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The influence of environmental, physiological and social factors on canine search effectiveness.

A STUDY OF CANINE SURFACE AREA SEARCH AND RESCUE DOGS IN GERMANY

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Introduction

The use of search and rescue (SAR) dogs is a cheap and effective alternative tool in the search of the 100,000 people that go missing in Germany annually[1]. It is especially cost effective, since the yearly average of 572 hours in training is done voluntarily by dog handlers. The value of this on an annual basis to the economy is estimated at about EUR 8,008[2] and the value of this work to the families of missing people cannot be expressed in numbers.

Regardless of its usefulness and effectiveness, there is lack of research on the ingredients that make SAR dogs more effective (Greatbatch et al., 2015). Specifically, little research has been done to determine the influence of environmental factors, such as humidity, temperature, and wind strength. The same goes for physiological and social factors, such as the age of the dog, years of training and handler- experience or wellbeing. This is, however, helpful information to improve the way in which these dogs are trained. Ultimately, the more knowledge we gain on how to improve SAR dog effectiveness, the more lives can potentially be saved. That is why this research sets out to investigate this.

To do this, several variables on the handler, the search dog, the search, and the environment will be collected on 10 different German air-scenting teams that are certified or have a stable way of indicating. They will be tested during winter and spring during ca. 5 different searches each[3]. At first, physiological and social data on the dog will be collected by means of a survey, as well as variables relating to experience and wellbeing of the handler. The topography and state of vegetation will be judged on a scale of 1-5, as further explained in the methodology. Secondly, the Skywatch BL500 will be used to measure humidity, temperature, wind speed and altitude, both at the beginning and end of the search. Search effectiveness, the independent variable, is measured as the time in which they can find a victim within a specific search area. Lastly, the influence of all these dependent variables will be tested to determine what plays a significant role in search dog effectiveness.

Before the methodology is further explained, a literature review will first introduce canine SAR work, after which the focus shifts to canine SAR work in Germany. Then, an overview of the training is presented, which is by no means meant to be exhaustive, as it is not the core of this thesis. Search tactics and requirements of the handler are also outside of the scope of this research. The former has therefore been held constant in the collection of data. After, a brief overview of the olfactory system is provided. Lastly, the literature review and a brief video explain and highlight the evidence on environmental, physiological, and social factors. This is the core of the desk research and crucial for the field research. Next, the methodology is discussed, followed by a presentation of the results. Finally, a conclusion discusses the main takeaways, the limitations and further research ideas. To make the research more practical, a textbox with key-takeaways is presented in every chapter of the literature review.

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[1] https://www.bundesverband-rettungshunde.de/de/brh.html

[2] Trenz, Stefanie: Der Einsazt von Hunden in sozialen Dienstleistungen. Eine Betrachtung ausgewählter Möglichkeiten und ihres ökonmischen Mehrwerts. Unveröffentlichte Masterarbeit, Hochschule Nürnberg, 2019

[3] Based on sample size calculations with a confidence level of 95% and a confidence interval level of 5, 320 dogs need to be observed. Based on regression analysis, about 10 observations are needed per independent variable. This is not deemed possible within the scope of this research, which is why the findings cannot be generalized.

Significance and motivation

As described above, 100,000 people go missing in Germany on an annual basis. These people leave their friends and family behind in agony, who are thankful for anyone that can help them search for their loved one. This includes the use of SAR dogs, who can cover large search areas in an effective way. We have all seen the stories of rescue and recovery at Ground Zero, where some people made it out alive due to the quick work of the rescue workers and their dogs. There is no question that dogs, with their impressive olfactory capabilities, can be an effective tool in the search for missing people.

Research on the olfactory capabilities of dogs has increased greatly in the last couple of years, although lots is still unknown. Some aspects of scent detection research are also difficult to replicate in a lab setting, as there are many environmental factors that come into play (Jinn et al., 2020). There has therefore been little research on the factors that should be considered when drawing up search tactics for a canine SAR mission. Increasing knowledge of scent movement is necessary to optimize our use of resources and to increase the survival chances of the victims we look for (Jones et al., 2004). In the end, the search effort is teamwork, and we need to know how to optimally support and read our dogs.

Based on my own experience in a canine SAR group in Germany, it is sometimes baffling to see how two very similar searches can be so different. Generally, this can be roughly related to the weather and how dense the vegetation is. Dog handler knowledge, however, is in my experience often quite limited and many could benefit from an increased understanding on how to optimize search tactics. The more we know, the better we can support our dogs by sending them into places where they are most likely to pick up scent. Why? Because appropriate search tactics can be the difference between life and death.

Literature review

Canine search and rescue; an introduction

Dogs are not just known and loved for their companionship, but also for their ability to be trained for a wide range of purposes, ranging from hunting to emotional support or other assistance, to sniffing out Covid-19, to wildlife conservation. Next to their sensitive noses, it is also their willingness to learn, loyalty and eagerness to work with their two-legged companions that makes them excellent partners for SAR work. Handlers and their working dogs can form a strong bond, which is beneficial to their success at work (Jamieson et al., 2018a).

The first use of SAR dogs can be traced back to the 1700s by the Monks at St Bernard hospice in Switzerland (Fenton, 1992). According to Jones et al. (2004), this may even date back 200 years earlier. SAR work has meanwhile been accepted as a cost-effective and efficient method. Large areas can be covered in a short amount of time, with dogs covering about 2.4 times more terrain than their handler during searches and their noses covering much more than that. Thankfully, their mobility enables them to operate in challenging environments, regardless of the time of the day (Osterkamp, 2020). Many success stories are known, but there is simply no standardized method to evaluate exactly how effective these dogs are in a realistic environment (Greatbatch et al., 2015).

Although this research exclusively focuses on air-scenting dogs and surface area rescue missions, it is helpful to note that typical SAR work can be divided into three different areas: tracking, trailing, and air-scenting. These are essentially different ways to locate a missing person. Although different definitions of these areas exist, Jones et al. (2004) states that one major difference is whether the dog works on a leash, which is the case for tracking dogs. They follow the specific track from the missing person, which is not always the shortest route, by keeping their nose close to the ground. Since they are following a specific track, they also need to be given a scent article containing the scent that matches that of the missing person. Examples of scent articles are socks, shoe inlays or anything else that would carry an uncontaminated and unique scent. Another dog that needs a scent article, is the trailing dog. He may be working on or off leash and does not follow the exact track but may work within a few meters from it. Air-scenting dogs, on the other hand, do not need a scent article as they just look for any human scent. They normally work off leash and follow the shortest distance to the missing person once they get into the scent pool. Since they work off-leash and work by sniffing the air as opposed to the ground, they can cover significant areas (Jones et al., 2004). These areas can be described as a search segment, which ‘’is a subarea of a larger search assigned to a single modality to search in a single task’’ (Chiacchia et al., 2015 p.1). The search segments are split between the different teams and the handler needs to determine a search strategy, depending on the wind direction, time of day, vegetation, specific traits of the dog as well as the topography of the area to be searched. This is important, as it maximizes target detection and enables the dog and handler to work together efficiently. (Cablk et al., 2008).

Another way to classify the different SAR dogs is by environment, such as urban, disaster, water, or avalanche. Lastly, there may be a differentiation between live find teams and cadaver, or human remains

detection. Some dogs are trained to identify both types and even indicate articles that belong to the victim, which can be a helpful indication of the victim's whereabouts (Jones et al., 2004).

The way SAR groups are organized and evaluated differs per country and region, but there is a worldwide umbrella organization called the International Search and Rescue Dog Organization (IRO). They have tested over 2,000 certified dogs around the world, according to international standards and in all areas described above. They represent more than 115 different organizations from 39 different countries. The testing does not only expect a dog to find and alert to the missing bodies, but it also requires the dog handler to be able to navigate, conduct first aid, understand basic scent theory and to read their dogs body language. Moreover, obedience is tested, as well as agility. The modular training system of the IRO prepares the team for emergency situations in a step-by-step manner, until they complete the mission readiness test successfully. This is a more extensive test to be completed within a window of 24-36 hours, which includes a day search and a night search both approximately covering a search area of 60.000m2. At least 50% of the search area should be covered by natural cover. The third search is a search along a path with a maximum length of 3,000 m, including orientation with a map, compass, and GPS. All three searches should be completed within 60 minutes and should have a minimum of 10 hiding possibilities. To pass the test, at least 70% of the victims need to be found.

The training and certification standards of the IRO are also aligned with other standards to some degree, such as those from the International Search and Rescue Advisory Group (INSARAG). This comprises a global network of 90 different countries and various organizations under the United Nations (UN) umbrella. To better coordinate humanitarian efforts across countries, they have successfully created the UN General Assembly Resolution on "Strengthening the Effectiveness and Coordination of International Urban Search and Rescue (USAR) Assistance" in 2002[4]. Their main task is to coordinate efforts from various USAR teams. Although this mainly concerns rubble search dogs and not area search dogs, which is the focus of this research, it is an essential body that is worth mentioning. INSARAG also has close ties to Germany, due to their work with the Technische Hilfswerke (THW). This is a federal agency, which belongs to the department of the Federal Ministry of the Interior. This organization provides technical relief where necessary and also has USAR units. Other than THW, REDOG is another noteworthy INSARAG certified training body. They are a Swiss association that trains volunteers and their dogs for search and rescue disasters. Dog units may also be available through law enforcement or organized SAR units, such as the National Organization for Search and Rescue (NASAR). In Germany, there are several aid organizations that focus on national SAR missions, and they test the teams according to shared guidelines, or they have developed their own minimum standards. These are further described in the next section that zooms in on SAR dogs in Germany specifically.

Once the team has been evaluated by the IRO or a local organization, they become a valuable asset. Dogs are a cost-effective method of searching for missing people. In fact, it has been calculated that a 1-hour search with SAR dogs is 50 times more cost efficient than searching with helicopters. This calculation includes the cost of equipment, as well as the time of volunteers or staff. The costs of canine SAR units are comparable to human search chains, although you can cover a much smaller area with that type of search method (Trenz,

[4] https://www.insarag.org/

2020). This is further amplified by the fact that well trained SAR-dogs have been found to have incredible endurance. They do not only cover an area that is 2.4 times greater than their handler during an average search, but they also recover quickly. Specifically, after performing 4 searches of 20 minutes (with breaks in between) their heart rates and body temperature normalized after 20-40 minutes (Koehler, 2004; Wilhelm, 2007).

The history of canine search and rescue in Germany

Although dogs have likely been used for avalanche rescue work for centuries, the exact beginning is hard to identify (Jones et al., 2004). There is documentation from the 17th century, which refers to dogs guiding lost hikers over the Great Saint Bernhard Pass in the Western Alps. The monks in the monastery and hospice of the Great St. Bernhard pass even started breeding their own type of dogs: the Saint Bernhard. This breed was likely smaller and more agile back then, which enabled them to save many hikers. This occurred especially during the 9 months that the path was hard to find, due to snow and extreme cold. Unfortunately, a fire in the monastery in 1550 destroyed earlier documentation on the dogs that were kept and bred there for rescue work.

In Germany, it can be said that today's surface area rescue dog work has its roots in the medical training dog that was used to find wounded soldiers on the battlefield. In 1885, the German military started thinking about using medical dogs to support them in their military efforts. Due to limited training methods and high expectations, the first couple of tries in the army failed. Until the first world war started, this effort was up to the private citizens. One noteworthy contributor was Jean Bungartz, who founded an association for medical dogs to support the army in 1890. The army soon gave Bungartz' association responsibility for the training in exchange for payment, which included the dogs' upkeep. It was, however, private citizens that carried out the responsibility. The support from the army ended in 1911, as no major advances had been made and no unified guidelines had been drawn up. (Bungartz, 1892; Wegmann, 2021)

In 1917, Swiss Major A. Berdez re-published a book that originally came out in 1903, with instructions on the training and use of medical dogs. Although this book was well-received, the start of the first world war really reignited the discussion and interest in this topic. This was reflected by the output from the association of Jean Bungartz, which had increased from barely 1,000 trained teams (mostly paired with ex-military personnel) to over 4,000 dogs. The high number of dogs was achieved by recruiting them amongst private citizens and breeders. This was mostly done on a voluntary lending basis, although many did not make it out alive after their service. Towards the end of the first world war, many armies were supported by trained medical dogs and many countries, including France and England, set up kennels for them. In 1916, a dog school for war services was founded in Hubertville, which included training for messaging, patrolling, guarding and other specializations. (Wegmann, 2021)

Noteworthy is also that in 1915, the German Defense Ministry set up a medical dog replacement depot in Berlin. This was led by Paul Böttger, a colleague of Konrad Most who is now known as a pioneer in dog training. During the war, more than 30.000 dogs served in Germany as guard- messenger- or medical dog

and they saved many soldiers. Unfortunately, less than 10% of them made it out alive and were returned to their original owners (Wegmann, 2021).

After the first world war ended, the development of the use of dogs and training methods had made great strides. Again, it was mostly private citizens that continued its development, although the use of medical dogs was only for military purposes. Aversive methods were not commonly used, as the focus was rather on dogs enjoying their work. This also meant that the relationship between the dog and its handler was incredibly important and valuable (Bungartz, 1892).The early medical dog had on a harness and carried supplies up to 5 kilos, including a blanket, a first aid kit, potentially ammunition and food for a few days. Additionally, messages could be hidden in the dogs' collar or a light could be attached to its harness (Wegmann, 2021).

In the early days, ''search tactics'' as we call it today, did not exist. The instructions were to not stay behind your dog too far. This was also a difficult thing to develop, as there is lots of human scent on a battlefield. Human search chains were formed, divided into patrol groups with 100-250 meters distance between them. From that practice the search tactic to send the dog alternately to the right and left between the different patrol groups emerged. This had to be done systematically, to ensure that there was no victim left on the battlefield. It also turned out, that this was easier with some breeds than others. Herding dog breeds, for example, tend to run in circles instead of straight lines. In training, a lot of focus was put on successful finds by the dogs to teach them that it pays to follow the instructions from their handlers. Only when this worked out, dogs were sent on searches without successful finds (Wegmann, 2021).

Another interesting difference with the SAR work as we know it today, was that noise had to be avoided for safety purposes. This is similar to the recall/refind indication we know today, whereby the dogs take a short stick or pipe into their mouth and silently retrieves their owner. The device, called a bringsel, is suspended from the collar and it is used as an indication that a successful find has been made. During the war, dogs were also taught to automatically go back to their owners if the search was not successful. Moreover, they were only taught to recognize persons sitting and laying down as victims and to leave walking or standing persons alone. Another difference with how we know it today, was that they had to be able to do their job with different dog handlers and not just their own (Wegmann, 2021).

When the second world war started, the need for dogs increased once more. The army expropriated dogs from private citizens, in exchange for payment. These citizens had priority in purchasing their dogs back, once the war ended in case they survived. This did not only happen in Germany, but in several countries as the usefulness of dogs had become more widespread. In Germany, about 200,000 dogs served during the war, most of them shepherds. There were area surface search dogs, as well as avalanche search dogs at work. Sadly, approximately 25,000 died during their service. During the last few years of the war, a new idea was born in England. Some dogs appeared to be looking for people under the rubble of collapsed houses. This is where the idea of the rubble search dog emerged, as another line of work for SAR dogs. Back then, however, the training methods did not differ significantly from the training for the medical dog or today's surface area search dog. That changed a few years later, when Switzerland established an association for disaster dogs in 1972; ''der Schweizerische Verein für Katastophenhunde (SVKA).

In 1976, the many private organizations came together under the Bundesverband fur das Rettungshundewesen (now called Bundesverband Rettungshunde e.V. or BRH). Slowly but surely, the realization surfaced that a well-trained canine SAR team is an invaluable method to find victims quickly and not just on the battlefield. This was further proven after dogs were successfully used during several catastrophes, such as the earthquake in Friuli (Italy) in 1976, Bucharest (Romania) in 1977 and Algeria in 1980. This only strengthened trust in the capabilities of dogs and furthered the development of better training methods. The federal state, however, did not feel responsible for SAR dog work anymore. Instead, they pushed this onto the civil protection (Katastrophenschutz) of the different states. The private canine SAR organizations were given the choice to join one of the civil protection organizations, such as the THW, the fire department or aid organizations like the red cross. Next to that, a few private organizations were established to focus on training dogs for this line of work (Wegmann, 2021).

The Bundesverband Rettungshunde e.V. have now been training SAR dogs since 1983 and they are the largest organization of their kind in Germany, with more than 90 training units. They have more than 600 certified dogs and more than 1,000 still in training[5]. Their success rate of finding people during a SAR mission is 7%[6]. This is normal, given that the area that is being searched is a small subsegment of a larger area where the person may have been last seen, or is likely to be. Often, however, the victim has already moved on to a different area or was never there to begin with. During their examination, they test the dog and handler in obedience, and they also require a successfully completed ''Begleithundeprüfung'', a state-approved test that evaluates aspects such as obedience, behavior towards people and behavior in stressful situations. Moreover, zooming in on surface area exams, there is an area search covering 20,000-30,000m2. This test needs to be completed within 25 minutes, with 1-3 hidden victims. Similar to the IRO guidelines, the natural coverage of this area should be at least 50%. Next to the Bundesverband Rettungshunde e.V., there are also many aid organizations in Germany that have a canine search & rescue group, such as the Arbeiter-Samariter-Bund (ASB), or das Deutsche Rote Kreuz (DRK).

The increasing demands and resulting structure in this line of work also led to the development of guidelines for training and certification. The certification tests, however, may differ from each other. For example, there is a common examination and regulation guide for canine SAR teams called the Gemeinsame Prüfungs- und Prüferordnung für Rettungshundeteams or GemPPO. This is a guideline followed by several aid organizations in Germany, which stipulates that a team has 20 minutes to search an area of 30,000m2 with 0-2 hidden victims. The test also includes a reference indication, whereby the dog indicates on a body in an open field at a maximum distance of 30 meters. This way, the judges can have a closer look at the way the dog indicates and if there is sufficient distance to the victim. The dog should not harass the victim and indicate quickly for a length of time decided by the examiners. The test also includes obedience to judge the directability of the dog at a distance, whether he can be carried with a muzzle, the general level of obedience and the way the team works together, as well as the dogs' reaction to other dogs and humans[7]. Due to the voluntary nature of these groups, it is helpful to have many certified teams that can be called upon (Möller and Schmalfuß, 2009).

[5] https://www.bundesverband-rettungshunde.de/de/
[6] https://www.bundesverband-rettungshunde.de/de/brh.html
[7] http://www.rhs-finsterwalde.de/files/GemPPO-2018.pdf

Canine search and rescue training

SAR training does not only differ per country, but also per organization as it is highly dependent on who the trainer is. For context, to qualify as a trainer for the ASB or DRK, one must complete a certification of three weekends and preferably have a certified dog[8]. The training is quite extensive, with most dogs spending 12-18 months to complete it with about 20 hours of weekly training (Jones et al., 2004). This section will introduce learning theory, after which it will briefly shed light on SAR training. Since the training itself is not the core part of this thesis, this section is by no means meant to be an exhaustive training manual.

Canine learning, a quick introduction

SAR training is a combination of classical and operant conditioning. To understand what those are, we draw on the early work from I. Pavlov and B.F. Skinner. ''Conditioning is a learning process in which one's behavior becomes dependent on the occurrence of a stimulus in that environment'' (Akpan, 2020, p. 1). The first type, called classical conditioning was discovered by I. Pavlov, a physiologist. The basic concept is that an initially neutral stimulus is introduced, such as a clicker. This is associated with an unconditioned stimulus, such as a treat (or something else that is positive), by giving it to the dog as soon as they hear the ''click'' sound. After a few repetitions the dog is likely to salivate when it hears the ''click'' sound, in expectation of the treat. This is when the response has been conditioned: the dog salivates even though there is no treat (Pavlov, 1927).

B.F. Skinner, a psychologist by training, believed that classical conditioning is too simplistic of an explanation. He posited that we should take a closer look at causes and consequences[9]. Hence, operant conditioning is focused on the fact that if a particular stimulus-response pattern is reinforced, the individual will increase that behavior. When the consequence is negative, there is a decrease in that behavior (Akpan, 2020; Skinner, 1938). Since there are various ways of rewarding and punishing, operant conditioning can be divided into *adding* a reward or punishment or *removing* a reward or punishment. This means that there are four options as displayed below.

Procedures that strengthen the behavior or the probability thereof

1. **Positive reinforcement**: handler cues dog to bark, and it gets a reward, such as treat or toy.
2. **Negative reinforcement**: a dog pulling on the leash is relieved of the constant pressure when it stops pulling.

Procedures that weaken the behavior or the probability thereof

3. **Positive punishment**: a dog harasses the MP for its reward and the handler throws a leash at the dog.
4. **Negative punishment**: the dog does not bark on cue, and it does not get a reward.

It is important to note that reward-based methods have been found to have a significantly higher success rate than aversive methods. Those methods that include positive punishment cause pain, suffering, emotional

[9] The concept of operant conditioning is based on Thorndike's (1898) law of effect, although B.F. Skinner is regarded as the founder of operant conditioning.

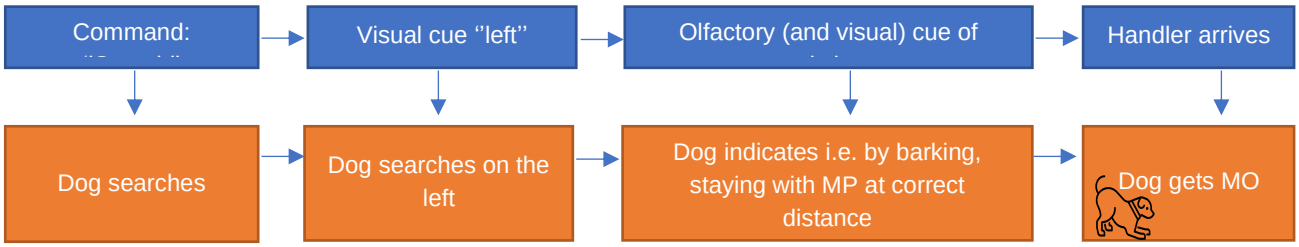
instability, symptoms of depression as well as aggression and a general increase in problematic behavior (Abdel Fattah and Abdel-Hamid, 2020; Arnott et al., 2014; Haverbeke et al., 2008; Hayes et al., 2018).

Besides the consequences (C) described above, it is helpful to take Antecedents (A) and the Behavior (B) into account. This is called the ABC of learning.

- **Antecedents**: what happens immediately before, such as whether there are distractions around, where the handler is, what the dog is doing,
- **Behavior**: the behavior of the dog. What does he do when I call him?
- **Consequences**: what happens immediately after. This is where the operant conditioning options come in. Does the dog get positively reinforced for coming when I call him?

The chain of behavior of a SAR dog will eventually look like the one described in figure 1. This means that we ask the dogs for several different types of behavior, which should be practiced separately until the behavior is performed well enough for the chain to be put together. This is because the behavior, whether right or wrong, is reinforced by the behavior that follows. If the dog runs into the victim, but then backs up to indicate and the MO is given, he learns that it is totally fine to run into the victim at first. To solve problems like that, the chain of behavior should be broken up in smaller pieces again and the indication with proper distance should be practiced until the dog does not run into the MP anymore. Only then can the chain be reintegrated.

Figure 1: Typical chain of behavior in search and rescue



Source: own image

SAR training in brief

SAR training starts by teaching dogs what scent to search for: in this case live human scent. This is a case of classical conditioning: whenever they find someone, something great happens. Once the dog has internalized this process, you can often observe a natural reaction in the form of drooling as soon as they have found the MP. This is because the previously neutral stimuli (missing person (MP) or victim) is paired with an unconditioned stimulus, such as sausages (motivation object or MO). When the dog is deprived of the MO outside of SAR work, he will likely be extremely motivated to work for it. At first, the MP will show the dog that he or she has a special reward, such as sausages or a toy When the dog goes up to the MP, he will be rewarded either by the MP or the dog handler, depending on the preferred method. The dog does not have to indicate yet at this stage but should be given his MO at an appropriate distance from the MP. This is necessary to ensure that the dog does not learn to jump on the victim or harass them for a reward. When this does happen, trainers may switch from positive reinforcement methods to negative punishment, for example by asking the MP to stand up and break off the exercise. This step will be gradually made more difficult, with the

MP moving further away or even out of sight. As soon as the dog shows that he understands what we want, the dog handler can introduce a command, such as ‘’search’’. Eventually, the MP goes into a hiding spot before the dog enters the search area. The dog will be rewarded for finding the MP without indicating until the indication is good enough to be integrated with the searching.

Eventually, the dog will have to search longer stretches, which needs to be built up slowly without frustrating the dog. Search endurance is therefore beneficial, which is where documentation comes in handy on how long your dog has searched on specific training days and how quickly victims were found. Endurance can also be strengthened by exercising the dog on treadmills, by swimming or jogging. In addition, dog handlers may want to practice other types of nose work with their dog to practice several aspects of SAR work (Beutler, 2020, 2021). To generalize learnings, training should take place in different areas (forests, fields etc.) and with many different victims, to ensure that we can ask them to search in places they have never been and to search for people they have never met before. Scent variations will help to improve detection, recognition, discrimination, and perception of the scent we want them to find (Osterkamp, 2020). This means practicing with strangers, but also with children and victims with diseases who likely smell or look differently. Moreover, during a real mission, victims may be scared of dogs and start yelling, they might talk to them or try to pet them. These scenarios should be trained so that the dog indicates reliably, also during a real mission.

Since this research only focuses the barking indication, it is the only indication that will briefly be described. The alert should only be given when the target odor (in this case the MP) has been found. The dog should stay with the victim until the handler is with them and the alert should be controlled[10]. In vast wilderness areas, this may not be the best indication, but it works well for smaller areas (Bulanda and Bulanda, 2010). Although other methods exist, this is often trained by getting the dog to bark out of frustration or eagerness, as they want their MO but cannot get to it. When the dog seems to understand what we want from them, a verbal cue is introduced. This verbal cue can later also be used by the helper during searching. More advanced exercises include the handler petting the dog during the indication, the handler walking around the area or removing him or herself again, taking on different positions, talking or even singing (Beutler, 2020, 2021).

Key take-aways for training purposes:

1. Take small steps. Make sure the indication is fully correct before integrating with searching
2. Train with many different types of victims (visual and odor)
3. Train realistic SAR scenarios, for example with an MP who talks to the dog.
4. If the chain of behavior is not fully functional, break it up in smaller steps
5. Keep documentation of the training to track progress and plan ahead

[10] According to the IRO Mission Readiness Test, the dog must remain within 2 meters of the victim without touching.

The canine olfactory system and its role in search and rescue

‘’Olfaction links the dog’s brain to their external environment’’ (Osterkamp, 2020, p. 18). Although some of the details are still unclear to humankind, we know that an average sized dog has 44 times more receptor cells than we do and that their scenting abilities are 1,000–10,000 times more sensitive than ours (Ostrander et al., 2007; Wegmann, 2021). This is not surprising, as dogs have historically used their noses to find food, to look out for danger and to find partners for reproduction.

The olfactory system consists of two main parts, which are physiologically independent in the collection of smell signals and the impulses to which they respond, the main olfactory epithelium and the vomeronasal organ, a tubular elongated organ. The former is more in front, in the nasal cavity and the latter can be found between the nasal and oral cavity. The olfactory system is complex, and details are largely outside of the scope of this research. It is nevertheless an essential element of SAR work, which is why it will roughly be described below, starting with the two different pathways in the olfactory system. Lastly, the role of the brain will be discussed in olfaction.

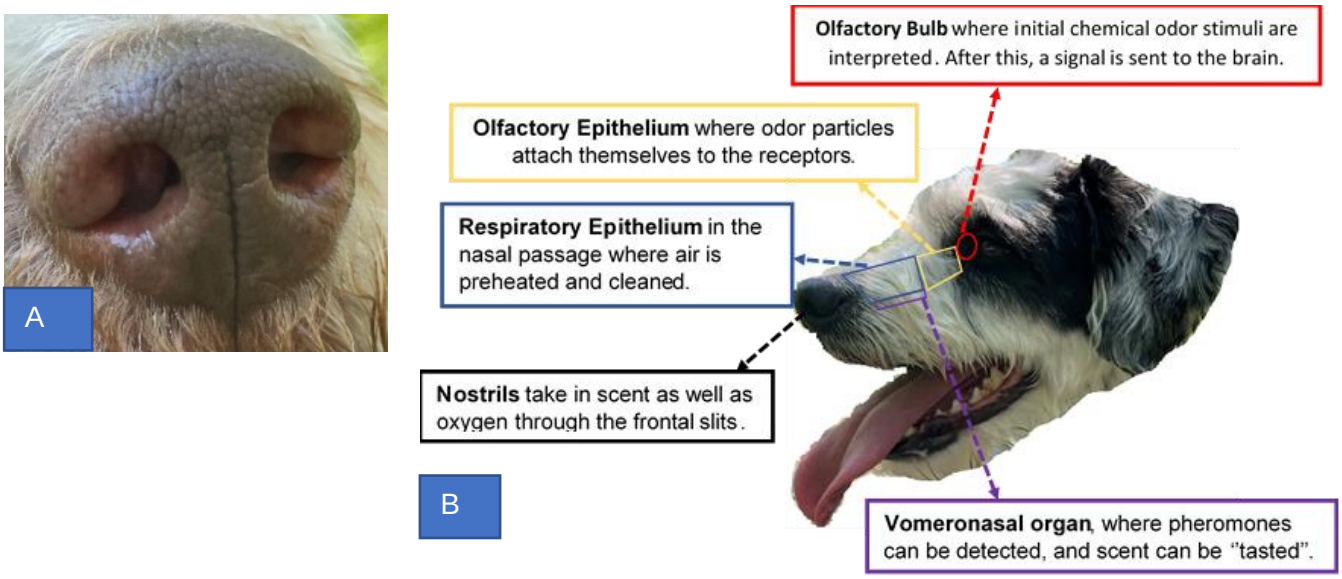
Main olfactory epithelium

The main olfactory epithelium (see figure 2B) contains olfactory receptor cells that interact with odorants. With more than 300 million of them, bloodhounds have the largest amount of olfactory receptor cells (Beebe et al., 2016). This compares to about 5 to 6 million in humans (Hayes et al., 2018; Hummel Shaffer, 2018). Each of these cells binds to a single type of odorant. The stimulated receptor cells then send a signal to the olfactory bulb, which is located under the frontal lobes and involved in the initial processing and filtering of information. This does not only allow for discrimination, but it also enhances the sensitivity of odor detection and can filter out background odors. The information from various scent receptors is put together like a puzzle to characterize the perception of a scent, which is something that has to be learned. When dogs search for live human scent, they need to distinguish this from background noise or interference (also called ‘’detection’’) as they identify it, a unique combination of olfactory receptors is activated (Gadbois and Reeve, 2014; Kokocińska-Kusiak et al., 2021). What the odor puzzle and discrimination process look like can differ from dog to dog even when they are trained on the same target odor. A pregnant woman has a different odor puzzle, and a bleeding person does too. To ensure that this does not lead the dog to dismiss these types of victims, training needs to be varied accordingly.

Interesting to note is that dogs can acquire a separate odor sample through each nostril (differential sniffing) and that they can also determine wind direction with their wet noses. These abilities aid them in determining the source of the scent (Osterkamp, 2020). During sniffing, scent is inhaled into different pathways. A fold of tissue inside the nostril takes the air for respiratory and breathing purposes and separates it. The upper pathway deposits about 12-13% of each breath into the olfactory region, where it is stored for the time-being. The other 87-88% flows down the lower pathway, into the lungs. This pathway is also used for exhalation, which means that the air flows through the olfactory area on its way out (Hummel Shaffer, 2018; Kokocińska-Kusiak et al., 2021). Exhaled air exits via the slits on the side of the nose, to minimize air and odor disturbance (see figure 2A for a frontal close up). Noteworthy here is that both the respiratory and scenting pathway are connecting to a dog’s lungs. Therefore, a dog must close its mouth during the sniffing process, posing difficulty

during high temperatures. In fact, a dog's scenting ability is reduced by as much as 40% when it is trying to regulate its temperature through panting. Another factor that limits their olfactory capabilities is dry nasal membranes, either from smoke, atmospheric conditions, or dehydration. This means that it is essential to take water on a search and to keep your dog hydrated (Hummel Shaffer, 2018).

Figure 2: a dog's nose up close (a) and the olfactory system (b)



Source: own images modified according to Kokocińska-Kusiak et al. (2021)

The vomeronasal organ

The vomeronasal organ, also called the Jacobson's organ, is connected to the mouth by the nasopalatine duct, which begins behind the upper incisors on the palate (see figure 2B). It has two fluid-filled sacs, which makes it possible for the dog to taste and smell at the same time. Moreover, it is layered with its own receptor cells. The information from these cells is also transmitted to the olfactory bulb for initial processing. It is thought that this organ is mainly used for detecting pheromones relating to sexual activity, but this is likely not the case given observations of bird hunting dogs tasting the water to pick up scent (Osterkamp, 2020). Moreover, SAR dogs have been observed to react differently when they search for extremely stressed persons. Since the assessment of emotions takes place via the vomeronasal organ, we can deduct from this observation that they likely use it during searching (Grunow and Langkau, 2011; Hummel Shaffer, 2018; Wegmann, 2021).

Brain

The olfactory signals are transmitted to the brain via the olfactory bulb. This is a crucial step, as it is related to the memory as well as the recognition of odors (Osterkamp, 2020). A virtual picture is being formed for the dog to attempt to identify the target odor (Hummel Shaffer, 2018). Interestingly, different brain areas are at play during different stages of the search. During the first part, the dog displays a basic emotion called seeking. The neurotransmitter during this step is dopamine, of which the amount can differ per dog breed (i.e., livestock guarding dogs have lower base-line levels). Dopamine, also referred to as a reward chemical, is associated

with various cognitive processes and believed to play a role in motivation. Once the dog has solved the puzzle and gets its reward, endorphins are released (Gadbois and Reeve, 2014).

Key take-aways for training purposes:

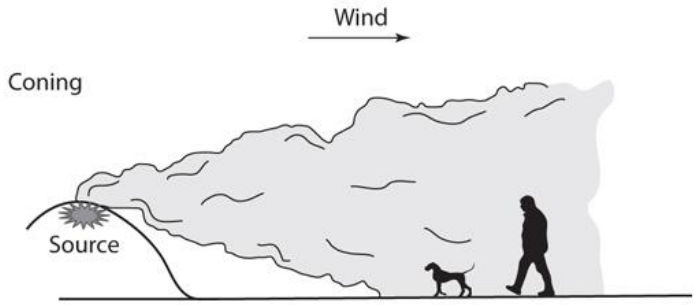
6. Always take water on a search to keep your dog hydrated.
7. If a dog is panting, keep in mind that their olfactory capabilities are reduced by 40%.
8. We do not know exactly what odor puzzle the dog associates with SAR work, which is why we need to train with many different types of victims, to provide sufficient variation.

Influential variables on canine search and rescue effectiveness

Environmental factors

Scent will follow similar patterns under stable weather conditions, depending on what the vegetation and topography looks like. If all these factors are stable, scent will be trapped in the same locations and follow the same direction and patterns. The fact is, however, that these factors are not stable. Wind speed changes every second, temperature changes throughout the day and vegetation changes throughout the year. According to Osterkamp (2020), the main factors influencing scent transport are the gravity flow of air, convection, and wind. He suggests that these processes result in scent plumes that can be compared to smoke plumes from a chimney (see figure 3). This section is divided into convection and gravity, wind and lastly site conditions, such as vegetation. The descriptions below are only relevant for MP above soil and on land.

Figure 3. A scent plume or cone under close to neutral air stability and in the presence of wind



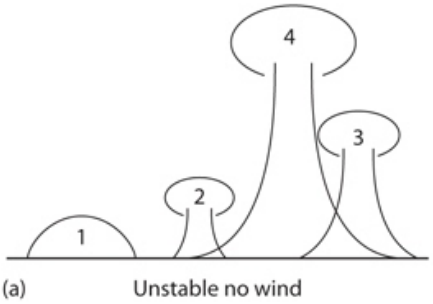
Source: Osterkamp (2020)

Convection and gravity

Air is a mixture of gases, mostly nitrogen and oxygen. Cold air sinks and warm air rises as it has fewer molecules, making it less dense. This process is called convection, which is driven by temperature differences (see figure 4). Osterkamp (2020) claims that the convection process moves from 0.8 square meters at a speed of 30 centimeters per second at intervals of about 4 per minute. Additionally, warm temperatures make scent molecules more energetic, enabling the scent to escape the source more easily. This is especially the case

for human scent, given that it has a large surface area with more surface that comes in contact with air (Osterkamp, 2020). If we assume that the MP has a body temperature of 37 degrees, this means that in most weather conditions the MPs scent will initially rise until it cools down to the point that it is equal to the temperature outside. On hot summer days of 35 degrees, there is not much room for the scent to be pushed up. On extremely hot summer days of 40 degrees, there will essentially be a sort of blanket over the MP which prevents the air from rising. This results in a stagnant scent pool, which the dog will only be able to pick up when extremely close to the source. The more temperature difference between the MP and the air, the more dynamic the scent will be in the absence of side wind. Noteworthy here is also that hotter temperatures complicate searching for other reasons, as panting may reduce their ability to detect scent. According to Osterkamp (2020), dog handler experience has indicated that temperatures up to 18 degrees Celsius enable the dogs to perform light work without much complication. Generally speaking, a dogs' ability to work is reduced in higher temperatures, as it is a strain on stamina (Robbins et al., 2017).

Figure 4 The convection process, as described by Osterkamp (2020)



Source: Osterkamp (2020)

The process of convection is influenced by the differential temperatures of the layers of air, which is again influenced by solar insolation. This means that not only the angle and intensity of the sun should be considered, but also the time of the year and cloud cover. An atmospheric stability classification system was suggested by Pasquill in 1961[11], but this was found to mostly hold up during the night, during relatively stable or neutral conditions. Daytime instability was found to only be correctly estimated in 1%-32% of the cases. This result is not surprising as this system was never meant to be a stand-alone method (Kahl and Chapman, 2018). Pasquill's stability classification system was later extended with the measurement of your shadow (Graham, 1994; Lavdas, 1976), as displayed in figure 5. For a person measuring about 1.83cm, a shadow of 1 meter or less indicates strong radiation which makes searching more difficult. Between 1 and 2.5 meters indicates moderate radiation and anything more than 2.5 meters indicates slight radiation. Although this method is also likely not 100% accurate, it can serve as an additional tool to understand atmospheric stability. Searches during late spring or summer, that occur in the middle of the day have the least probability of success. This is due to the scent plumes forming ''loops'' as thermal convection moves it up and wind that moves it horizontally. The scent plumes may continually come down to the ground and rise up again downwind

[11] Later published in 1979

from the victim, which makes it extremely difficult for the dog to follow it back to its source. The presence of dust devils may reveal these types of conditions to the dog handler (Osterkamp, 2020).

Figure 5 Solar Radiation and Cloud Cover as suggested by Lavdas (1976) and Pasquill (1979)

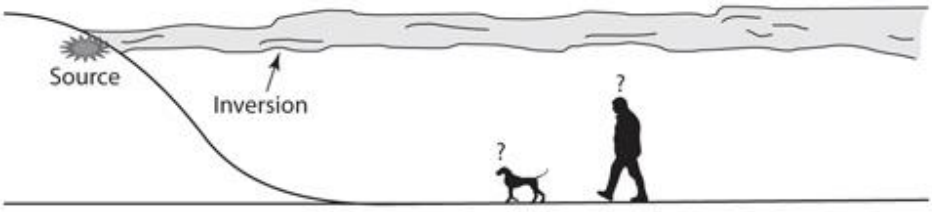
	Day			Night	
	Solar Radiation			Cloud Cover (cc)	
Wind Speed (mph)	Strong <3½ ft	Moderate 3½–8½ ft	Slight >8½ ft	Cloudy > or = 4/8	Clear < or = 3/8
<4	A	A–B	B	E	F
4 to 7	A–B	B	C	E	F
7 to 11	B	B–C	C	D	E
11 to 13	C	C–D	D	D	D
>14	C	D	D	D	D

**Class A= very unstable, B= moderately unstable, C= slightly unstable, D= neutral, E=slightly stable and F= stable.*
Source: Lavdas (1976), Pasquill (1979) and Osterkamp (2020)

Dog handlers can use the tool described above as input for their search strategy, since turbulence is a major limiting factor in the olfactory search process (Chiacchia et al., 2015). In fact, Graham (1994) suggests that the distance between the sweeps or lane widths should be adjusted based on air stability. For very unstable air stability (A), he finds that the probability of detection is only 13% if the lane width is 100 meters, whereas this is 95% for stable air stability (F). The take-away here, is that dog handlers dealing with a search in very unstable air stability conditions, should choose smaller lane widths to increase the probability of detection. Decreasing the lane width from 100 meters to 25 meters would increase the probability of detection from 13% to 82%. Although these estimations will never be precise, they can serve as a useful starting point.

To make matters more complicated, air is also heated or cooled when it comes in touch with different surfaces, such as vegetation or rocks and soil. The ability of surfaces to absorb heat depends on whether the surface is level or sloped and the type of material (Osterkamp, 2020). The darker the surface, the more heat it absorbs, with dark rocks able to heat up to 80 degrees Celsius. This will therefore also heat up the scent plume and potentially carry it upwards out of the reach of the dog, depending on weather conditions. If the surface is cooler than the air above this process is reversed, potentially making it easier for the dog to detect as the scent falls or even sticks to the surface. A highly stable configuration of that is called inversion, which can be compared to a blanket covering the scent. If the dog is in a valley inversion (as displayed in figure 6) and the MP is higher up and above the inversion, the dog will not be able to detect the scent, if it stayed in the valley inversion. The scent will spread downwind above the inversion layer, which consists of warmer, lighter air floating on top of the heavier cooler air (Osterkamp, 2020). At night, however, air will cool and fall down the slope following the rules of gravity and taking some of the scent with it. Scent pools may form in a depression, as cold air is unable to rise up the slope on the other side. It therefore generally makes sense to send the dog into depressions at night times or in shaded areas and up the slopes during day times and in sunny areas.

Figure 6: Inversion by Osterkamp (2020)



Source: Osterkamp (2020)

Another environmental factor influencing air stability is humidity. This is not surprising, as water molecules are lighter than air, which result in a quicker rising of the scent. It may also increase odor intensity (Gutzwiller, 1990; Kuehn et al., 2008; Osterkamp, 2020) and the dog's ability to trap odorants (Jenkins et al., 2018). As described in the section above, physical, and chemical properties of odorants influence the ability of it to bind to receptors and therefore the dogs' perception of scent. One study by Jinn et al. (2020) found that of the 10 meteorological factors that were measured, relative humidity and air temperature were the most significant. Specifically, colder and more humid conditions made it easier for the dogs to search. Other authors, like Greatbatch et al. (2015) did not find humidity to be an important factor. Overall, Osterkamp (2020) suggests that light precipitation, dew, and humidity increases the availability of scent to dogs, whereas heavy precipitation decreases it as it takes scent down with it and is absorbed by the soil.

Wind

Much simpler to understand is the influence of side wind, which carries scent across the search area. This results in scent cones or plume that is more concentrated at the source and less at the edges. Higher wind speeds will carry the scent with it at a faster pace than slower wind speed. However, due to the influence of the dynamics above, as well as obstacles that may be in its way, scent does not only move horizontally but also vertically and perpendicular. Due to this turbulence, scent cones are not always continuous, but can also occur as discontinuous or extremely scattered, which makes it more difficult for the dog to follow it to the source (Cablk et al., 2008; Jones et al., 2004). According to Osterkamp (2020), this may even make it impossible for the dog to follow the scent back to its source. This is when the handler needs to help the dog with his or her knowledge of scent movement, by sending the dog into a direction where it is likely to pick up the scent again. Dogs can sense the direction of the wind due to their wet noses and can discriminate scent between the nostrils or by moving along the plume.

Given that wind is a significant factor, it is helpful to refer to the Beaufort Wind Scale, modified by Osterkamp (2020) and reflected in figure 7. The wind scale measures the wind speed from relatively calm air (Beaufort number 0) to a strong breeze (Beaufort number 6). The author claims that even light air can transport scent across a distance of 80 meters within the time span of 1 minute.

Figure 7 Beaufort Wind Scale, modified by Osterkamp (2020)

Beaufort Number	Description	Wind Speed (mph)	Visible Effects on Land
0	Calm	<1	Calm, smoke rises vertically.
1	Light air	1–3	Direction of wind shown by smoke drift but not by the wind vanes.
2	Light breeze	4–7	Wind felt on face; leaves rustle; wind vanes moved by wind.
3	Gentle breeze	8–12	Leaves and small twigs in constant motion; light flags extended.
4	Moderate breeze	13–18	Raises dust and loose paper; small branches move.
5	Fresh breeze	19–24	Small trees in leaf begin to sway; crested wavelets form on inland waters.
6	Strong breeze	25–31	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty.

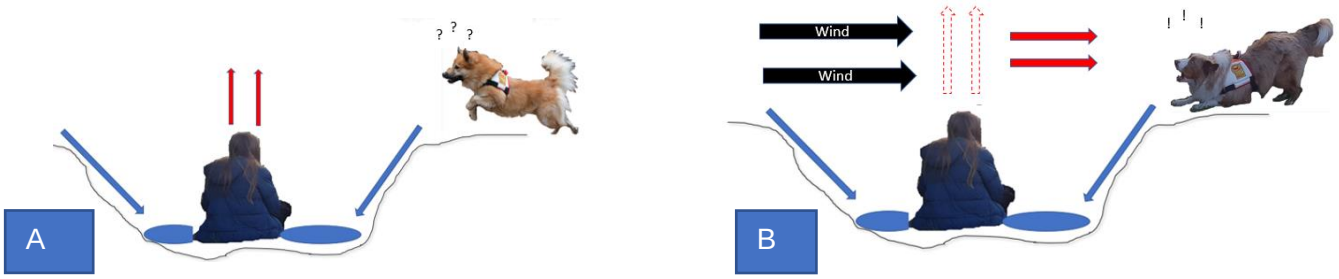
Source: Osterkamp (2020)

Overall, it can be said that it is not always the case that higher wind speeds mean that the dog finds the MP faster as they are likely to pick up the scent from a greater distance. For context, under favorable conditions dogs have been found to detect whale scat from a distance of 1.93km (Rolland et al., 2006). Research by Cablk et al. (2008) has found that although wind speed does influence the distance at which dogs picked up the scent of tortoises, it did not influence the number of successful finds in trained dogs (Cablk et al., 2008). The authors, however, did not focus on the extent of the way the wind speed influences the search time.

Site conditions

As already touched upon above, gravity plays a role in scent movement. This means that scent will move differently in flat areas than it does in sloped or even mountainous areas. It will also be warmed by the sun differently as described above. It is therefore important to consider the topography of the search area. As air cools down in the shade or at night, it tends to flow down the slopes or mountains and is likely to form scent pools in depressions. As displayed in figure 8A, this can pose difficulties for the dog when the MP is located in the depression and there is no wind. The dog handler therefore needs to be aware of these circumstances and send the dog into depressions under these search conditions. Once there is even a light breeze, this can dramatically alter the probability of detection (see figure 8B).

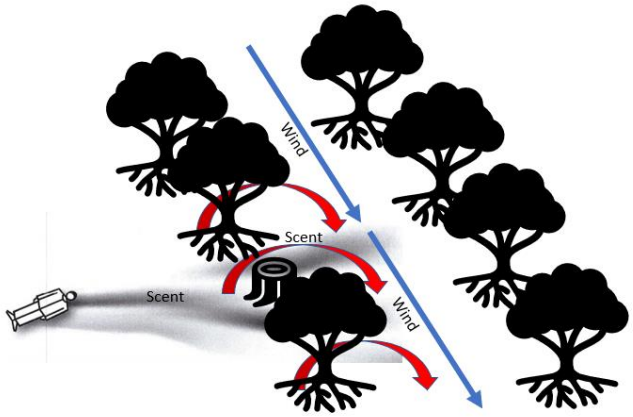
Figure 8 influence of topography in the absence of wind (a) and in the presence of wind (b)



Source: own images

Scent can also be channeled by obstacles, which can be seen in search areas containing valleys, canyons paths, walls, at the edge of a forest or with streams of water. Scent can be channeled down these obstacle free paths if the wind is at an angle to the channel (see figure 9).

Figure 9: Channeling in the absence of sun



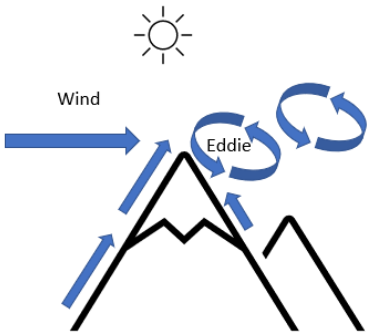
Source: own image

Another important factor to consider is the vegetation and other potential obstacles that may disturb the movement of scent, by causing mechanical turbulence. Osterkamp describes the effect of mechanical turbulence as ‘’a boulder in a stream of water’’. He suggests that the size of the obstacle matters, as it will influence the airflow for a downwind distance 5 to 10 times the height of the obstacle. At low wind speeds, this results in a whirl of air on the downwind side of an object, also called eddies or whirls of wind (see figure 10). At high wind speeds, this results in eddies at both sides of the object. This does only occur with bushes or trees, but also when air flows over an object that suddenly stops, like the top of the mountain (see figure 11) or the edge of a house.

Figure 10: Forming of eddies and complications due to obstacles

Source: own image

Figure 11: Forming of eddies on the top of a mountain



Source: own image

It is, however, not just the type or size of vegetation that matters but also its density, as scent may get caught in it or stick to it depending on the number of binding sites for scent molecules. Natural surfaces tend to have many binding sites, which scent molecules can easily stick to. Metal, on the other hand, does not have this property (Osterkamp, 2020). Trees for example also tend to stick out and its surface gets warmed up by the sun first, as it is closer to it than the soil or other vegetation. It also warms up air that comes in contact with it and pulls it up alongside its surface. Any scent from a victim that is hidden directly under or even near a tree may be attracted in that direction and stick to it. It is therefore not unusual that a dog will alert next to a tree, even if there is nobody directly hidden there. If that happens, it makes sense to move upwind and search in the vicinity (Janki, 2019; Osterkamp, 2020; Wegmann, 2021). To demonstrate the difficulty of finding victims near or in trees under certain conditions, several members of the SAR team of ASB Südhessen, including myself have some video material (‘’Sullivan und der Baum) that can be found here. The process of scent diffusion is demonstrated with smoke bombs.

Water also has the ability to bind scent to it and transport the scent of a person further down the stream (Janki, 2019). Dog handlers must also keep in mind that the sun heats up and cools down land faster than it does water, meaning that air likely flows towards land during the day to replace the rising air. In the absence of wind, air likely rises over land and falls down over the water, forming a loop. At night, land cools down faster than water, pulling air towards the water. If there is water in the search area of the dog handler, it makes sense

to let the dog search close to the water and around it, if possible, to increase the probability of detection. A good understanding of these dynamics by the dog handler will influence his or her search strategy and increase the chances of a successful find (Jones et al., 2004).

Physiological factors

Breed

As can be deducted from the description of the dog's olfactory abilities, their skull, nose shape and genetics may influence it. This is especially the case looking at the total surface area, where one may conclude that more receptor cells mean better detection skills. Research to confirm this, however, is lacking (Hayes et al., 2018). Some authors even found that Pugs outperformed German Shepherds on scent detection, whereas 9 out the 10 Greyhounds in this research failed motivation criterion (Hall et al., 2015). Other research found that breeds that normally get selected for scent work (such as German Shepherds) perform better than short-nosed breeds as well as breeds that normally do not get selected for such tasks (Polgár et al., 2016) and yet other authors find no differences at all across domestic breeds (Elodie and Dahl, 2022). Research looking at working dogs suggests that it is more about specific traits, such as highly play or food motivated, boldness, a high level of willingness to cooperate with their handler , high athletic capability, low distractability and obedience as well as independence when working off leash (Beebe et al., 2016; Jamieson et al., 2017; Rooney et al., 2004; Svartberg, 2002).

Age

Age may play a role for different reasons. On the one hand, the experience of the dog (in case age equals experience) may make it a better SAR dog as concluded by Greatbatch et al. (2015) and Lazarowski et al. (2019). Age may also negatively impact their ability to complete other tasks, as aging is associated with a general decline in cognitive function (Chapagain et al., 2018; Tapp et al., 2003), which includes olfactory abilities (Kokocińska-Kusiak et al., 2021). Chapagain et al (2018), however, do not find that age affects learning and conclude that dogs that live in a stimulating environment may not be as prone to cognitive decline as previously thought. In the context of SAR work, Koehler (2004) measured lower cortisol concentrations in dogs aged 4-7, as compared to younger dogs. This likely reflects lower stress levels, which would theoretically indicate an increased ability to concentrate. She also measured higher heart rates and reduced body temperature, which may be related to reduced ability to regulate this with age.

Sex

There has been research that shows that female dogs may be more cooperative in trying to solve problems with humans and that they are more social towards them. Wei et al. (2017) also find that cells in the olfactory bulbs of females are more active as compared to those in male dogs and that they may have a stronger memorizing ability of scents. On the other hand, male dogs have been found to be more bold, quicker to adjust and more inclined to interspecific social play in comparison to female dogs, which may be favorable to working dog capability (Scandurra et al., 2018; Wilhelm, 2007). Other research finds that there are no differences at all (Rooney and Bradshaw, 2004). The influence of neutering dogs on their working performance or trainability also yields different results. Some find that intact males and females perform better (Abdel Fattah and Abdel-Hamid, 2020) or that intact female dogs learn more quickly and more accurately with higher success rates

(Mongillo et al., 2017). Yet others find that neutering does not make a difference in female dog performance, but increases performance in male dogs in some breeds (Serpell and Hsu, 2005). Looking at well-performing dogs, it appears that authors cannot agree on specific sex differences or fail to find any (Serpell and Hsu, 2005; Svartberg, 2002). Svartberg (2002) claims that dogs in general are more likely to succeed as working dog when they have a certain level of boldness which is not related to the sex.

Social factors

As indicated above, there are several behavioral traits that appear to be positively correlated with working dog performance. Social factors have also been found to play a role. Since this research is focused on dog-handler teams that view their dog as part of the family, all dogs have their basic needs fulfilled. Moreover, none of the dogs are chained up outside or live an isolated life in any other way. This section will therefore focus only on dog handler traits and experience as well as the closeness of the team.

Dog handler traits and experience

The conscientiousness score of the owner's personality has been found to be positively correlated with success (Alexander et al., 2011; Arnott et al., 2014; Hayes et al., 2018; E. M. Payne et al., 2015). This can be explained by the likelihood that a conscientious person is more disciplined in their training approach. Nevertheless, the handler should also have certain skills, such as familiarity with and understanding of their dogs' body language and behavior (Jamieson et al., 2018b). This will also help the handler in better understanding the dog's limitations and motivations and to shape their perception in a more positive manner. Having a positive attitude and good understanding of dog behavior has indeed been found to be a significant factor in dog training. This is also referred to as agreeableness, with more agreeable personalities, likely using fewer verbal corrections and using more positive training methods (Elyssa Payne et al., 2015). Safety and positive reinforcement appear to help create a learning environment where dogs remain positive, which increases their ability to learn (E. Payne et al., 2015).

According to McGreevy et al. (2017) a good animal trainer also has essential traits relating to timing and effective communication. The former allows them to positively reinforce the dog at the right moment. This is beneficial for learning and minimizes frustration for the animal. The latter is related to providing clear signals verbally, but also with their body language (Jamieson et al., 2018b; Rebmann and David, 2000). Some of this knowledge is likely to be correlated with experience, as dog handlers can be assumed to get better over time. Indeed Svartberg (2002) finds that experienced dog owners perform better at obedience tests, although this is not confirmed by Lefebvre et al. (2007). This may be explained by the handlers in Lefebvre's research, who were likely more experienced than the average dog owner. Adequate training and continual performance evaluation of the team is likely an important factor (Hurt and Smith, 2009; Jamieson et al., 2018b).

Closeness of the team

The dog handlers' view of their dog as companions, employees, working mates or workplace resources has been found to impact the success of the team. Particularly, those that had a greater attachment to their dogs also tended to have a better working relationship and therefore achieved greater success (Arnott et al., 2014).

Other research adds that engaging in activities and having the dog for other reasons than just companionship is beneficial for the bond (Meyer and Forkman, 2014). This also relates to general welfare and enrichment, whereby chained dogs with less human contact are less likely to succeed (Arnott et al., 2014).

Lefebvre et al. (2007) found that Belgian military working dogs who engaged in off duty sporting activities with their handlers, performed better than those that did not. The explanation that is given points to the improved handler-dog bond, which benefits the success of the team. This was tested differently by Jamieson et al. (2018), who experimented by switching up dog-handler detection teams. The results were that dogs performed better in terms of detection accuracy and distraction with a familiar handler (Jamieson et al., 2017). This again highlights the importance of a team and trust between them, especially during stressful events, such a SAR operation. What was found to be a negative influence on the bond was the presence of children in the family, which can be explained by the owners having less time to interact with their dog (Meyer and Forkman, 2014)

In a SAR environment, significant interactions between dog handler and dog stress have been found, with more pronounced results for an all-female team (Wojtaś et al., 2020). In other environments, it has also been found that dogs mirror the stress levels and emotions of their owners (Katayama et al., 2019; Sundman et al., 2019). Susceptibility to stress on the handler's part is an important piece of this puzzle, as it significantly impacts the dog and the performance of the team (Sundman et al., 2019; Wojtaś et al., 2021). Correctly pairing the team's personalities is not to be underestimated. A dog handler prone to stress, paired together with a dog with low nerve strength may not be the best match. Besides compatibility, adequate training methods that fit the experience of the handler and motivation of the dog are important (Beebe et al., 2016; Smith et al., 2003; Wojtaś et al., 2020).

Key take-aways for training purposes:

9. Pay attention to topography and time of the day. Scent generally moves down at night and up during the day. Send your dog up the mountain during the day and down during the night.
10. Pay attention to dense vegetation and send your dog in and around these areas.
11. If there are paths that may channel wind, it is efficient to send your dog down these obstacle-free footpaths, as scent is likely pulled along it.
12. If your shadow is less than 1 meter, search conditions may be especially difficult. Sweep size needs to be reduced to increase the probability of detection.
13. Trees attract scent and in certain conditions most of the scent pool may be ''glued'' to the tree. When your dog alerts here, move upwind or circle around it to find the source.
14. Pay close attention to your dog's body language. Does he have scent, but cannot work out the source? Support him by sending him towards areas where the scent pool likely continues.
15. Spend time with your dog outside of SAR training to bond.
16. Try to have fun and to create a positive learning environment for your dog by providing security and using positive reinforcement.

Methodology

To research search dog effectiveness, various variables need to be collected on (a) the dog (b) the handler (c) the search (d) the environment. Some of these variables are collected by means of a survey (see appendix 1), which is given to the handler in advance of the search. The environmental data is collected during the search itself at an interval of 5 minutes, with the Skywatch BL 500[12]. The average of the first and last measurement point will be taken for the statistical analysis. The variables are further detailed below.

(a) Dog: As described above, there are different physiological factors that may influence the effectiveness of the dog. Based on the literature review, the following variables are collected:
    a. Age
    b. Breed
    c. Sex
    d. Experience dog in years
    e. Well-being dog (scale of 1-5)
    f. MO (food/toy or both)
    g. Dog exercised before training (no/0-15 minutes/15-30 minutes)
    h. Time last eaten if MO is food in hours

(b) Handler: The handler can influence the dog in two ways. First, he or she has the task of choosing a fitting search tactic, which needs to be customized to the dog, the weather as well as the topography and vegetation. This is roughly summarized in dog handler experience, although search tactic is held constant in the collection of the data. Second, the relationship between the dog and the handler is of great significance, as described in previous sections. Hence, the following variables are collected:
    a. Dog handler experience in years
    b. Dog handler well-being (scale 1-5)

(c) Search: There are several aspects of the search that are tracked, with the most important one being the time that it takes the dog to complete the search (''search effectiveness''). Other than that, the search area in m2 will be noted, as well as the amount of time the MP has been in hiding. All of the searches will only have 1 missing person and the overall search tactic is held constant zigzagging into the wind. How and where the dog handler sends their dog is not held constant, but rather up to the handler and his or her experience and type of dog. This results in the following variables:
    a. Search area in m2
    b. Searching time in seconds from start until the dog alerts
    c. Amount of time MP is missing in seconds
    d. Distance the MP is removed from starting point in meters (diagonal – shortest distance)

(d) Environment: As noted previously, there are many environmental factors that potentially influence the search effectiveness of the dog. The environmental factors are tracked with the skywatch BL500. Moreover, the vegetation and topography is assessed on a scale of 1-5, with 5 being extremely dense vegetation and extremely mountainous areas. The variables for this section are therefore as follows:
    a. Average wind speed, measured at beginning and end of the search (Beaufort scale)
    b. Average temperature, measured at beginning and end of the search

[12] https://bl.skywatch.ch/

c. Average humidity, measured at beginning and end of the search
d. Vegetation (scale 1-5)
e. Topography (scale 1-5)
f. Time of the day (morning or afternoon -dummy variable)

Firstly, the categorical (ordinal) data will be recoded in SPSS, a statistical software suite, by using dummy variables. That means that the following variables will be recoded into dummies:

- Breed, with a dummy for mixed breed
- Sex, with a dummy for female
- Exercise, with a dummy for dogs that exercised 15-30 minutes beforehand
- Reward, with a dummy for dogs that only get a food reward
- Dog wellbeing, with a dummy for dogs that scored highest on the 1-5 scale (and therefore a 1)
- Handler wellbeing, with a dummy for handlers that scored highest on the 1-5 scale (and therefore a 1)
- Vegetation, with a dummy for the areas with a dense or extremely dense vegetation (4 and 5)
- Topography, with a dummy for the areas that are relatively mountainous (3)[13]
- Morning or afternoon search, with a dummy for searches that took place before 12:00 (noon) or searches whereby the largest part of the search took place before 12:00 (noon).

The remaining variables will be categorized as scale variables, meaning that they can be included in the regression analysis as is. Moreover, the assumptions of the linear regression analysis will be checked beforehand, to ensure that the results are reliable. These assumptions are as follows:

- Linear relationship: Is there are linear relationship between the independent variable (search effectiveness in seconds), and the dependent variables as noted above?
- Residual independence: Are the residuals are independent and is there no correlation between consecutive residuals in time series data?
- Homoscedasticity: Do the residuals have constant variance at every level of search effectiveness and is the scatterplot therefore sufficiently scattered?
- Normality: do the residuals follow a normal distribution.

[13] This is the highest value in the sample for topography

Results

Descriptives – an overview of the data

After removing two datapoints (outliers) with extremely long searches, there are 41 observations that can be used for the regression analysis. These observations consist of 16 different dog-handler teams, with searches on 6 different dates and locations in Hessen and Rheinland-Pfalz. Most data was gathered at the ASB Südhessen, and only some at the Malteser in Mainz. The searches took place in January, February, March, April and twice in June 2022. The searches had a success rate of 100%.

As displayed in figure 12 below, the scale variables show that the age of the dog in the sample ranges from 2 to 10 years old. These dogs have an average experience of 3.5 years and their handlers nearly 7 years. Most of the dogs in the sample (39/41) are rewarded with food and most eat the night before the training, which explains the nearly 9 hours between their last meal and the training. This, however, varies quite a bit in the sample from 2 hours to 18 hours. The search area was on average nearly 23,000 m2, which is close to the maximum certification area of 30,000 for the GEMPPO exam guidelines, which all of the teams need to follow. The temperature ranged from 2º - 32º degrees Celsius, with an average of 16º degrees Celsius.

On average, the distance of the missing person from the starting point was 164 meters. This was measured by taking the shortest geographical distance from the starting point to the hiding spot. MP spent on average about 17 minutes in hiding before they were found, and dogs spent an average of 7 minutes searching. The latter varied from 1 minute to nearly 21 minutes and it is exactly this variation that this research will try to explain.

There was not much wind during the searches, with most of the searches only having a light breeze. At most, there was a gentle breeze (Beaufort scale 3), meaning that small twigs and leaves were in constant motion. Humidity levels ranged from 29-90%, with an average of 56%. Although not displayed in figure 12, mixed breeds accounted for about 35% of the observations, Australian Shepherds 26% and Icelandic sheepdogs 12%. The sex of these dogs was almost evenly distributed, with 49% male and 51% female dogs. Interesting to note is that 84% of the dogs in the sample get a food reward and the rest a toy or both. Lastly, most dog handlers (almost 80%) either did not do anything with their dog before the training, or just a 15-minute walk. The remaining 20% exercised their dog between 15-30 minutes.

The search areas were not extremely mountainous, with the highest value being a 3 on a scale from 1-5. Some of the search areas, however, were extremely dense in terms of vegetation. As indicated in the methodology section, both variables were recoded into dummies for the highest values. For topography, this means that a dummy was included for everything with a 3 and for vegetation everything above a 3 was taken as there were not enough observations with a 5.

The variables that did not have much variation were the wellbeing variables. Most dogs and handlers were doing extremely well or very well before their respective searches. The lack of variation means that its significance cannot be accurately measured statistically.

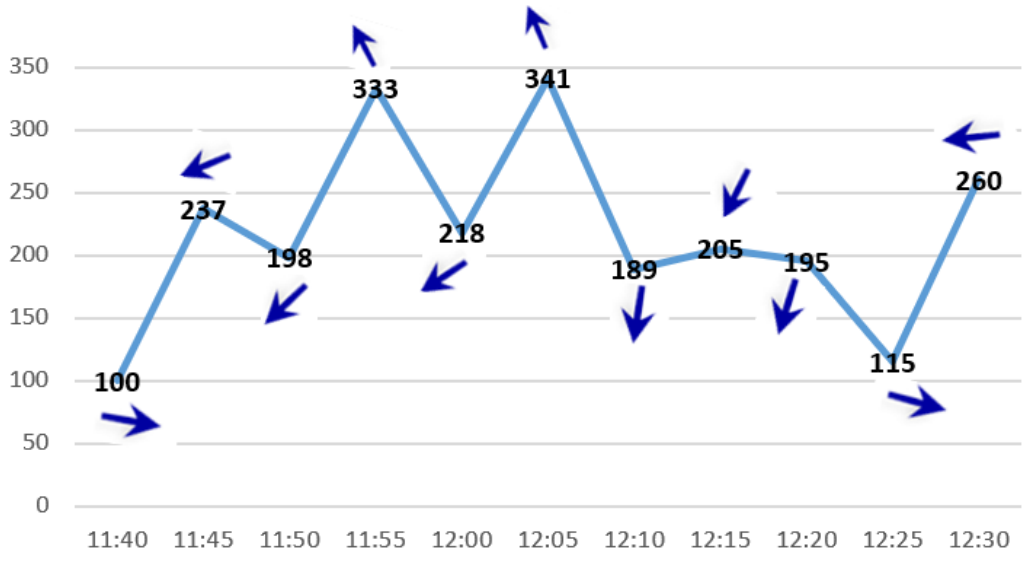
Figure 12: Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Age	41	2	10	4.43	2.128
DogExperience	41	1	8	3.55	1.947
HandlerExperience	41	1	25	6.73	5.489
LastEaten	39	2	18	8.79	5.782
SearchArea	41	10,400	37,500	22,970.73	7,201.363
MPDistance	41	70	260	164.02	54.063
SearchEffectiveness	41	61	1231	426.86	308.541
MPinhiding	41	300	3600	1036.10	776.997
AverageTemp	41	2	32	16.09	10.333
AverageWindspeed	41	.00	3.00	1.3171	1.12781
AverageHumidity	41	29	90	55.99	16.893
Valid N (listwise)	39				

Source: SPSS – own data analysis

One of the outliers that was removed from the dataset, was a 45-minute search with temperatures between 26º and 28º degrees Celsius. Since the skywatch gathers data every 5-minutes during the search, the changing wind direction is an interesting aspect to highlight. There was only a light breeze, increasing the difficulty for the dog. Together with the constantly changing wind direction, high temperature and an unfamiliar search area, the circumstances were complicated to both dog and dog handler, to the extent that they would not have found the victim without help from the trainer. This was the case even though the dog was relatively close to the hiding spot and simply failed to pick up on the scent pool until he was in close proximately of <10 meters. The victim's scent was likely pulled up along the nearby trees, out of reach of the dog. At the start of the search, the wind came approximately from the East, with a reading on the compass of 100º (see figure 13). After 5 minutes, the compass reading changed to 237º, which means that the light breeze came from the Southwest. Another 5 minutes later, this changed again to 198º, with wind approximately coming from the South. Figure 13 shows that the wind direction can change quickly and drastically, which can complicate searching efforts. Dog handlers should therefore regularly check where the wind is coming from, to ensure that they are sending the dog in the right direction and supporting them in the right way.

Figure 13: Wind direction during a 45-minute search



Source: own image

Discussion of the results

Before the regression analysis is conducted, the data is thoroughly checked to ensure it fulfills all the assumptions. None of the independent variables have a correlation higher than 0.9, which would disqualify them from the multiple regression. The model is homoscedastic according to its residual plot and residuals are normally distributed. No clear pattern can be seen in the plot of the residuals, leading to the assumption that the regression is linear. Moreover, the data fulfills all other assumptions noted in the methodology for the linear regression to be reliable. Nevertheless, multicollinearity was found for some of the independent variables, that led to a Variance Inflation Factor (VIF) of more than 10. This means that several independent variables influence or inflate one another. For example, dog wellbeing and handler well-being, as well as humidity and temperature are too strongly related. This leads to the removal of temperature, given the lack of significance in the first regressions. Moreover, dog wellbeing is removed given the difficulty of estimating this. Topography and vegetation also have too high a VIF factor, leading to the removal of topography given the limited distribution. After the removal of these variables, the VIF factors are all below 10.

A linear regression is then conducted, with all scale or dummy variables with the exception of the ones noted above. The independent variable is the search effectiveness of the dog, meaning the time in seconds from start to indication. As can be seen in figure 14, the model is significant on a 1% level and has an explanatory value of 89.2%, which is rather high. The latter means that the model is a good fit, although this drops to 64.7% when only significant predictors or independent variables are taken into account. Moreover, with a Durbin-Watson outcome close to 2:0, there is little autocorrelation in the model.

Figure 14: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.892[b]	.795	.647	183.441	1.766

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2878413.094	16	179900.818	5.346	<.001[c]
	Residual	740315.517	22	33650.705		
	Total	3618728.611	38			

Source: SPSS – own data analysis

The linear regression model output, as displayed in figure 15, shows that several independent variables are significant in explaining search effectiveness. Most significant on a 1% level (p = .005), is the distance from the starting point to the victim. This is logical, given that the dog needs to run longer to find someone hidden 200 meters away, versus 100 meters away. It is therefore not a surprising find and explains the positive and significant coefficient. Nevertheless, this variable had to be included in the regression model as a control variable, to ensure that all likely explanations for search effectiveness are considered.

Average humidity (p = .027) appears to play a significant role in explaining search effectiveness as well. Specifically, the more humid it is, the quicker a dog finds the victim (negative coefficient). As noted previously, water molecules are lighter than air, which result in a quicker rising of the scent. According to Gutzwiller (1990), Kueh et al. (2008) and Osterkamp (2020), it may also increase odor intensity and therefore increases the scent available to dogs. The findings are also in line with research by Jinn et al. (2020), although I do not find air temperature to be significant in earlier regressions.

Given the small sample size, it is not unusual to set the significance level to 10% (Tong, 2019). This means that handler experience (p = .07) becomes significant, which is in line with findings by Svartberg (2002). Experienced SAR dog handlers were likely better at supporting their dogs during the search, as compared to younger ones. Specifically, the findings indicate that the more experienced the dog handler is, the quicker the MP is found. This also supports the previous assumption that experience, and knowledge are likely correlated.

None of the other physiological or social factors were found to play a role in this dataset, although the sample is quite small, and the results may look different with more data.

Figure 15: Linear regression output

Model		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(Constant)	390.510	377.957		1.033	.313		
	DogExperience	-6.639	31.177	-.042	-.213	.833	.242	4.126
	HandlerExperience	-37.256	19.591	-.439	-1.902	.070	.174	5.735
	LastEaten	8.599	7.999	.161	1.075	.294	.414	2.416
	SearchArea	.016	.011	.381	1.402	.175	.126	7.954
	MPDistance	4.035	1.279	.711	3.154	.005	.183	5.468
	MPinhiding	-.074	.059	-.190	-1.241	.228	.398	2.514
	AverageWindspeed	-12.503	38.697	-.046	-.323	.750	.462	2.166
	AverageHumidity	-6.544	2.760	-.358	-2.371	.027	.407	2.455
	DummyVegetation	-49.082	237.950	-.058	-.206	.838	.117	8.542
	DummyFemale	-157.242	154.738	-.256	-1.016	.321	.147	6.824
	DummyMixedBreed	92.038	110.097	.147	.836	.412	.301	3.325
	DummyExercised	-193.262	153.188	-.267	-1.262	.220	.207	4.828
	HandlerGoodDayDummy	41.335	87.122	.066	.474	.640	.480	2.082
	FoodRewardDummy	-247.544	197.495	-.247	-1.253	.223	.240	4.161
	MorningSearchDummy	-80.998	71.491	-.128	-1.133	.269	.734	1.363

Source: SPSS – own data analysis

Key take-aways for training purposes:

17. More experienced dog handlers are likely to find more quickly, which highlights the role of the handler during a search.
18. Sweep widths can potentially be increased slightly when it is very humid, as compared to less humid conditions.
19. Wind direction should be checked at several points during the search to ensure that you know where to send your dog.

Conclusion

This research attempted to explain SAR dog search effectiveness amongst 16 surface area SAR dogs in Germany. Search effectiveness is defined as the number of seconds a dog needs from starting point to indication. Several environmental, physiological, and social factors were considered, although most were not significant in explaining search effectiveness. Given the small sample size, the outcome cannot be generalized and likely looks different in a larger sample.

Variables that did appear to play a role were how far away the victim was hidden, average humidity and handler experience. The former was included as a control variable, as its explanation is quite logical: the further away the MP is hidden, the longer it takes for the dog to find them. This is likely for most cases, except when the hiding spot is extremely difficult in terms of (a) scent movement (b) hiding spots below or above ground (c) covered hiding spots, for example with leaves and branches. Secondly, average humidity was an interesting finding. Specifically, the more humid it was, the quicker the dog found the victim. Given the discussion in the literature review, there are studies that do not find any significant role of humidity such as that by Greatbatch et al. (2015). Osterkamp (2020) his explanation on increased odor availability makes sense and dog handlers may want to keep this in mind when determining sweep widths. The more humid the weather, the wider the sweep width can potentially be. Given the lack of detail, however, this should be an area for further research before it is implemented.

Lastly and not surprisingly, dog handler experience is a significant factor in explaining search effectiveness. It must be stated, however, that the average dog handler experience in the sample was quite high, which potentially distorts the results. Nevertheless, the outcome makes sense, given the number of factors a SAR dog handler needs to incorporate into their search tactics. In this sample, it is likely that experience and knowledge are correlated, although an experienced dog handler is not necessarily a good one. To determine that, further research should be conducted on a larger sample, also considering training methods and personality traits, such as the conscientious score, agreeableness timing and communication skills, familiarity with and understanding of their dogs' body language and behavior (Abdel Fattah and Abdel-Hamid, 2020; Jamieson et al., 2018b; McGreevy et al., 2017; E. Payne et al., 2015).

Besides the statistical analysis, the research has also highlighted several key take-aways for training purposes, which are once again repeated below. These are not only based on the observations, but also on the literature review. Although these are by no means meant to be exhaustive, they provide the key takeaways from both desk and field research that dog handlers can use to improve the search effectiveness of the overall team:

1. Take small steps. Make sure the indication is fully correct before integrating it with the search.
2. Train with many different types of victims (visual and odor).
3. Train realistic SAR scenarios, for example with an MP that talks to the dog.
4. If the chain of behavior is not fully functional, break it up in smaller steps.
5. Keep documentation of the training to track progress and plan ahead.

6. Always take water on a search to keep your dog hydrated.
7. If a dog is panting, keep in mind that their olfactory capabilities are reduced by 40%.
8. We do not know exactly what odor puzzle the dog associates with SAR work, which is why we need to train with many different types of victims to provide sufficient variation.
9. Pay attention to topography and time of the day. Scent generally moves down at night and up during the day. Send your dog up the mountain during the day and down during the night.
10. Pay attention to dense vegetation and send your dog in and around these areas.
11. If there are paths that may channel wind, it is efficient to send your dog down these obstacle-free footpaths, as scent is likely pulled along it.
12. If your shadow is less than 1 meter, search conditions may be especially difficult. Sweep size needs to be reduced to increase the probability of detection.
13. Trees attract scent and in certain conditions most of the scent pool may be ‘’glued’’ to the tree. When your dog alerts here, move upwind or circle around it to find the source.
14. Pay close attention to your dog’s body language. Does he have scent, but cannot work out the source? Support him by sending him towards areas where the scent pool likely continues.
15. Spend time with your dog outside of SAR training to bond.
16. Try to have fun and to create a positive learning environment for your dog by providing security and by using positive reinforcement.
17. More experienced dog handlers are likely to find more quickly, which highlights the role of the handler during a search.
18. Sweep widths can potentially be increased slightly when it is very humid, as compared to less humid conditions.
19. Wind direction should be checked at several points during the search to ensure that you know where to send your dog.

As noted, a major limitation of the research is the limited sample size. The outcome cannot be generalized and is specific to the 16 dog-handler teams observed in Germany. Given the interesting take-aways, such as those on humidity, it would be interesting to continue the data collection and to run the regression analysis with more data. This is especially the case, given that several variables such as topography and vegetation theoretically should make a difference, but do not appear significant in this dataset. Another interesting idea for further research is the measurement of one’s shadow and whether this would help dog handlers to improve search tactics and therefore search effectiveness.

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Appendix 1: Fragebogen

Name:		**Datum:**	
Suchgebiet:			

1. Erfahrung Hundeführer: ……..Jahren
2. Erfahrung Hund……..Jahren
3. Geprüft
   ☐ Ja ☐ Nein
4. Falls ja, wie viele Jahren schon?
5. Alter Hund ……Jahren
6. Geschlecht Hund
   ☐ W ☐ M

7. Rasse ……..
8. Motivations Objekt (MO)
   ☐ Spielzeug ☐ Futter ☐ Futter + Spielzeug

9. Falls Futter: wann hat deinen Hund zuletzt gegessen?.....
10. Habt Ihr Heute schon etwas gemacht (Gassi/tricks)?

☐ Nein ☐ Ja, 0-15 min.☐ Ja, 15-30 min☐ Ja, 30+ min.

	Sehr gut	Gut	Neutral	Schlecht	Sehr schlecht
11. Wie geht es dir?	☐	☐	☐	☐	☐
12. Wie geht es deinen Hund	☐	☐	☐	☐	☐