
40 90% and 100% [174]. A subsequent study with eight dogs showed that five steps were
41 sufficient to determine the direction of the trail [327]. All experiments shared the common
42 characteristic of relatively short trail lengths, ranging from 50 to approximately 100 meters. The
43 age of the trails varied from 15 minutes to one hour. The trails were laid on plowed fields,
44 grass, and partly on asphalt. Haberhauffe conducted research on longer and older trails with
45 15 dogs. The ground conditions included cultivated fields, dirt roads, meadows, railway tracks,
46 asphalt, and forest floor. The length of the tracks ranged from 1200 to 2000 meters. The dogs
47 were able to work on tracks that were aged 17 hours and exposed to 5 hours of continuous
48 rain. Furthermore, a case is reported in which a tracking dog worked on a track that was aged
49 6 days and approximately 1500 meters long [125, pp. 51-52; 55-57].

50
51 However, these findings cannot be explicitly attributed to mantrailing. Harvey & Harvey (2003)
52 were the first who showed that bloodhounds were able to locate a person using his scent
53 sample. The scent sample was obtained by using a specialized device (Scent Transfer Unit
54 100 - STU-100) to draw the scent of the person from the upper body, arms, and hands of the
55 subjects onto a gauze pad through suction [328, 329]. The trails, ranging from 0.5 to 1.5 miles

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1 in length, were laid on various surfaces (grass, asphalt, concrete, or dirt road). These surfaces
2 included natural terrain in a park, on a campus, and paved surfaces in a busy urban
3 environment. The locations were chosen because the likelihood of random contamination by
4 human traffic between the trail laying and the search conducted 48 hours later. The trails were
5 laid in such a way that two individuals started simultaneously at the starting point, walking
6 towards their respective target points. About 50m before reaching the target point, one person
7 turned left and the other turned right, creating a Y-shaped path. At the endpoint, the target
8 individuals hid behind a natural object, such as a tree, for approximately 10 minutes.
9 Afterwards, the target individuals were transported away from the endpoint by a vehicle. To
10 conduct the search, the target individuals were brought back to their respective endpoints after
11 approximately 48 hours without crossing the trail again. The search began by presenting a
12 neutral gauze pad as a negative sample. Negative samples refer to scent articles that were
13 either not contaminated with human scent or from individuals who have never been present at
14 the location. Subsequently, the scent article of a target individual was presented to the dog for
15 searching. The dogs used in the study, which varied in age, were trained using the same
16 method [273] and were divided into a group of experienced and inexperienced dogs based on
17 their training and operational experience. The results showed that the inexperienced dogs
18 were successful in locating and indicating the person from whom the scent article originated in
19 53.3% of the cases, while the experienced dogs were successful in 96% of the cases.
20 However, it should be noted that only a small number of five trials per participating dog were
21 conducted. Therefore, statistically significant results were only observed in the four dogs with
22 100% success.
23
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25 In the following year, Stockham et al., 2004 published an article on the police application of
26 dogs in scent trailing, presenting insights and case examples from the Federal Bureau of
27 Investigation (FBI). According to the article, the FBI and the Southern California Bloodhound
28 Handlers Coalition conducted a feasibility study on October 21, 2001, to determine the
29 durability of human scent after decontamination for biological agents. Five sheets of paper
30 contaminated with the scent of the target person were irradiated with an average dose of 40.7
31 kGy and 39.5 kGy. All six dogs involved in the test were able to track the trail to the target
32 person and correctly identify them. Furthermore, a case from May 13, 2002, is described in
33 which a mail carrier in Philadelphia discovered a package in a mailbox that resembled an
34 improvised explosive device. The following day, a similar package was found in a mailbox
35 located one and a half kilometers away. After two days, a scent article was created from the
36 remains of these two packages using the STU-100, and an attempt was made to pick up a
37 scent trail from one of the mailboxes using a bloodhound. The attempt was successful, and
38 the dog led to a neighboring district. Another dog was deployed there, leading the law
39 enforcement officers to a house where the suspect lived. Independently, the parallel
40 investigations also led to this suspect, who was subsequently sentenced to 16 months in prison
41 in a subsequent court hearing. In another case study, the investigation of a pipe bomb attack
42 in July 2002 is described. The pipe bomb exploded inside a vehicle in Washington, DC,
43 severely injuring the driver. Shortly after the attack, the half-brother, Prescott W. Sigmund, of
44 the victim disappeared. In the vehicle subsequently found, belonging to the half-brother, a
45 farewell letter was discovered. After seventeen days, a dog was deployed in the neighborhood
46 with a scent article derived from the bomb fragments, and it followed a scent trail to Sigmund's
47 front door. The dog was then deployed at the parking garage where the vehicle had been
48 found. Despite the high temperatures of approximately 38°C in the preceding days, the dog
49 was immediately able to track the scent trail from there to a bus stop. According to the handler's
50 assessment, it was at this point that the suspect (with a vehicle) was picked up or boarded a
51 bus. After a four-month manhunt, Sigmund turned himself in to the police in Missoula, Montana.
52 In the interrogation, he confirmed the findings of the dog's search work, stating that he had
53 driven his vehicle to the parking garage, left it there, and subsequently left the city by bus. In
54 the ensuing trial, Sigmund was found guilty and sentenced to 32 years in prison. This case
55 example also supports the durability of human scent on bomb fragments and in a heavily
56 trafficked urban environment [113].
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1 Stockham et al. further describe that in May 2003, the FBI hosted a research workshop with
2 dog handlers at its academy in Quantico. Within this workshop, the durability of aged human
3 scent trails in a densely populated residential area was tested. The test was designed to
4 determine if the scent of target individuals would persist at their primary residence and survive
5 their prolonged absence. This was examined using the scent of a person who had relocated
6 from Stafford, Virginia, to Albuquerque, New Mexico, after residing in a house for seven years.
7 Six months after their move, a test was conducted to determine if a dog could pick up a scent
8 trail of this test subject at a street intersection several houses away. Using a scent article
9 crafted from a letter sent by the former resident, a bloodhound was able to pick up the
10 corresponding human scent and track a trail to the relevant house. In this test, the letter
11 intentionally sent from Albuquerque, New Mexico, to Stafford, Virginia, via the U.S. postal
12 system, as the letter had been irradiated with Cobalt 60 at an average rate of 39.5-40.7 kGy
13 for 59 minutes upon its arrival at the U.S. Army's Research Institute of Infectious Diseases,
14 Fort Detrick, Maryland. Despite being irradiated and heavily contaminated, this scent article
15 was successfully utilized in this blind test to locate the now-unoccupied former residence of
16 the test subject after six months [113]. According to the dog handler, the house was, however,
17 the 2nd or 3rd house away from the intersection where the scent article was presented to the
18 dog, resulting in a very short trail. The handler stated that the dog did not trail as such but just
19 seemed to be drawn to the house in question [330, personal communication].
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22 In 2004, another study was published that examined whether trailing could be performed using
23 a scent article that had been subjected to high thermal exposure (due to explosion or
24 combustion). The scent articles were obtained from explosion fragments or fire residues using
25 the STU-100 in this investigation as well. The trails were run in an urban public park frequented
26 by joggers and people walking pets. The trail was laid out such that two individuals, a target
27 person and a distractor person, would walk from a common starting point for approximately 14
28 meters. At that point, the designated path would diverge at a 45-degree angle, and each person
29 would continue for an additional 18-27 meters to their respective hiding place. The results
30 recorded whether the dogs indicated a scent at the start and began trailing, as well as whether
31 the correct individual was indicated at the end of the trail. In 78.3% of cases, an individual
32 scent trail could be established, and in 70% of cases, the correct target person was indicated.
33 Among the dogs that could pick up a trail, 88.6% correctly indicated the target person, with no
34 false-positive indications [127]. Each of the 20 dogs participating in the study completed six
35 trails. Due to the relatively small number of attempts, statistically significant results could only
36 be observed in dogs with a 100% success rate, which applied to two dogs. A negative probe
37 was not conducted.
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41 The study conducted by Harvey et al. (2006) aimed to investigate whether human scent is
42 genetically determined and whether environmental influences, such as cohabitation, affect this
43 scent. Scent samples were prepared as described above [112]. The participants included both
44 unrelated and related individuals, including monozygotic twin pairs. Furthermore, a distinction
45 was made between individuals living together in the same household and those who did not
46 cohabit. This specific selection of subjects allowed for the examination of the effects of primary,
47 secondary, and tertiary odors [30, 41]. The experimental design was as follows: All tests were
48 conducted in a park on grassy terrain within a cordoned off area. In scenario 1, the target
49 individual had to cover a distance of approximately 180m and hide behind a tree or similar
50 object at the end. The scent article contained a scent sample from another person or a negative
51 sample. In scenario 2, two individuals ran together from a starting point for about 90m and then
52 split into opposite directions in a Y-shaped path, each running for approximately 45m and
53 hiding behind a tree or similar object at their respective target points. Using a randomly
54 selected scent article containing the scent of either Person A, Person B, or a negative sample,
55 the corresponding scent trail and target person had to be located. The results showed that,
56 except for the twin pairs, significant discrimination of all non-cohabiting test subjects by all dogs
57 was achieved in both scenarios. This was also true for unrelated individuals living together in
58 scenario 1. Although significant results could still be observed for related individuals living
59 together by the majority of the dogs, the discrimination rate decreased. None of the dogs could
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1 achieve significant results in scenario 1 for cohabiting twins, and only one dog could do so for
2 non-cohabiting twins. In scenario 2, three dogs were able to achieve significant discrimination
3 results for cohabiting twins, and five dogs for non-cohabiting twins. Generally, differentiation
4 of monozygotic twins, regardless of whether they lived together or separately, seemed to be
5 challenging [258]. This finding is consistent with previous studies on dog scent discrimination
6 of objects (Kalmus, 1955; Hepper, 1988). Weather conditions appeared to have no impact on
7 the overall performance of the dogs. Based on their results, Harvey et al. conclude that
8 bloodhounds employ a multifactorial approach, utilizing genetically determined primary odor
9 and environmental indicators, namely secondary and tertiary odors, in differentiating human
10 scents. Nevertheless, they point to the apparent predominance of genetically derived odor-
11 type [258].
12

13 A comparable design to the study published by Stockham in 2004 is presented in the work of
14 Curran et al., 2010. The STU-100 was also used to produce scent samples from explosive
15 fragments. Prior to the detonation of the device, it was touched by two target individuals to
16 simulate their handling of it. The target individuals ran approximately 800m from a common
17 starting point, and the path then split in a Y-shape. Afterwards, they hid in a building.
18 Additionally, six other individuals were placed in the test area as decoys while the teams were
19 running their trails. This ensured that the dogs could not simply locate and identify any present
20 individual; they had to identify the correct person. The trailing exercises began approximately
21 four hours up to six hours after the trails were laid. For a dog team to successfully complete
22 the exercise, the dog had to follow the trail of the target scent and identify the specific target.
23 All twelve dogs involved in the study were able to pick up a scent trail and identify the target
24 individual with a success rate of 72.7%. In a second and third trial, an additional trail of
25 approximately 800m in length was laid by a target individual, who was to be found and
26 indicated at the end of the trail. In trial two, the individual trail was successfully picked up and
27 the target person indicated with a success rate of 91.7%. In the third trial, the scent trail was
28 successfully picked up in 10 out of 11 cases, but only 6 cases resulted in identification. In two
29 instances, the distractor individual was mistakenly indicated [24]. It should also be noted that
30 a negative control trial was not conducted in this study, and the number of trials (n=35) was
31 relatively small. Due to the manner the scent samples were collected, the clear assignment to
32 one person was only possible to a limited extent, as scent of two targets were potentially
33 present on the material and therefore the indication of one of the two persons was scored as
34 a correct identification.
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39 Prada (2010) conducted a study investigating the impact of contact and non-contact scent
40 collection techniques. The study extensively assessed the characteristics of textiles used for
41 collecting human scent samples and conducted field experiments with mantrailing dogs to
42 observe any performance deviations when varying the textiles used for collection. The study
43 involved bloodhounds of varying ages (2 to 10 years) with different levels of training and
44 operational experience. Field experiments were conducted in university campuses and urban
45 areas, with scent trails aged approximately 24 to 48 hours and involving two changes in
46 direction. The primary evaluation criteria included whether the dogs initiated trailing and
47 reached the first and second decision points. The experiments, revealed that depending on
48 the collection material, dogs initiated trailing in 57-100% of cases. The correct identification of
49 the first decision point varied from 0% to 67%, and the second decision point was correctly
50 identified in 0% to 60% of cases, depending on the collection material and trail age. Some
51 experiments included negative control samples. Three out of all negative control samples were
52 falsely identified as positive. The study also conducted further experiments on human scent
53 identification by dogs using debris fragments after an explosion [255], with detailed
54 descriptions and results provided above [24].
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58 In a separate doctoral thesis aimed at identifying VOCs present in hand odor, hair, fingernails,
59 and saliva, field experiments involving mantrailing dogs were carried out to investigate their
60 performance in different scenarios [256]. The study conducted a series of experiments to
61 assess the olfactory capabilities of dogs in detecting and tracking scents from various sources,
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1 including hand odor, hair, fingernails, and saliva. The scent samples were collected on the day
2 of trail laying using an STU-100, as mentioned above, or the Human Scent Collection System
3 (HSCS). The HSCS is also a device that generates a dynamic airflow and non-contact collects
4 scent samples on a sorbent carrier. As a comparison, the scent article with hand odor was
5 considered.

6 For hair odor, trials were conducted with varying trail ages (1h, 24hrs, 48hrs) and two decision
7 points. It was recorded whether the dogs initiated trailing and subsequently reached the first
8 and second decision points. Dogs initiated trailing in 75% of hand odor cases and 77% of hair
9 odor cases. The first decision point was reached in 17% (hand) and 9% (hair) of cases, while
10 the second decision point was achieved in only 8% of hand odor cases. Dogs performed better
11 than expected by chance when presented with samples collected using the STU-100. Trail age
12 had a notable impact, with the most significant difference observed at the start, where the
13 response varied by 18% between 1-hour and 48-hour aged trails. However, the dogs were not
14 consistently able to navigate the first and second decision points correctly, irrespective of trail
15 age.

16 For fingernail odor, trials were conducted with a trail age of 1 hour. Dogs initiated trailing in
17 71% of hand odor cases and 63% of fingernail odor cases. The first decision point was reached
18 in 29% (hand) and 25% (fingernail) of cases, but the second decision point was not reached
19 in any instance.

20 For saliva samples, trials also had a trail age of 1 hour. Dogs initiated trailing in 94% of hand
21 odor cases and 88% of saliva odor cases. The first decision point was reached in 44% (hand)
22 and 25% (saliva) of cases, while the second decision point was reached in 6% of both hand
23 and saliva odor cases.

24 A series of experiments compared the two devices (STU, HSCS) for collecting scent samples.
25 The trail age was one hour. The target individuals were not present at the site. Dogs initiated
26 trailing in 87% (HSCS) and 79% (STU-100) of cases. The first decision point was reached in
27 43% (HSCS) and 58% (STU-100) of cases. In 88% of cases, negative control samples were
28 not correctly identified [256].
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32 A study on outdoor scent trailing was presented as part of a doctoral thesis by Wolf (2016). It
33 investigated the influence of aging human scent trails on the performance of trailing dogs in
34 tracking. Specifically, trails aged 1 day, 1 week, and 1 month were examined. These trails had
35 a length of approximately 500 meters and traversed both natural and urban surfaces. The trail
36 route included at least one decision point at the start and along the trail. The trails were laid
37 out by transporting the target individuals by car to the starting point and having them follow a
38 predefined route to reach the respective target location. The target individuals were then picked
39 up from the target location by car. For conducting the search, the target individuals were
40 brought back to their respective target locations on the day of the search, after the
41 corresponding time duration (1 day, 1 week, 1 month), without crossing the trail again. The
42 search began with presenting the dog the scent article of the target individual. Sterile cotton
43 compresses measuring 7.5 x 7.5 cm were used as scent articles, which were previously taken
44 out of the packaging by the target individuals and rubbed against various body parts (hands,
45 face, neck, décolleté, forearms). These gauzes were then placed in a glass container with a
46 screw cap. The participating dogs in the study were of different ages and were trained using
47 various methods. They possessed verified basic qualifications and operational experience. In
48 total, 18 dogs participated in the study, and 145 trials (divided into 63 trails aged 1 day, 54
49 trails aged 1 week, and 28 trails aged 1 month) were conducted. Success was defined as the
50 search team reaching the target location and the dog successfully identifying the target. Three
51 criteria were distinguished regarding the accuracy of scent tracking. "Trail Running" - the dog
52 shows no deviation from the trail or deviates ≤ 50 m at a decision point but then independently
53 orients back towards the trail and follows the same path back to the trail to continue tracking
54 it. "Trail running despite deviation" - The dog follows the trail very accurately but takes more
55 than 50 m when checking the wrong arm or does not return to the trail using the same path.
56 Minor deviations were defined as follows: The dog deviates ≤ 50 m from the trail but does not
57 turn around. Instead, it runs parallel to the trail for a distance of ≤ 50 m and then returns to the
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trail, or the deviation from the trail is > 50 m and ≤ 150 m, but the following criteria are additionally fulfilled:

- a. The deviations only occur at the start.
- b. There are only up to two deviations per trail.
- c. The dog independently orients back towards the trail within a maximum of 150 m and follows the same path back to the trail to continue tracking it.

“Air scenting” - In this case, the dog deviates significantly from the trail. The following deviations fall under this category:

1. The dog deviates > 50 m but ≤ 150 m and
 - a. does not return to the trail using the same path.
 - b. runs parallel for > 50 m, regardless of the distance to the trail.
 - c. deviates from the trail more than twice at distances > 50 m ≤ 150 m.
2. The dog deviates > 150 m from the trail (including parallel running).

The results of this study have shown that dogs are generally capable of tracking scent trails aged 1 day, 1 week, and 1 month. In total, 82 (33x day = approx. 52%, 33x week = 61%, 16x month = 57%) out of 145 trails were found. This corresponds to a success rate of 57% across all trail ages. The dogs were less successful when wind speeds exceeded 11 km/h. The author acknowledges relevant criticisms of the study design in the discussion. For example, the presence of the target individuals on the day of the search and the absence of negative trials were highlighted [134].

A recent dissertation investigates olfactory navigation in mammals [257]. In this context, mantrailing experiments were also conducted. Six dogs (four German Shepherds, one English Border Collie, and one Labrador Retriever) were used. An approximately 800m long trail with various decision points was laid out. The trail was aged one hour. The target person was present on-site. The endpoint of the trail was hidden behind tall shrubs and trees, obscuring the target person from the view of the handler and the dog. Unwashed t-shirts or a scent sample obtained by swabbing the neck with a cotton swab were used as scent articles. Various data were recorded during the search, including the inclination of the dog's head, various meteorological data, the average distance from the laid trail, the trail path during the search, tortuosity, and the area of the region detected between the experimental trail and the dog's worked trail. A total of 15 searches were conducted. The dogs were able to find the target person in 93% of cases. The dogs predominantly searched within a range of 10m from the laid trail. They kept their noses closer to the ground when they were near the scent trail (within 10m) and also when they were between 20 and 30m away. At further distances (more than 40m), the dogs more frequently searched on the ground. The predominant relative humidity remained the factor that most strongly influenced how close the dogs searched to the original trail. Additionally, higher wind speed led the dogs to search at greater distances. However, wind direction did not affect the search behavior of the dogs [165, 257].

A doctoral thesis published in 2020 investigated whether mantrailing dogs can selectively trail individual scent trails and whether the detection and trailing of individual scent trails is possible after time intervals of one month, two months, three months, and six months [135]. A total of 675 trials were conducted for the investigation of individual scent trail trailing, involving seven certified dogs (3 private rescue dogs, 4 police dogs) and 190 test subjects. Each trial was carried out at a T-junction, where the urban environment was selected in such a way that the dog could only go left, right, or back. Two target persons simultaneously entered the apex of the T-intersection, and then each person walked approximately 100m to the left or right. Afterwards they and positioned themselves hidden to avoid visual cues for the dog. The handlers had to choose between the scent articles of target person A, B, or a negative sample, and start the dog on the trail approximately 5 minutes after it was laid. Based on the dog's search behavior, the handler had to determine whether a negative was present or the dog was tracking a scent trail. The trial ended when the handler reported a negative based on the dog's

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1 indication behavior or when the dog crossed the boundary of the decision area while trailing
2 the target person. The evaluation focused on whether the dog targeted the correct person.
3 Depending on the scent articles used, success rates ranged from 50% to 92%. Police dogs,
4 with an average success rate of 82%, were overall more successful than private dogs with
5 65%. An overall success rate of 75% was achieved. Regarding scent articles made from
6 axillary sweat and saliva, all dogs participating in the study with 190 test subjects were able to
7 statistically significantly ($p < 0,01$; $p < 0,05$) detect an individual human scent trail alongside a
8 simultaneously generated different individual human scent trail, and independently track the
9 course of this scent trail towards the target person, regardless of the gender or age of the
10 person being searched for, in a multitude of trials per dog ($77 \leq n \leq 103$). At the same time, it
11 was also statistically significantly ($p < 0,01$) determined by all dogs whether there was any scent
12 trail of a person present on-site. These results were previously published [259]. This work has
13 received criticism [331, 332]. The criticism focused, among other things, on the interpretation
14 of whether dogs can "smell" DNA. Woidtke et al. clarified that such a statement was not made
15 [333]. Furthermore, it was criticized that the number of negative samples was too low,
16 suggesting a manipulation of the data [334, 335]. The authors have responded to this and
17 presented possible reasons for the number of negative samples, emphasizing that even with
18 a reduced probability of selecting a negative sample, as in the experiment, the experimentally
19 observed correct decision rate remained statistically significant and, moreover, a (theoretical)
20 increased number of negatives overall would have resulted in a higher success rate than
21 described. Thus, the reexamination of the study data did not reveal any impact of the lower
22 negative samples on the study results [336].

24 In another part of this study, the detection of aged scent trails was investigated using seven
25 dogs that had previously shown reliable results. Scent samples from 40 individuals were used,
26 and the scent trails were exclusively set in urban environments, ranging from several hundred
27 meters to over 4 kilometers in length. The unique trail design involved simultaneous starts by
28 at least two individuals, followed by divergence at an intersection or junction and at least one
29 change in direction. Test subjects were picked up at the trail's endpoint by a vehicle with closed
30 windows and ventilation turned off to prevent air exchange. Notably, there was no return of the
31 person to the original target location. The search of the scent trail was conducted at different
32 time intervals corresponding to trail ages of one month, two months, three months, and six
33 months. Dogs started their search either at the trail's beginning or at some point along its
34 course, resulting in varying distances to cover. Handlers determined the presence or absence
35 of a scent trail based on the dog's behavior, with trials concluding under specific circumstances
36 (e. g. the dog performed a false positive or the dog's deviation from the actual path). The
37 success of the trials was evaluated based on the dogs' ability to detect the scent trail on-site
38 and effectively trail it. Three categories were established for evaluation: Category I indicated
39 scent detection at the starting point (The dog detects and follows a trail leading away from the
40 starting point. Success is achieved if the dog tracks a progressive trail from the initial point,
41 using the scent article from the runner who laid the trail, without considering the direction in
42 which the trail is followed.), Category II involved vector-oriented scent trailing (The dog detects
43 and follows a trail leading away from the starting point, with the direction corresponding to the
44 vector pointing to the endpoint of the trail or running parallel to the laid trail. Success in this
45 category means the dog works on a progressive trail, staying within 150 meters of the actual
46 trail, and getting back on the trail or remaining in close proximity to it during the course.), and
47 Category III focused on trail-proximate scent trailing (The dog detects and follows the trail
48 leading away from the starting point, closely matching the runner's actual path with minimal
49 deviations (<50 meters). The indication of the actual endpoint is not considered in the
50 evaluation. It's worth noting that despite precautions, the possibility of scent components
51 entering the environment and creating a continued trail could not be ruled out). Out of 217
52 attempts, 178 (82%) were evaluated as correct according to Category I, indicating successful
53 trailing or recognizing the absence of a scent trail (true negative). Concerning vector-oriented
54 scent trailing, on average, dogs covered a distance ranging from 25% to 36% (with an average
55 of 234 out of 598 meters) of the total trail length. Regarding trail-proximate trailing, in half of
56 the experiments, the trail was traced for more than 50m, with an average distance directly
57 traced from the starting point between 150m up to 352m, while the average distance traced

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1 from the entire trail accounting for 15% up to 30% of the total trail length (corresponding 189m
2 up to 583m) The individually correctly traced portions extended up to 1015m. However, it is
3 important to underscore that reaching the actual endpoint of the trail was accomplished only
4 in a limited number of instances, highlighting the complexity of this task. The results varied
5 depending on the age of the scent trail, and a relatively high number of false negative
6 indications were observed (approximately one-fifth of the cases), indicating that despite the
7 presence of a scent trail, some dogs did not initiate trailing. On the days of the experiments,
8 weather data such as humidity, soil temperature, or temperature gradient between laying the
9 trail and the experiment day was measured on-site. Weather data did not show statistically
10 significant effects on success rates [135].

11 Finally, we would like to draw attention to the investigation conducted by Slotta-Bachmayr et
12 al., 2023. This study explored the possibility of scent detection from trails aged up to 64 weeks.
13 No target individual was present at the end of the track. The experimental design was
14 exclusively focused on investigating whether dogs can detect and follow a scent trail and
15 engage in tracking for the initial 100 meters. The results revealed that, on one hand, the
16 absence of a track (negative indication) was correctly identified in over 90% of cases. With the
17 exception of trails aged for 2 weeks and 4 weeks (success rate below 20%), the success rate
18 for other trail ages (1 week, 8 weeks, 16 weeks, 32 weeks, 64 weeks) was approximately 20%
19 among the participating dogs. Considered over all dogs, however, this is in the realm of
20 coincidence [124].

21 No further published studies on mantrailing are known besides the ones presented above.
22 However, it is worth mentioning an experimental series conducted by the German police with
23 mantrailing dogs. This series took place from 2014 to 2016 and was titled "Ausarbeitung alter
24 Individualgeruchsspuren mit PSH" roughly translated as "detecting and follow aged individual
25 human scent trails using mantrailing police dogs" and examined trails aged one month with no
26 target person on-site. The experimental design did not follow a strict scientific approach. The
27 participating dogs had undergone different training programs and were evaluated according to
28 various certification requirements. For instance, a certification regulation for service dogs in
29 one state required the successful completion of a (only) 30-60 minutes aged trail covering
30 approximately 400m, while others mandated a minimum 24-hour aged trail over 2000m. The
31 participating dogs ranged in age from 2 to 9 years, and their operational experience varied
32 from none to several years. Therefore, heterogeneous performance levels were expected [112,
33 253]. Each of the 41 participating dogs completed only one trial, which hinders statistical
34 analysis. Furthermore, there was no comparability among the respective test locations within
35 the experiment. The scent articles used were also not comparable. On the other hand, the
36 experiment was considered successful only if the dog arrived at the end of the laid trail.
37 Examining the results in more detail, it can be noted that out of the 41 dogs, 13 did not start at
38 the starting point, and 11 dogs ran in a different direction, with the majority going in the opposite
39 direction. Nonetheless, 17 police dogs exhibited a search behavior that matched the laid trail
40 up to a certain point. The 17 service dogs that started, trailed from approximately 100m up to
41 around 700m on the laid trail. This is consistent with the results of the above mentioned studies
42 on tracking aged trails [134, 135]. While the first mentioned study had the target person present
43 at the location, this was not the case in the second study.

44 The results of the studies presented demonstrate, firstly, that well-trained dogs can reliably
45 determine the absence of a scent trail (negative indication). Secondly, they indicate that even
46 with trails significantly aged than 48 hours, some dogs were capable of detecting the scent trail
47 and following it over a longer distance, albeit without reaching the trail's endpoint. Practical
48 experiences underscore that weather conditions, particularly high air and ground
49 temperatures, wind speeds, and heavy precipitation, can hinder or even make it impossible to
50 track a scent trail.

51 7 Future directions

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1 The studies described so far have shown, on the one hand, that there is now a wide range of
2 research available, particularly on the behavior of dogs, their trainability, and performance. On
3 the other hand, it has become clear that there is still a significant need for research, especially
4 in areas where dogs are used for law enforcement purposes, but not limited to that (see, for
5 example, MacLean et al., 2021), particularly regarding the reliability, but also the awaited
6 weight of evidence of canine deployments presented as evidence in court. We have
7 extensively addressed this issue in a previous investigation [4]. Furthermore, there is a
8 substantial need for further research specifically related to mantrailing. This includes the
9 central question of which dog breeds may be particularly suited for specific tasks. Government
10 agencies, in particular, have a strong interest in utilizing only suitable dogs due to their limited
11 resources and the often lengthy and expensive training process. Some studies have
12 addressed this question, such as [228, 239, 338, 339], and the references therein. However,
13 no comparative study is known that explicitly focuses on which breeds are particularly suitable
14 for mantrailing or scent-tracking tasks. Apart from breed considerations, the behavioral
15 characteristics, trainability, and expected operational success also play a crucial role. Several
16 studies have examined or measured behavior traits that are conducive to these tasks [142,
17 183, 184, 192, 340-344] and the references therein. The applied training methodology is
18 closely related to these factors. It is notable that a majority of the existing studies have focused
19 on training dogs for substance detection, such as narcotics. Examples include [312, 345-348].
20 However, there is currently a lack of studies regarding the most promising training methods for
21 mantrailing, the required time frame for achieving high success rates in operations, and
22 whether this training should commence early (during the puppy stage) or can be applied
23 uniformly to dogs of all age groups. In addition to the questions related to the selection, training,
24 and maintaining of dogs, there is also a need for research in other areas. For instance, the
25 origin and composition of the human scent signature are still not fully understood. Furthermore,
26 a fundamental problem remains unresolved: How do dogs recognize an individual person or
27 their scent trail based on what components? How to assess not only its true positives, but also
28 its false positives on traces, closer to the operational needs than experiments on scent
29 controlled prints? Assessing this error rate could become mandatory in some jurisdictions as
30 in the USA, following the NAS Report requiring such experimental criteria to admit such
31 methods as scientific [349]. This also pertains to questions about how long the human
32 (individual) scent trail remains detectable in the environment for dogs and whether it can be
33 tracked. Only the aforementioned studies [134, 135] are known to have examined scent trails
34 over a week old. Partially, Slotta-Bachmayr et al., 2023 have addressed this question. These
35 investigations are intended to be extended with regard to tracking beyond 100 meters [350].
36 Additionally, anecdotal reports and insights from operational activities describe the ability to
37 track so-called vehicle or car trails. However, there are no corresponding studies available on
38 this topic. Some of the authors of this article have just completed the practical part of a relevant
39 study. Given the circumstances presented in court, as in Woidtke et al. (2023), there is also a
40 need to investigate whether worn clothing items or objects inherently generate a traceable
41 scent trail.

8 Conclusion

42 Our work has provided a comprehensive overview of the current state of research related to
43 the detection and tracking of human scent trails. We know that dogs have a high capacity for
44 scent detection, and their sense of smell is the most important sense they rely on. They also
45 possess complex cognitive abilities that influence their behavior and their ability to detect and
46 track scents. They have a precise understanding of the object or scent (and the associated
47 object/person) they are searching for. Mantrailing is based on the premise that for a dog, each
48 individual represents a unique scent profile. It is even supported and explainable in light of the
49 recent discovery of a direct connection between the olfactory bulb and the occipital lobe [225].
50 But mantrailing is about scent trace tracking. How does such a trace evolve (degrade,
51 downgrade) and how then is the performance of dogs changing? Hints as practitioners

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1 description of dogs ability to track aged trail pattern in difficult and changing environment, or
2 that have been exposed to extreme thermal conditions are good clues, but needs better
3 performance assessment. Individual behavioral traits are also essential for success as a
4 working dog. A certain degree of autonomy is an important characteristic of working dogs. It
5 has also been observed that both training methodology and the relationship in the handler-dog
6 dyad are significant for successful search work. A balanced perspective is particularly
7 necessary when it comes to their use in forensic applications, as it is unquestionable that the
8 results of dog deployments can be subject to errors. Some aspects of the dogs' performance
9 have been critically questioned [9] or partially doubted [7, 10] unfortunately without publishing
10 explicit results of self-conducted practical studies. However, considering the published
11 research and the practical experiences of numerous handlers, it cannot be seriously disputed
12 that dogs in some instances were capable of detecting human scent trails that have aged well
13 beyond 48 hours and potentially tracking them to their author. Equally accurate is the
14 observation that research has revealed instances in which the dogs failed to detect a trail,
15 deviated from the correct direction, or even commenced trailing despite the absence of a trail.
16 Regrettably, the provided studies do not elucidate the underlying causal factors for these
17 incidents. This lack of clarity is unsurprising, as the study design, beyond a controlled
18 laboratory setting, allows for a variety of explanations. Consequently, commonly cited
19 influences encompass weather conditions, local variables (terrain, buildings, traffic, etc.),
20 passage of time, or the existing expertise (as mentioned earlier) concerning the depth of
21 training and experience of both the canine and the handler, as well as the handler's influence
22 on the dog. Nonetheless, the attainment of successful results should not be solely attributed
23 to air scenting, handler knowledge, or mere coincidence. This holds particularly true given that
24 these factors, due to the study design's specifics, were eliminated as possibilities in certain
25 referenced scientific investigations. Regardless of this, it is proposed that in evaluating canine
26 performance, greater attention should be directed towards the achievements of individual dogs
27 rather than the collective outcomes of the participant canines. This recommendation is
28 especially pertinent considering that due to the sample's characteristics (selection and quantity
29 of participating dogs), the findings cannot be universally applied to all dogs.

30 The criticism rightly draws on insights from other research fields (e.g., analytical chemistry
31 regarding the composition of scent trails or microbiology regarding changes in composition due
32 to bacterial activity). However, it should be noted that there is still a lack of comprehensive
33 understanding regarding the cues that dogs use for individual scent trailing. The traditional
34 response is the demand for standardized training and testing protocols, ideally with uniform
35 examination requirements that align with deployment scenarios. Within the testing process, it
36 must be ensured that neither the handler nor accompanying or examining personnel provide
37 unintended cues. Good references for this are the ASB Technical Report 025 [266] and the
38 ANSI/ASB Standard 026 [263]. Obviously, they are only part of the answer: traditional
39 explanatory models may need to be reconsidered in light of new approaches [75], as it could
40 explain the limited number of published studies considering its forensic applications [4, 351].
41 The PACM introduced by Eckenrode et al. (2021) addresses part of this knowledge gap. The
42 intense discourse on this topic is welcomed. Further research and comprehensive support for
43 such research endeavors are desirable.
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