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META-ANALYSIS OF SCENT DETECTION CANINES AND POTENTIAL FACTORS INFLUENCING THEIR SUCCESS RATES

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Abstract

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Meta-Analysis of Scent Detection Canines and Potential Factors Influencing their Success Rates

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Objective: This is a meta-analysis focused on the success rates of scent detection canines and potential factors that could influence their accuracy. A series of statistical analyses were conducted to determine if certain demographic factors, such as the dog's gender, age, and breed, have an effect on a scent dog's accuracy during a search. Or if more circumstantial factors, like the dog's level of experience in scent work, the type of target scent, and their handler's awareness of the target's location, affect the outcome of the search.

Materials and Methods: A dataset was created from 37 different articles consisting of 215 canines (203 dogs and 12 wolves). Due to several sections that were missing information, not every canine could be used in every test. Six hypotheses were tested in this analysis: 1) 137 dogs were included to determine if females make better scent dogs; 2) 135 dogs were used to determine if older dogs are more accurate; 3) 7 breed categories included 180 dogs to see which breeds are better for scent work; 4) 95 dogs were used to determine if more experienced dogs are more accurate; 5) 5 target scent categories included 196 to determine if dogs are better at locating some scents over others; and 6) if the handler's knowledge of the target's location affects the outcome of the search.

Results and Conclusion: It was determined that a dog's gender, age, and level of experience did not significantly influence the dogs' success rates. The breeds that were originally bred for herding tasks performed significantly better than the breeds originally bred to assist in hunting. The dogs in this dataset were significantly less accurate in locating the scents of chemical mixtures, including narcotics, explosives, and other chemical scents. Dogs tend to be better at locating biological scents. At first, the handler's knowledge of the experiments did not show to be a significant factor in the results of the search. However, there were 7 dog-handler teams that took both blind-experiments and known-experiments, and their results were statistically significant. Meaning that the dogs are using their handler's body language to locate their targets rather than their sense of smell. Further research with a larger dataset and more complete demographic information is needed to confirm these findings, but this dataset can be used as a starting point for similar analyses in the future.

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Introduction

Utilizing the nose of the domestic canine has been a long accepted practice, and dogs have been exceptionally successful in scent detection work (1,2). In the face of the most advanced electronic devices, such as an electronic nose or scent transfer unit, a canine's acute sense of smell is still the most effective tool for locating survivors of an avalanche or a collapsed structure, illegal substances, and human remains (1,3–15). These devices may be impressive, but are limited in their abilities and are not always practical to use in the field when compared to a trained dog that can cover larger areas quicker and provide immediate feedback (8,12,13,15–17). A dog's sense of smell is more powerful than humans are able to comprehend, and it is for this reason that they have been used in scent detection work (3,8,18–21). Compared to humans, a dog's nose is close to 100,000 times more sensitive (21–26). The process of domesticating the wolf started around 15,000 years ago, and through intentional breeding practices has caused the now domesticated dog to specialize in specific jobs to work alongside humans (27–32). Dogs have become a versatile tool in working with humans, and their cooperative nature has become indispensable (32–34). With canines still being the superior scent detector, it is important that they be used to their fullest potential.

A major setback encountered by handlers, trainers, and organizations that work dogs is the fact that around 50% of dogs trained for work do not reach a level of proficiency that is acceptable to actually enter the workforce (14,15,35–44). In narcotics detection programs, only 30% of dogs become working drug dogs (32,39). It has been suggested that the cause of these failures is behavior-related (14,45). This means that over half of the dogs selected, trained, housed, and cared for are expelled from the training program or retire early from the organization that needs them. Although this paper will not go into the amount of money needed to breed, train, house, and provide medical care to working dogs in training, this is still a considerable waste of resources when less than half of the dogs selected for training are able to work. This paper will focus on scent detection dogs, how accurate they are, and what factors make them more dependable in the field. This information can help handlers and trainers predict which dog out of a litter will make a more reliable scent dog.

Canines vs. Humans

Unlike humans, dogs do not rely on sight when attempting to locate an item or individual and this makes canines more effective during a search in a variety of environments (16,46–52). Whether they are in a dark room or in broad daylight, dogs prefer to use their sense of smell to locate their target and are no less accurate in either setting (52). The overall size of the target is of little importance to a dog since they do not necessarily search with their eyes (46,50,53,54). Whereas for humans, the smaller the target, the smaller the chances are of them to locate it (46,50,53,54). The vegetation density did not hinder the dogs during a search, but caused a considerable decline in the detection rates of humans (46,49,55). This supports the use of detection dogs in biological conservation work as they are able locate more targets and can do so considerably faster than humans (56).

The benefits of using biological conservation dogs, also known as wildlife detection dogs, far outweigh the drawbacks. When locating plants, the dogs tended to give more false positive alerts than the human surveyors, but this can be considered negligible since dogs have fewer false negative responses (50). In searches involving invasive plant species, false negatives can be detrimental to the environment if the invasive plant reproduces (50).

Many experiments have been conducted to test and compare the efficiency of humans and dogs during conservation surveys, and the results are incredibly similar (46,48–50,54–58).

When searching for the carcasses of bats and birds, human surveyors were only able to locate between 9% and 42% of their targets, where dogs could locate between 71% and 96% of their targets (46,48,49,55–57). When searching for invasive plants species, the human surveyors located 59% of the plants, and the dogs found 81% (50). In surveying for desert tortoises, dogs were overall 91% accurate, and were able to find neonatal and juvenile tortoises that humans were rarely capable of finding (54). Even though humans are capable of locating their targets in a search, the addition of scent dogs makes the search more efficient and productive in a short amount of time.

The Dog Nose

Half of a dog's nose consists of olfactory sensory cells, and roughly one-eighth of their brain is meant for interpreting odors (12). The olfactory system of a dog is extremely sensitive, and they have proven themselves capable of distinguishing humans by scent alone (2,16,59–63). Dogs are even able to discriminate between twins, and only being less proficient in discriminating identical twins (2,59,63,64). Their extreme sense of smell is due to the number of olfactory receptor cells (ORCs) they have (59–62,65,66). Receptor cells are directly responsible for vision, taste, and smell (13,66,67). In order for mammals to have color vision, only three types of cell receptors are needed; the sense of taste requires about five types; but the sense of smell requires 1,000 different types of receptors (13,66,67).

For dogs, the olfactory process starts at the nostrils as the dog sniffs, the odor particles inhaled pass through the respiratory epithelium, and then attach to ORCs in the olfactory epithelium (3,13,21,65–70). Each of these ORCs have cilia that have surface odor receptors onto which the odor particles attach (3,21,65). These ORCs are directly connected to the olfactory bulb by axons (21,65,71). Multiple receptor cells are needed since each cell can attach to only one, or a small number of, odorant (67). Signals from these receptor cells are sent to the dog's olfactory bulb, and then to different areas of the olfactory cortex where the odor particles are interpreted based on which ORCs and axons, and how many ORCs and axons are activated (3,13,21,66–68).

All mammals are able to detect different odors, but they vary widely in their ability to do so and it is directly correlated with the number of ORCs they possess (66). The human olfactory system is not as menial in comparison, people are able to recognize their own pet dogs by scent alone with 71.43% success rate (72); however, to successfully track their dog through a wooded area would be quite a feat. In total number of ORCs, humans have about 5 million and dogs have >100 million (21,58,66). In total number of cilia each of those ORCs provide, humans have roughly 25 cilia per ORC, and dogs have hundreds of cilia per ORC (21). The number of cilia each of the ORCs possesses give dogs their ability to detect the most minute traces of odorants with every sniff (21,73).

Canines in the Field

A dog's acute sense of smell can be invaluable during a search or an investigation, and it is imperative their alerts be accurate. However, dogs are not perfect (61,74,75). They will miss their targets on some occasions, and alert to it in places where it is not on others (13,75). Dogs have good and bad days similar to people, as is seen in an experiment by Alexander et al. (2015) where one of the dogs simply refused to work on one of the trial days (76). Another experiment by Curran et al. (2010) had a handler end the trial completely because their dog became aggressive towards one of the staff (77). This can be a small inconvenience in some situations, but can also hinder a forensic investigation.

To reduce the chances of a false alert from a scent detection dog, there should be a combination of tools used during the search if and when available such as manual probes and ground penetrating radar (GPR) (78,79). A false positive alert from a narcotics canine may lead to an unnecessary search of an innocent person (80), and a false negative alert from a bomb dog will lead to dangerous materials getting past security checkpoints (4). In order to use scent dogs effectively in the field, it is important to understand their olfactory limitations, behavioral phenomena, and environmental factors that could elicit a false response (4). Past researchers have been able to identify a number of these problems and potential solutions.

One explanation for a dog giving a false positive alert has to do with the handler. There is a duality when it comes to the relationship between a dog and their handler. On the one hand, the bond between them has to be well established in order for them to be an effective team in the field (13,66,81). Changing handlers affects the dog's performance during a search in that they become more distracted for longer periods of time and are more stressed during the search (81). On the other hand, it has been proven through past experiments that dogs are able to read their human's behavior and use the observed social cues to accomplish a task (82–87). Canine-human communication begins with eye contact, and dogs will behave differently if their owner's gaze, head, and body orientation is directed elsewhere (82,87,88). This ability to read and understand certain gestures is specific to humans, as dogs do not tend to respond to non-human items such as a mechanical hand offering the same gesture (89). Past researchers found that pet dogs can interpret human gestures such as pointing, gazing, nodding, head turning, and glancing better than apes (82,86,89–94). Dogs are comparable to a human toddler (2-3 year-old) when it comes to interpreting adult human gestures as a way to communicate (82,95).

This means if the handler knows where the target is, or if they simply believe they know, the dog most likely will alert to that location (96). The handler giving their dog physical cues will prompt the dog to follow suit despite what the dog smells (97,98). This has been the cause of many false positive alerts in professional detection dogs (96). It is for this reason that the experimenters, trainers, and handlers be aware and take precautions to avoid this to protect the integrity of the search and the crime scene (13,66). Having a dog that is confident, independent, and trusts their nose helps alleviate this issue, but the handler still needs to be aware of unintentionally cueing a response from the dog (98,99).

A false negative alert from a scent dog can be because they have reached their saturation point. This is the phenomenon when the dog experiences so much of a familiar scent at such a high quantity that they no longer recognize it as the same scent (4,100). The dog becomes overwhelmed with the scent of the target and are not able to process it correctly (4,100). Humans can also experience this issue, just on a different scale (4,100,101). This occurrence is similar to a human smelling a rag with a single spritz of a perfume, versus smelling a rag soaked in that same perfume. They are the same scent, but some people might describe one rag as smelling pleasant and the other rag as nauseating. The threshold for humans occurs when the concentration of the odorant changes 100-fold or more (101,102). For dogs, that threshold occurs when there is a 10-fold change in the odorant concentration (101). In a study where two dogs were trained and tested to detect human waste in samples of water, one of the dogs had reached that saturation point and would not alert to a sample even when the experimenters, observers, and handler were able to see and smell the contamination (103). This is also well documented in explosive detection dogs where the dogs that are trained on small quantities of explosives give incorrect responses when presented with larger amounts of that same sample (4,104). To greatly reduce the chances of getting a false negative alert and to confirm an alert given by a single dog, multiple scent dogs should be utilized if available.

In a working environment, it is vital for detection dogs to be able to detect their target scents in different mixtures and quantities. Issues regarding scent generalization, discrimination, and saturation points can be solved through continued training with exposure to different mixtures and amounts of their trained scents (4,104–107). It was discovered that dogs trained with a single target scent had some difficulty in alerting to that scent when it was presented in mixture (105–107). Dogs given only mixtures of scents and trained to alert to the common denominator scent are more successful in discriminating their target scents in different contexts (105,106,108). This is a complex training method that may take longer for the dogs to master, but it has been proven that they perform better when they encounter that scent in a variety of different contexts, mixtures, and quantities (105,106,108).

Canine-Based Evidence in Court Cases

Tracking evidence began to be admissible in court in 1893 with *Hodge v. Alabama*, but the opinions of the courts regarding canine-based evidence has evolved since then and its acceptance is now based on if the dog and handler meet several foundational requirements (13,109). These requirements include:

1. The handler’s qualifications (13,110).
2. The breed of the dog (13,111).
3. The dog’s training in tracking or trailing (13,111).
4. The dog’s reliability (13,111,112).
5. If the dog was put on the trail where the suspect was likely to have been, or if they sniffed an object that the suspect most likely touched (13,110,111).

6. If the dog was put on the trail while it was within the period of his reliability (13,111,113).
7. The trail was not contaminated (13,110).
8. If there was nothing that indicated that the dog's tracking or trailing evidence was unreliable (13,114–116).

Meeting the foundational requirements is not meant to be an inflexible and overwhelming process, they have become more specific over time and have evolved based on research and past court decisions (13). The handler must be fully qualified and be considered an expert witness (13,110). The breed of the dog has become less important over the years, and the requirement is generally considered fulfilled if the dog is able to discriminate between individuals by scent, has experience in actual cases, and has proven to be reliable with at least 70% accuracy (13,111,112,117). The legality of a search involving canines and maintaining the integrity of the crime scene is of utmost importance in a forensic investigation (13,66,115). If the propriety of the search is called into question because of the dog handler's negligence or by the handler not following proper legal procedures, the evidence discovered as a result of the improper search could be inadmissible in court or give the defendant grounds to appeal the verdict (13,66).

This kind of evidence is not treated the same in every state (13). There are 36 states that have accepted canine-based evidence in court, and five states have rejected that kind of evidence (13). This is due to the fact that the dog's tracking evidence alone is not enough to prove that a person is guilty of a crime, however, it can be used to corroborate other evidence discovered (13,118). It becomes a serious problem when handlers exaggerate the abilities of their canines, and defend the dog's alert even if there is nothing found (13,80,119). When a handler confuses their dog's positive alert to a scent and the dog simply "showing interest" can potentially mislead the investigators and could lead to the conviction of an innocent person (13,120).

Canine-based evidence should never be used to determine one's guilt (13,64,118). Even though the best of trained detection dogs possess an incredibly sensitive olfactory system, they are just animals that are well versed in the game of hide-and-seek (64). Judge Stevan T. Northcutt of the Florida Second District Court of Appeal pointed out a problem with using canine-based evidence in criminal proceedings:

> "Although we commonly refer to the 'training' of dogs, manifestly they are not trained in the sense that human beings may be trained. … Rather, dogs are 'conditioned,' that is, they are induced to respond in particular ways to particular stimuli. For law enforcement purposes, the ideal conditioning would yield a dog who always responds to specified stimuli in a consistent and recognizable way, yet never responds in that manner absent the stimuli. But this does not happen. While dogs are not motivated in ways that humans are, neither can they be calibrated to achieve mechanically consistent results." (13,121)

The American Kennel Club claims that the nose of a bloodhound is so accurate in trailing an individual that it was the only canine-based evidence that could be used in court (13,122). However, there is a myth regarding the origin of the bloodhound's accuracy (13,123). This myth comes from when slave owners would let their dogs loose to track down runaway slaves, but these dogs were mostly mutts (13). It can be argued that this history has been applied to scent dogs in general, and that it has led some people to expect too much from them in terms of accuracy. A study regarding a scent dog's breed and olfaction system was conducted, and it was determined that public opinion of certain breeds for scent work was largely based on historic ideas, rather than data (124).

A dog's olfactory system does differ between breeds, and bloodhounds are known to have 300 million olfactory receptor cells (ORCs) while German shepherds have 225 million ORCs (26,125–127). However accurate bloodhounds may be, there are still more German shepherd (23) and Belgian Malinois dogs trained as scent detection canines than there are bloodhounds (13,127,128). This is because the German shepherds and Belgian Malinois have the preferred behavioral traits that make them more trainable for scent detection whereas a bloodhound can be more stubborn and rebellious (2,32,126,128–133). However, if put in the right line of work, the stubbornness of bloodhounds can be beneficial since once they detect a scent, they are far less likely to leave that scent and will track it for miles (32,130,134). This suggests that a dog's olfactory system alone is not what makes a successful detection dog (68,124,128).

Applications and Relevance

The research presented in this paper is relevant to any field of work that could require the detection of the slightest difference in odors to locate something; like skeletal remains in forensic anthropology, evidence in crime scene investigations, human beings in search-and-rescue missions, fugitives in tracking and man-trailing, invasive plants or insects in biological conservation efforts, and illicit drugs or explosives for law enforcement. Scent detection dogs can be used in all of these fields since they are able to detect the slightest bit of scent particles that humans would never notice (124,135–137). This research can also help further understand what factors can affect a dog's accuracy and what can make them more reliable. Dogs, and wolves, have been studied in a multitude of experiments testing various aspects of their scent detection capabilities. This analysis is centered around a dog's ability to locate their target scent and if certain characteristics regarding the dog and handler can affect their accuracy. The characteristics tested were the dog's gender, age, breed, years of experience, the type of target scent, and if the handler was blind during the search.

The aim of this research is to directly compare a scent dog's success rate with their gender, age, breed, experience, target scent, and handler's knowledge of the experiment by using a series of statistical analyses. A total of 203 dogs and 12 wolves were compiled to test six hypotheses, and the results of these statistical tests will determine if there is a relationship between these factors and the dogs' rates of success. This information can possibly assist trainers in selecting the dogs that are predisposed to being the better scent dog, or if the better scent dogs come from experience and training, or if the handler affects the outcome of a search.

Hypotheses

Males vs. Females. It is expected that female dogs will perform slightly better than males. Past researchers have not been able to definitively determine if one gender performs better than the other mainly due to small sample sizes, however, the odor receptors of female dogs tend to be more active than male dogs' (68,138). There is also the fact that male dogs are on average more aggressive than female dogs, which is a behavioral trait that is not tolerated in scent detection work (139). Where females are not only less aggressive towards others, but also less distractable (139,140).

Age. Older dogs are expected to have higher success rates than younger dogs. It is not uncommon for younger dogs to improve as the experiment progresses, meaning that their scores at the beginning of the test will not be as high as their scores at the end of the test; whereas older dogs tend to remain consistent throughout the experiment (1). It is known that a dog's olfactory epithelium will begin to atrophy at age 14 (66,141), but all the dogs in this dataset are under the age of 12. Since older dogs are known to be able to process and remember complex odors better than younger dogs (68,138), this will give them an advantage during a search making them more accurate.

Breed of Dog. To determine if some breeds make better scent dogs, 180 dogs were organized into seven different breed categories based on the history of the breed and for what task they were bred. It is expected that the breeds intended for hunting, and tracking will outperform the others. Since not all breeds behave the same (2,27,131,132), they should not be expected to perform the same during scent work (16). However, this idea that only a handful of breeds are better for scent work may be driven by past opinions and is not entirely supported by data (124,142). The focus becomes less on the breed, and more on the breed's trainability (32,99). This was seen when pugs were outperforming German shepherds in a scent detection task (124). When performing tasks alongside domesticated dogs, wolves tend to struggle more in connecting with and cooperating with the handler making them less trainable (33,131).

Experience. Dogs with more experience in scent work are expected to be more proficient during a search than dogs with less experience. This is because dogs learn more through training and exposure to their targets and to various scent mixtures (54,61,105,105,123,143). It has been documented that a dog who is already trained in scent work can easily transition into a different kind of scent work and learn to locate new scents (1,13,54,144,145). During the scent experiments, the more experienced dogs maintained a constant accuracy rate as the trials progressed, whereas the less experienced dogs would increase in accuracy as the trials continued (1,54). In contrast, some research found that there is no significant correlation between a dog's experience and their rate of success in detection trials (17).

Target Scents. It is expected that detection dogs will be more accurate at locating some target odors over others. Where a narcotics detection dog may have to learn four to six individual odors, a bomb dog might need to learn nine to 14 separate odors, but the human remains detection dog can come into contact with 424 distinct odors produced by the decomposing body

(78,142). With the scent of human decomposition being different from one person to the next, the process of decomposition and chemical reactions are similar, if not the same, (66,142), but the chemical compounds of illicit drugs or explosives can still vary. Regardless, dogs have shown to be capable at alerting their handlers to the presence of explosives (4,8), drugs (16), humans and human remains (18,59,60,62,63,146–148), animals (145,149,150), plants and bugs (1,17,50,51,53,151,152), and even cancer and other medical conditions (2,153,154). Although it is not currently known as to precisely which odors the scent dogs are alerting (142,155). But there is almost no literature about whether dogs have difficulty in locating one kind of scent over others.

Blind- vs. Known-Experiment. The handler's knowledge of the experiment, whether or not they knew the location of the target scent, was tested on 161 dog-handler teams to see if the dogs performed better when their handler knew where the target was during the test. Dogs whose handlers already know the location of the target are expected to perform significantly better than the dog-handler teams that were blind to the target's location. A lot of studies have been done to determine that dogs respond to gestures given by their handlers and owners, so it is standard practice when testing scent dogs to conduct single- or double-blind experiments since it will also simulate a real-world scenario (33,82,87,88,96–98,156). In a simple task of bypassing a fence to get to a treat or favorite toy, dogs were able to achieve the goal on their own, but became significantly more proficient at it if they saw humans perform the task (157).

This research is a meta-analysis of scent dogs and will allow a better understanding of what can influence their accuracy; as well as consolidate data from past researchers that can be used in future analyses. The results from these statistical analyses will indicate if there are certain demographic factors like gender, age, or breed, that will help predict which dog would be the best candidate for scent training. The results will also show if there are any circumstantial factors that have an effect on a dog's success rate, like how long the dog has been in scent work, the type of target scent they are trained on, or if their handler was blind during the experiment. Knowing this information can help understand what circumstances make a scent dog more accurate and what could affect their accuracy.

Materials and Methods

Combining data from 37 different articles, a Microsoft Excel spreadsheet was created with the dogs' demographic information and success rates for 203 dogs and 12 wolves. The software SPSS 20.0 was used to run the statistical analysis along with statistical calculators from the Social Science Statistics website (socscistatistics.com). Because the different articles did not always report a complete demographic profile for each dog, this dataset has several missing sections. The pieces of missing information made it impossible to use all 215 canines for each test.

The success rates for each dog were calculated from the results recorded by the original authors from their individual experiments, and each calculation was done differently depending on how the experiments were set up and what information was provided. If the article did not already indicate the success rate of the dogs in their experiment, the success rates were calculated by taking the sum of correct alerts given by each dog and dividing it by the total number of correct alerts the dog should have given. For this analysis, the terms success rate and accuracy are used interchangeably. Not every article gave the number of true positive alerts given by each dog, and only a few gave the total number of true negative alerts. An alert is considered a true positive when the dog correctly alerts to the station that contains their target scent. An alert is a true negative when the dog correctly ignores a station where no target scent is present.

In the experiments where the researchers set up stations, also called a line-up, for the dogs to inspect, the number of stations with targets was divided by the number of targets the dogs found. If the number of stations containing non-target scents, like distractor odors or controls, was given, then those were included in the calculation.

$$Accuracy = \frac{(True\ Positives + True\ Negatives)}{Number\ of\ Stations\ in\ the\ LineUp}$$

Some experiments were not conducted as a line up with a set number of stations. Instead, they were set up as free-searches in areas where target scents could be planted, buried, or otherwise scattered around within a defined area. The success rates for these experiments could only be calculated with the number of targets alerted on divided by the total number of targets available for the dogs to find.

$$Accuracy = \frac{True\ Positives}{Targets}$$

Even though false positive and false negative alerts were recorded in some of the articles, they were not included in this analysis. An alert is a false positive when the dog gives a positive alert at a station where no target scent is present. And an alert is a false negative when the dog ignores a station where a target is present. The focus of this analysis is meant to be on how successful the dogs are in finding their targets and giving a correct alert. This was also done so that the dataset and results from the tests would be more consistent. Not every article reported the false positive or false negative alerts and incorporating that data would have caused this dataset to be limited further.

Statistical Analyses

Three different kinds of inferential statistical tests were conducted using SPSS 20.0 to determine if there is an association between the success rates of different groups and how strong that association is, and to compare the means of certain groups to determine if there is significant difference. Each test used a significance level of 0.05, meaning that the results are statistically significant if the p-value is less than 0.05 ($p < .05$). Having a significance level of 0.05 is standard when running statistical test, and there was no reason to change it for this analysis.

An independent t-test is a kind of hypothesis test that compares the averages of two groups to indicate if the difference between the averages is statistically significant, or if the difference could possibly be the result of random sampling error. This test uses data from a random sample of a group to reach certain conclusions about the rest of the population. This analysis used independent t-tests to determine if the differences between the accuracy rates of male and female dogs, and between the accuracy rates of the blind- and known-experiments were statistically significant. In this analysis, the variable is the accuracy rates given as percentages, and the two independent groups are male dogs and female dogs, and the blind- and known-experiments.

A second type of t-test was used in this analysis called a paired t-test. A paired t-test uses a single group where each subject has a pair of scores, and it determines if the average change from the first set of scores is statistically significant from the second set of scores. This test differs from an independent t-test in that it uses two scores from the same subjects, dogs in this case, and an independent t-test uses completely different subjects in the two samples. An independent t-test looks for a difference between two groups, and a paired t-test looks for a difference in a group at two points in time. This test used the dogs that took part in a blind-experiment and then a known-experiment.

A Pearson's correlation test was used to compare the dogs' age in years to their success rates, and their years of experience to their success rates. This test is meant to determine if there is a linear correlation between two continuous numeric variables, and, if so, how strong that correlation is. A 2-tailed test will indicate whether the correlation is positive or negative. This test will provide a correlation coefficient known as *r.* The *r* value will indicate the direction and strength of the relationship. Having a positive *r* value indicates a positive correlation, and a negative *r* value indicates a negative correlation. The correlation is considered weak the closer the *r* value is to 0, and stronger the nearer it is to +1 or -1. An *r* value of 0 indicates no correlation.

Similar to an independent t-test, a one-way ANOVA test is used for comparing the averages of at least three groups and determining if the differences are statistically significant. This is a hypothesis test that makes conclusions regarding a whole population based on data collected from a sample of that population. In this analysis, the mean accuracies were compared between the seven different breed categories, and the mean accuracies compared between the five different types of target scents. If there is a significant difference between the groups, it is important to run a follow-up post hoc test like Tukey's Honest Significant Difference (HSD). The one-way ANOVA will indicate if any of the groups' means are statistically different. A Tukey's HSD test will identify which groups are significantly different by comparing the averages of the groups to each other.

Dataset Demographics

As stated previously, the dataset that was created had a number of sections missing data. This is a common practice for experiments like these in order to protect the identity of the dog-handler teams since some of the dogs are considered active-duty. Every source provided a dog with an ID and a rate of success. The overall rate of success for the 203 scent dogs and 12 wolves is 73%.

Males vs. Females. Only 137 dogs in this dataset could be used in the independent t-test that was used to determine if female dogs are more accurate than male dogs. There were 58 female dogs and 79 male dogs included.

Age and Success Rates. The Pearson's correlation test included 135 dogs who ranged in age from 0.5 years (6 months) to 12 years old, with an average age of 4.8 years. In terms of frequency, 2-year-old dogs were the most common age of dog (N = 23) in this dataset as is seen in Figure 1 below.

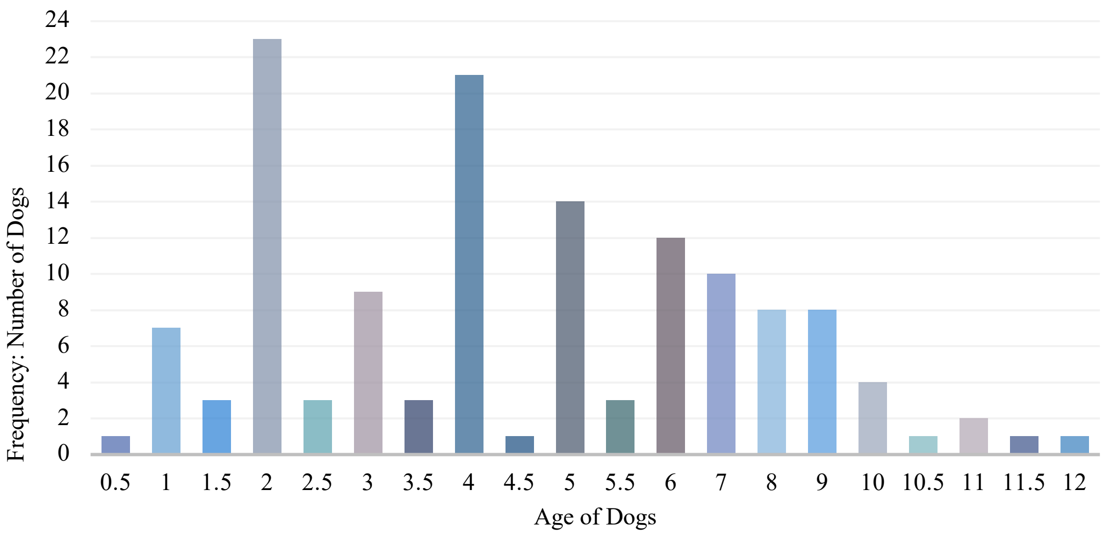

Figure 1: *Chart illustrating the number of dogs in each age group. Wolves are excluded.*

Breed of Dog. This dataset included 41 different breeds, not including the mutts, that were organized into seven categories of dog breeds based on the history of the breed. The breeds were categorized into five groups based on the original purpose for which the dog was bred (see Table 1 below for descriptions of each category). The group of mutts and wolves were put into their own categories. Gray wolves are included in this research, but only to test this hypothesis as its own category since wolves are not used by humans in scent detection work. Wolves are excluded in each of the other statistical tests.

Even though the AKC already categorizes dogs into six groups (122), only the histories of the breeds were considered for classifying the dogs because the physical appearance of the dogs were irrelevant to this research.

Table 1: *List of each breed category used in this analysis and a description.*

Breed Category:	Description:
Companion	Bred for urban life; toy breeds; no particular job
Herding	Bred to herd livestock
Hunting	Sighthounds – bred for spotting and chasing prey Gun dogs – bred for retrieving game after the hunter kills it
Mix Breed	Any mixed breed
Scent/Tracker	Bred to hunt by scent, tracking live humans/animals
Utility/Other	Bred for multiple purposes, guarding property or livestock, sled dogs, etc.
Wolf	Gray wolf

Experience and Success Rates. The Pearson's correlation test included 95 dogs. The most experienced dog had 8 years of experience. In terms of frequency, dogs with no experience were most commonly used in the experiments from which this dataset was compiled (Figure 2). This fact only shows that the experimenters provided the dogs' training themselves.

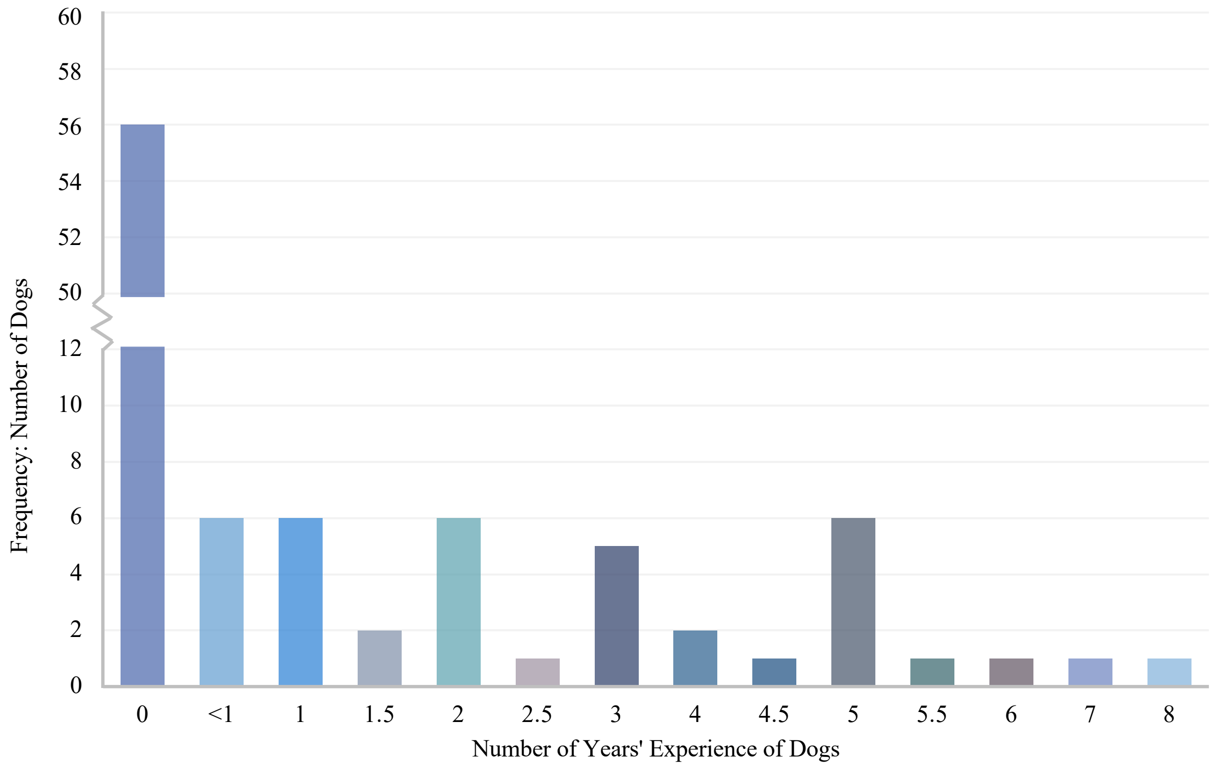

Figure 2: *Chart illustrating how many of the dogs in this analysis have different levels of experience. Wolves are excluded. The zig-zag line on the Y-axis depicts a break in the data where some values are omitted. This is done for practical reasons when there is a category that has a value much greater than the other categories, and displaying the entire chart in a fixed space would make the categories with smaller values harder to interpret. In this case, there are 56 dogs with 0 years of experience, but the other categories do not exceed 6 dogs. So, the values between 12 and 50 dogs on the Y-axis were omitted.*

Target Scents. This dataset included 196 dogs that were grouped into five different categories based on what they were trained to find. The five categories were designed to represent each type of search dog. The Animal Scent and Plant/Bugs categories were meant for the biological conservation dogs. The animal target scents include any scent that came from an animal regardless of living status, such as scat, raw meat, tracks, carcasses, etc. The plant and bug scents include any scent that came from plants or bugs regardless of living status.

The Human Scent category was intended for dogs trained to locate live humans as they would in man trailing and search-and-rescue missions. The Human Remains category was made to include the cadaver dogs, human remains detection dogs, and historic human remains detection dogs. The two categories were intended to separate the cadaver and human remains detection dogs, dogs who would be used in forensic anthropology and forensic investigations, from the trackers and man-trailers, dogs who would be used by police in a manhunt or a search-and-rescue situation.

The Chemical Mixtures category includes dogs trained on narcotics, chemical mixtures, and explosives. This group is meant to represent drug dogs and bomb dogs. They were grouped together because keeping them separate would have offered a smaller sample size.

Medical scent dogs, dogs trained to smell cancer or other medical conditions in a patient, could have been a sixth category. But this analysis focuses on how to improve and what can affect scent detection dogs in an effort to improve the field in which that they work. Since it is not entirely clear as to what the dogs are smelling in a medical sense (142,155), they were not used in this analysis.

Blind- vs. Known-Experiment. A t-test was used to determine if the dogs were relying on their own sense of smell, or if they are looking to their handlers for non-verbal cues to help them find their target. The terms “blind” and “known” that are used in this analysis are taken from an article by Cablk and Sagebiel (2011) (147). Since the scent dog is the one being tested for accuracy, they are blind to the location and number of targets for which they are searching in all experiments. If the handler is the only person who does not know the location or number of targets, the experiment is called a single-blind study. If the location or number of targets is known only to the experimenter who set up the test, it is considered to be a double-blind experiment since all other individuals will be blind.

The knowledge of the handler is the variable that is expected to influence the accuracy of the scent dogs. There might be people other than the handler and experimenter involved in the experiment such as an observer, assistant(s), trainer, etc. Since dogs will respond accordingly based on who is paying attention to them and what they are doing (87), each person could potentially influence the dog's alert, but only the handler's knowledge is being tested here since they will have the strongest bond with the dog. For the purposes of this analysis, double- and single-blind experiments are categorized together. If the handler knows the location and number of targets, then the experiment is considered a known-experiment. If the handler does not know where or how many targets are present, then the experiment if considered a blind-experiment. If the articles did not specify that the experiments were blind or known, those dog-handler teams could not be included in this test.

Results

Males vs. Females

An independent t-test was used to determine if the difference between the average accuracies of the male and female dogs are statistically significant. The female dogs (N = 58, $\bar{x}$ = 75%) compiled for this dataset did perform slightly better than the male dogs (N = 79, $\bar{x}$ = 73%) which can be seen in Figure 3.

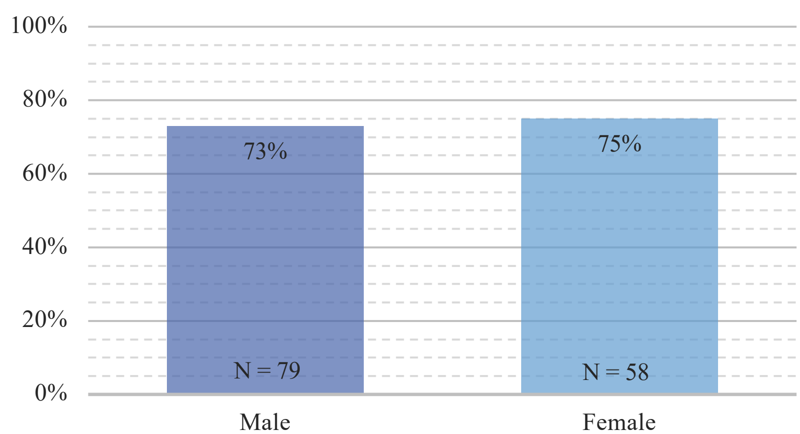

Figure 3: *Chart comparing the average success rates of male and female dogs. Wolves are excluded.*

The results of the independent t-test indicate the difference in average accuracies between the males (N = 79, $\bar{x}$ = 73%, SD = 22%) and females (N = 58, $\bar{x}$ = 75%, SD = 20%) are not statistically significant, [t(135) = -.743, p = .458 > .05]. The null hypothesis cannot be rejected since the results were not statistically significant.

Age and Success Rates

A Pearson correlation test was used to determine the relationship between the dogs' age and their accuracy in scent detection. The blue linear trendline in Figure 4 shows a very slight negative correlation between the dogs' age and success rate.

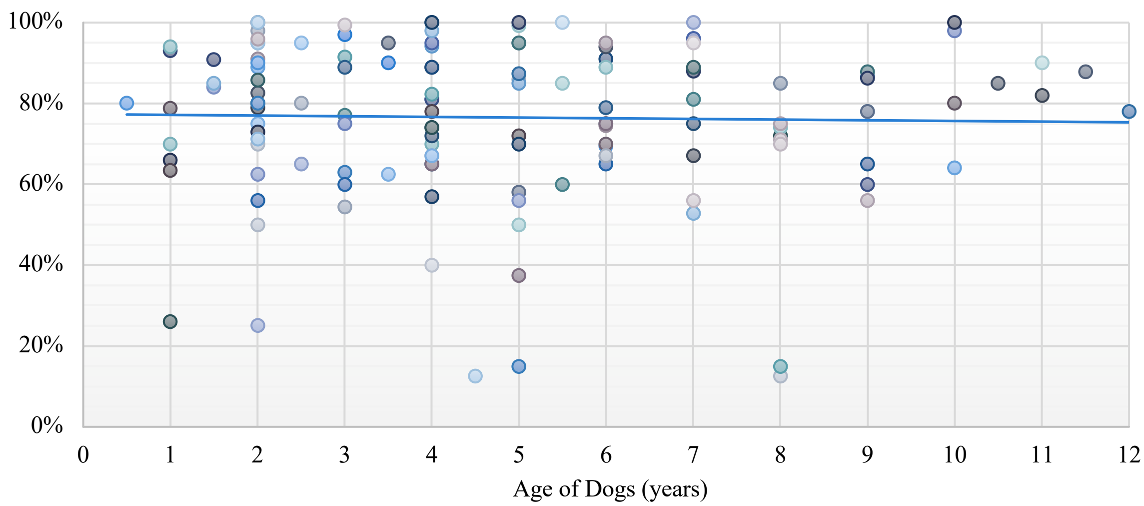

Figure 4: *Scatterplot comparing the success rates of the 135 dogs included in the age analysis. Wolves are excluded.*

The results of the Pearson's correlation test indicate a weak negative relationship, [r(135) = -.025, p = .775]. These results show no statistically significant association between a dog's age and how accurate they are in locating their target scent. The null hypothesis that states the correlation between a dog's age and accuracy rate is 0, therefore, cannot be rejected.

Breed of Dog

A one-way ANOVA was used to analyze the mean differences in accuracies between the seven breed categories. Figure 5 below shows a chart comparing the average accuracy rates for each breed category. On average, the Herding (N = 21) and Scent/Tracker (N = 18) breeds performed the best each with an accuracy of 83%. The Companion breeds (N = 14) are second best with a success rate of 76%. The Wolves (N = 12) are the third best being 72% accurate. The Utility/Other breed category (N = 9) and Mixed breed category (N = 27) are fairly close in accuracies at 70% and 68% respectively. The Hunting breed category performed the worst with an accuracy of 65%.

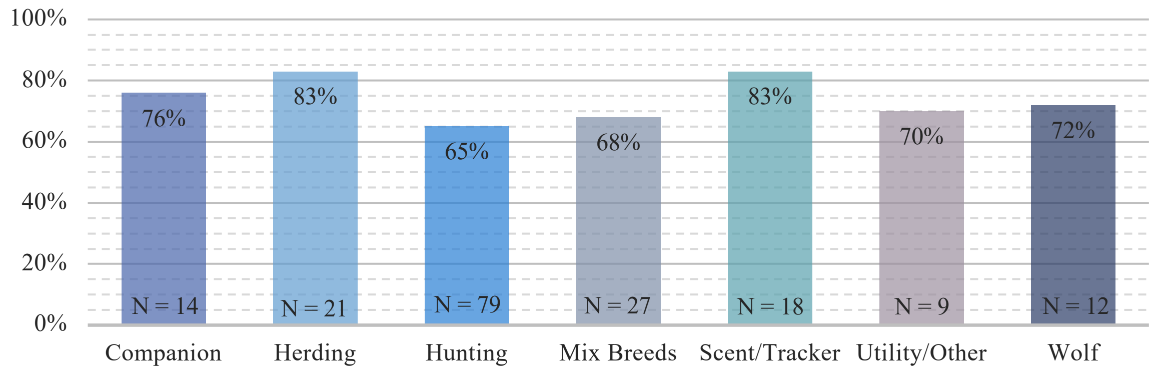

Figure 5: *Bar chart comparing the average success rates for the seven breed categories of the 180 canines included in the breed category analysis.*

This test determined that there is a statistically significant difference in mean accuracies between at least two of the breed categories (F(6, 173) = [2.673], p = .017). The null hypothesis can be rejected because the differences between the groups' averages are statistically significant and the seven breed categories are not equal.

The results of a Tukey's HSD test revealed that the difference in average accuracy rates were statistically significant between the Herding and Hunting breeds (p = .040). The results indicate that dogs originally bred for Herding ($\bar{x}$ = 83%; SD = 13%) tasks are more accurate than dogs bred for Hunting ($\bar{x}$ = 65%; SD = 29%). There are no other differences in mean accuracies between any of the other combination of categories that were statistically significant. See Appendix B: Table H for the full SPSS results with all of the breed category comparisons.

Experience and Success Rates

The Pearson correlation test included 95 dogs who range in years of experience from no prior experience (0 years) to eight years of scent work. The average years of experience was one year. The blue linear trendline in Figure 6 show a negative correlation between the dogs' level of experience and their success rate. The results of this 2-tailed test determined a weak negative correlation that is not statistically significant, [r(95) = -.126, p = .224]. In this case, the null hypothesis cannot be rejected since there is no correlation between the dogs' years of experience and their accuracy.

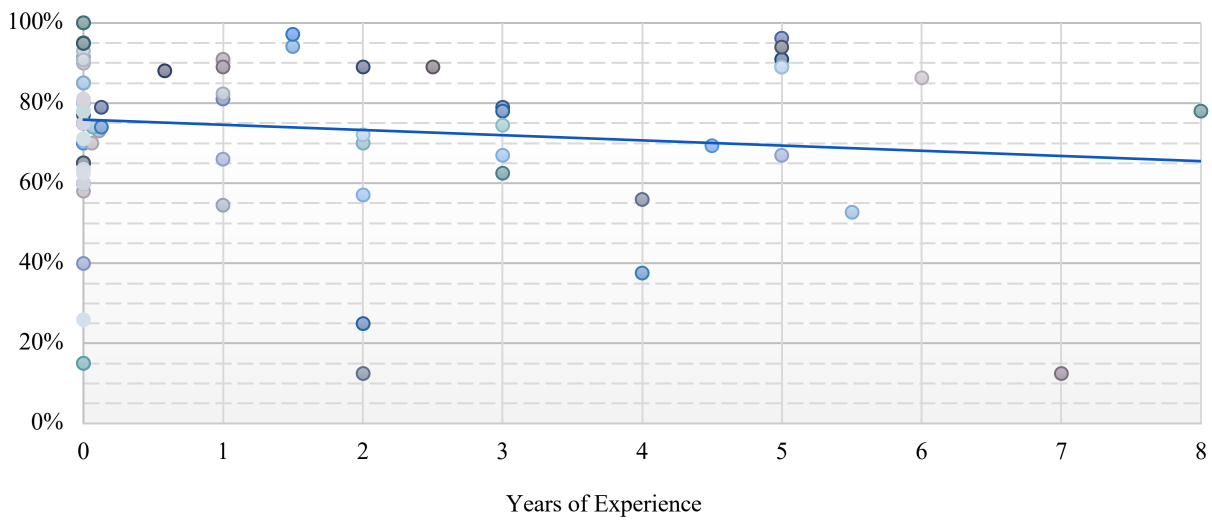

Figure 6: *Scatterplot comparing the success rates of the 95 dogs included in the age analysis. Wolves are excluded.*

Target Scents

The one-way ANOVA test compared the five categories of target scents, and the results indicate that there is a mean difference between at least two categories that is statistically significant (F(4, 191) = [11.76], p < .001). This means that the null hypothesis can be rejected, and the five target scent categories are not equal. Figure 7 shows a chart that gives the averages of the target scent categories.

The Animal Scent group was the most accurate out of the five categories ($\bar{x}$ = 79%; N = 65). With the Human Remains category ($\bar{x}$ = 77%, N = 36) as a close second best. Then the Plant/Bugs group ($\bar{x}$ = 75%; N = 38) and Human Scent category ($\bar{x}$ = 75%, N = 25) as the third best.

The Chemical Mixtures category ($\bar{x}$ = 47%; N = 32) performed considerably worse. This category is comprised of three different categories: narcotics, explosives, and other chemical mixtures. By themselves, the narcotics detection dogs (N = 17) averaged an accuracy of 26%, the bomb detection dogs (N = 7) averaged a success rate of 75%, and the dogs trained on a mixture of chemical scents (N = 8) averaged 69% accuracy.

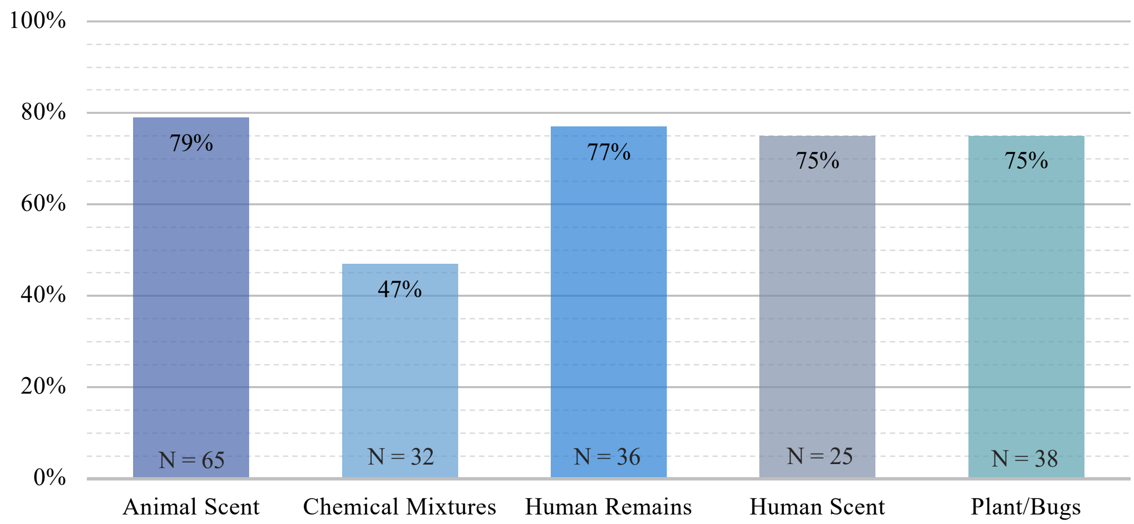

Figure 7: *Bar chart comparing the average success rates for the 196 dogs categorized by target scent. Wolves are excluded.*

A Tukey's HSD test revealed that the average accuracy rate for the chemicals scent category was significantly different between each of the other four scent categories. The mean accuracy rate for the chemicals scent was different between the mean Animal Scent ($p < .001$), the mean Human Remains scent ($p < .001$), the mean Human Scent ($p < .001$), and the mean Plant/Bugs scent ($p < .001$).

Blind- vs. Known-Experiment

An independent t-test was used to determine if the difference between the average accuracies of the blind- and known-experiments are statistically significant. The results indicated the average difference between the blind-experiments (N = 150, $\bar{x}$ = 80%, SD = 19%) and known-experiments (N = 11, $\bar{x}$ = 84%, SD = 14%) are not significant, [$t(159) = -.713$, $p = .477$].

The results did not show a significant difference between the averages, so the null hypothesis cannot be rejected.

There were 161 dog-handler teams in the dataset that were separated based on if the handler knew the location of the dog's target during the experiment, or if they were blind to its location. It is worth noting that it is the best practice to conduct blind-experiments when testing certain aspects of a dog's scent detection abilities, unless the research goals dictate otherwise. This has led the dataset to be limited in the number of dog-handler teams who participated in known-experiments. There are a total of 150 teams in the blind-experiments group, and 11 teams in the known-experiments. As seen in Figure 8, the teams in the known-experiments were slightly more accurate in their searches.

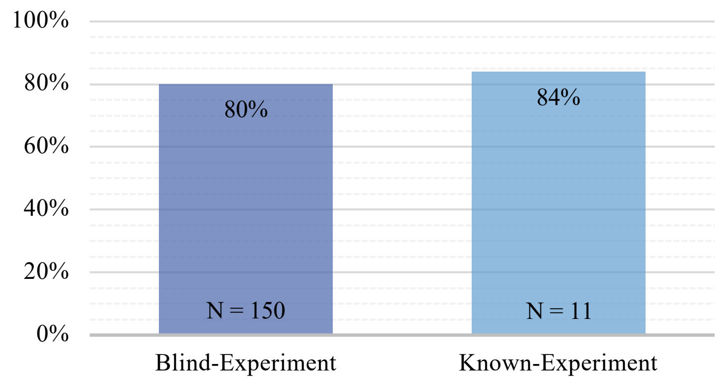

Figure 8: *Bar chart comparing the average success rates for the 150 dog-handler teams who took part in the blind-experiments and the 11 dog-handler team who took part in the known-experiments. Wolves are excluded.*

Special Case. A study by Calbk and Sagebiel (2011) (147) and another study by Glavaš and Pintar (2019) (158) assessed the ability of different dog-handler teams to locate human remains in an outdoor setting. These two studies had the dog-handler teams take part in both a blind- and known-experiment (N = 7). All seven dogs performed considerably better in the known-experiments ($\bar{x}$ = 84%) than they did in the blind-experiments ($\bar{x}$ = 70%) as is seen in Figure 9. Because there was a big difference between the averages, this prompted a paired t-test to be run in order to determine if this difference was significant. The results indicated a significant difference between the success rates of the blind-experiments ($\bar{x}$ = 70%; SD = 14%) and the success rates of the known-experiments ($\bar{x}$ = 84%; SD = 16%); [t(6) = -6.457, p = .001]. With an incredibly strong positive correlation (r = .935, p = .002), the dogs were more successful when their handlers knew the location of the targets. The null hypothesis can be rejected since there is a significant difference between the averages.

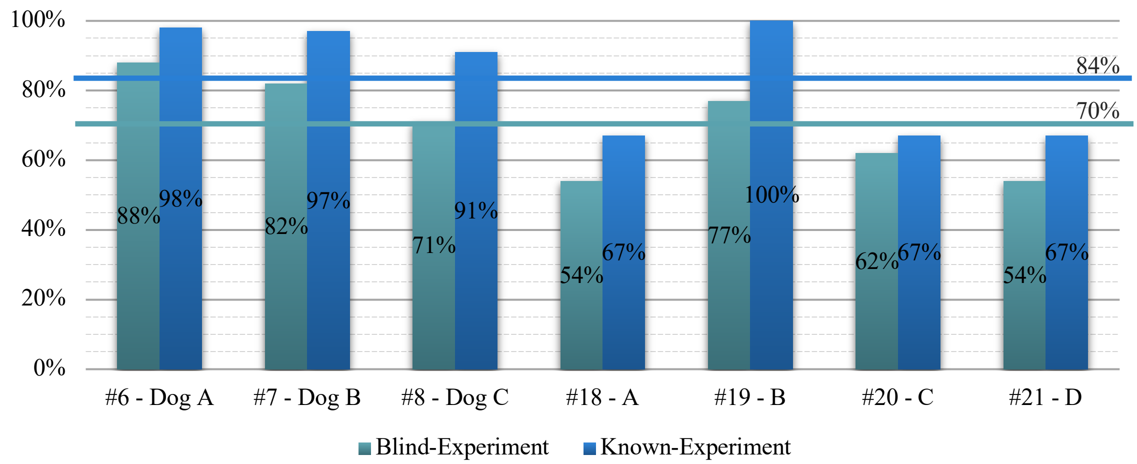

Figure 9: *Bar chart comparing the success rates for each of the seven dog-handler teams who took part in a blind-experiment and a known-experiment. The green line represents the average success rate of the dogs from the blind-experiment (70%). The blue line represents the average success rate of the dogs from the known-experiment (84%).*

Discussion

The purpose of this research is to conduct a series of statistical tests that will compare a detection dog's success rate to their gender, age, experience, breed, target scent, and handler's knowledge of the experiment. The results will be able to indicate if handlers or trainers can use demographic factors to indicate which dog will be the better scent dog. Or if a more reliable scent dog comes from experience, training, or if the handler themselves has an effect of the dog's success rates. Even though this dataset is missing several sections of data, it can still be used as a good starting point for similar analyses in the future.

Males vs. Females

Female dogs have olfactory cells that are more active, and a better long-term memory in odor recall than male dogs (68,138), it was expected that females would have a slight advantage in detection work and be more accurate than males. Female dogs having these abilities could be due to the fact that they look after their litter of puppies more, and they have to tell the difference between them by scent (138). Having a better sense of smell and stronger odor recall should make females better scent detection dogs. In addition to their better sense of smell, females are less aggressive and more focused than males (139,140), and this should make female dogs the first choice when being selected for scent training.

An independent t-test showed that there is no significant correlation between the gender of a dog and their success rates. The sample of female scent dogs in this dataset were on average slightly more accurate than the male dogs. If gender did have an impact on a dog's accuracy, it was expected to be a small effect. However, this difference in averages could be caused by random sampling error.

Age and Success Rates

The older dogs were expected to be more successful during scent work since they have a better long-term memory for odors and be able to process more complicated odors than the younger dogs (68,138). Since younger dogs have a more rudimentary olfactory system and ability for processing odors (138,159), it was expected that they would be less accurate in scent work. The Pearson correlation test indicated a weak negative correlation; however, it was not statistically significant. The weak negative correlation could have been due to random sampling error.

It is well known that the human body changes as it gets older, and the same is true for dogs and their olfactory system (66,141). Knowing that a dog's olfactory epithelium starts to atrophy at the age of 14 years (66,141), it is possible that a dog's accuracy does increase as they get older, but then will start to decrease as they reach the age of 14 and older. The dogs in this dataset ranged from 0.5 years (6 months) to 12 years old. Since all of the scent dogs were younger than 14 years, there should be a positive correlation with age. If there were dogs older than 14 years in this dataset, then it would be expected that their success rates would increase with age and then decrease after 14 years. However, more data is needed for this research.

Breed of Dog

The seven breed categories were chosen to study the natural olfactory ability of the dog and its breed. The dogs who were originally bred for hunting and tracking tasks, the Hunting and Scent/Tracker groups, were expected to perform better in scent work than the other breed categories. As expected, the Scent/Tracker category perform the best on average. The Herding breeds performed just as well on average, but the Herding group also performed significantly better than the Hunting breed category as indicated by a one-way ANOVA and a Tukey HSD test.

What was unexpected was the Hunting category performing the worst out of the categories. It can be argued that the reason the Hunting category did so poorly was because it consisted of sighthounds and gun dogs. These dogs were originally bred to assist in hunting. Where sighthounds typically do not rely on scent to find their prey. And gun dogs, although they can be used for tracking, are mostly used for retrieving the kill. For a complete list of which breeds used in this dataset were put into each category, see Appendix A.

A possible reason for this outcome could be in regard to how the breeds were categorized. Using more categories or different categories that focused on other aspects of the dog, for example, how cooperative the breed is in working with humans, would have resulted in different outcomes. Past researchers have classified breeds of dogs into groups like Cooperative Worker breeds and Independent Workers breeds since the cooperativeness of a dog's breed has influenced in how humans have used them (32,33,160). Cooperative Worker breeds refers to the breeds of dog that would work alongside humans constantly, where the dog would need to look to them for commands and direction (32,33,160). The Independent Worker breeds refer to the breeds that normally work with little to no human help (32,33). This method of breed categorization has a focus on how well the dogs and humans work together (32,33,160). Their Cooperative Worker breeds included gun dogs and herding dogs (32,33,160), but this analysis placed gun dogs with the sighthounds in the Hunting category and herding dogs in their own group. The Independent Worker breeds included scent hounds and livestock guardian dogs (32,33,160), whereas this analysis placed scent hounds in their own category and livestock guardian dogs in Utility/Other. Using the Cooperative and Independent Worker groups would have produced different results, and it could be argued that the breeds in the Cooperative Worker group would perform better in scent work due to how close they work with humans and how trainable they would be (33,34,125).

It is possible that simply splitting the Hunting category to separate the gun dogs and sight hounds would have shown that gun dogs are better at scent work than the sight hounds. This is evident all over the world as Labrador Retrievers are the most common drug dogs in the United States, United Kingdom, and Japan (16,32,39,139). Alongside Labradors is the English Springer Spaniel that this analysis put in the Hunting category, but is also a very common detection dogs

(16,32,139). With the breed's cooperativeness with humans, it is possible that they could have been as successful as the Herding breed category.

The Companion breeds were not expected to perform as well as they did. This may not have anything to do with what breed the dogs were, but with how trainable the dogs were. A study by Hall et al. (2015), had to exclude nine out of their the 10 greyhounds due to lack of willingness to participate, but their 10 pugs outperformed the German shepherd dogs in scent work (124). These results support the notion that a dog's breed may not be as important in determining their successfulness in scent work as previously thought. It was suggested by Hall et al. (2015) that olfaction may not be what makes a great scent dog, but possibly motivation, trainability, or general learning process (124). Trainability is defined as a dog's willingness to heed its owner in obeying simple commands, combined with a strong "fetch" drive, a high degree of focus, and low levels of opposition to being corrected (160).

Experience and Success Rates

Dogs who have more training and experience in scent work should be more accurate than dogs who just started training since they learn more through continued training and exposure to different scent mixtures and quantities (54,61,105,123,143,145). However, the Pearson correlation test determined there is a weak negative correlation, but that it was not statistically significant. These results could be due to random sampling error.

Another possible explanation for these results could be related to the age of the dogs. As common sense would dictate, a dog cannot have eight years of experience without being at least eight years old. Although there is no age limit as to when a dog can begin scent training, the dogs with the most experience might be older than the less experienced dogs. This would mean that factoring in the dog's age may provide more conclusive results.

Target Scents

Because not all scents are created equal, it was expected that dogs would be significantly less proficient in locating non-biological scents based on the average success rates. A one-way ANOVA and Tukey HSD test proved this hypothesis to be correct as there are some odors that dogs are less accurate in locating. Even though they are still capable, dogs trained on the scent of chemicals, like narcotics, explosives, and other chemical scent mixtures, are not the most accurate type of scent detection dog when compared to dogs trained on the scent of animals, human remains, live human scent, or plants and bugs.

These results may suggest that there are some odors that are more difficult for dogs to detect. This could mean that drug dogs, bomb dogs, and dogs trained on other chemical mixtures may need extra time and training to become proficient enough to go into the workforce. As these dogs appear to already be at a disadvantage compared to the other types of scent dogs since their target odors are more difficult to locate. However, more research with a larger dataset is needed to confirm these results.

Blind- vs. Known-Experiment

Because dogs can read and interpret the subtlest of gestures in human behavior to achieve a goal, their handlers can influence an alert from their canines without even realizing it (82–88,96). It was expected that there would be a correlation between the handler's knowledge of the location of targets and the dogs' success rate. However, when the 161 scent dogs were tested, the independent t-test produced no significant results. The reason for this could very well be the uneven sample sizes. Having 150 blind-experiments and only 11 known-experiments could have produced these surprising results.

So, a subsequent paired t-test was conducted on the dogs who participated in both a blind-experiment and known-experiment. The paired t-test revealed a statistically significant and very strong correlation between the dogs' success rate and whether it was a blind- or known-experiment. This means that the handlers are more than likely giving away the target's location, and, since dogs occasionally rely on their human's gestures over their own sense of smell (81,97), the dogs appear more successful during a search.

It is known that dogs will behave and react differently depending on how attentive their owner or handler is to them (88). Different breeds of dogs differ in how they communicate with humans (2,27,131,132). When simply meeting the human's gaze, wolves have a particularly difficult time with and require extra time, training, and socialization to be on par with dogs (27,33,90,91,161). Even dog breeds that are genetically more similar to wolves than other breeds take longer to meet their human's gaze, and will break eye contact sooner (27). As described previously as breeds in the Cooperative Worker group, gun and herding dogs respond to human cues better than the breeds in the Independent Worker group (32,33). This is a desirable behavioral trait to have in a scent dog (32,34,128), but can be detrimental if they do not also possess some degree of independence where they can make their own choices during a search if needed (32,34,66,139,162).

Limitations

This analysis was mostly limited in which dogs could be used in the statistical analyses, and how the dogs' success rates were calculated. Including all 215 canines in each statistical test conducted would have been ideal since having more canines in each test would provide stronger conclusions on scent dogs as a whole. However, the dataset compiled for this analysis is missing data in several areas. So, not every dog could be used in each statistical test. Unfortunately, this is a common trend in articles about canine scent detection (163). This analysis required each scent dog to have a success rate, and for that success rate to include relevant results of the trials from which they were derived. This analysis was interested in the scent dog's true positive alerts to their target scents, and true negative alerts ignoring any non-target scents, if provided.

Some of the trial results provided by the authors had to be excluded in the calculations for the success rates in this analysis. This was done because some of the trials were irrelevant to this analysis or detailed results could not be extracted from all trials. This was the case for a study done by Brisbin and Austad (1991) who, in one of their trials, tested if their scent dogs could discriminate between the scent of their handler's hand and the scent of their handler's elbow. This trial was to determine if dogs could discriminate between body-part specific odors, and was not seen as relevant to this analysis since the target scent was the scent from their handler. The other trials involved discriminating between their handler's scent and a stranger's scent or no human scent, and the results of these trials were used in this analysis. This was also done for an experiment by Cablk and Heaton (2006), where they provided detailed results for both dogs for one of their trials, but not the other two trials. The dogs took part in two other searches, but those results were cumulated into overall percentages, and the number of tortoises found by each dog could not be extracted. Because of the way the results of the other two trials were reported, they could not be used to calculate the success rates for this analysis.

Another reason for exclusion was because some of the information about the dogs was called into question. In an article by Cooper et al. (2014), the authors appeared to have miscalculated the age and years of experience of their dogs, so these dogs were excluded from the age and experience tests in this analysis. The authors listed a couple of their dogs as being younger than the number of years they had been doing scent work. This may have been a simple typo or a miscalculation, since they described the age and years of experience in terms of years, but then gave this information in months. Either way, this inconsistency was not explained or addressed in the article and caused the age and experience of the other dogs to be questioned. Because this issue would not have affected the dogs' gender, breed, target scent, or overall accuracy, they were only excluded from the Pearson correlation tests involving their age and number of years' experience.

In some experiments, the researchers used multiple dogs, but then did not provide a complete demographic profile for each of their dogs to be included in every statistical test. A study by Settle et al. (1994) indicated that their dogs were experienced in scent work, but did not indicate how long they until they mentioned later that one of their dogs had no prior experience. A study by Smith et al. (2003) did something similar, where they provided the years' experience for only one of the dogs, but did not provide or mention the experience of the others.

In order to determine the detection accuracy of scent dogs, the number of correct alerts and incorrect alerts are required (15). The success rates for this analysis were calculated using two different methods depending on how the original experiment was set up and what information was provided. There are several different ways to present the results of a scent dog's search. From the 37 articles that contributed to this dataset, the results were presented and referred to in a number of different ways. There are two ways of testing scent dogs, and that is to set up the experiment as a line-up or free-search. For a line-up experiment, the number of true positive and true negative alerts can be counted or calculated. For the line-up experiments, the success rate came from taking the sum of true positive and true negative alerts divided by the number of stations available for the dog to inspect.

$$Success\ Rate = \frac{(True\ Positives + True\ Negatives)}{Number\ of\ Stations}$$

For the free-search experiments, the success rate came from the number of true positive alerts divided by the number of targets available for the dogs to locate.

$$Success\ Rate = \frac{True\ Positives}{Number\ of\ Targets}$$

A serious problem occurs when multiple authors use these equations, among a few others, and refers to the results by different terms; while many other authors use the same names for their results, but use completely different equations. There is no consensus as to what the equations are calculating. This inconsistency in terminology is common in the literature pertaining to working dogs, and can be the cause of much confusion (45).

Because each article calculated and presented their results differently, the results for each dog had to be extracted and reduced to the form of raw data. This means that the total number of true positives, and true negatives if available, had to be counted or calculated based on what the original authors presented as their results and data. In a discrimination experimental setting, like a line-up, where the total number of targets and non-targets are known, the true negatives could be factored in. In a free-search experimental design, the number of true negative alerts could be limitless, so only the number of true alerts and targets placed or planted could be used.

Conclusion

With trainability proving to be more valuable in scent detection than gender, age, and especially breed, perhaps dogs should be selected for scent work based on their personality and willingness to work and be trained. Although, certain morphological features should be regarded (32,38,42,133,164–167), as a Pug or Chihuahua would not be cut out for a search-and-rescue mission after an avalanche no matter how willing or accurate they are in scent detection. Due to selective breeding, dogs have developed certain morphological features that optimize their ability to accomplish the tasks they were bred for (128,131). For tracking and most scent-related work, these features include an elongated nose, a large nasal cavity, an increased number of odor receptor cells, long hanging ears, and a dewlap (Figure 10) (125,128). Some of these morphological features can be disregarded, but the dog needs to be physically suited to work safely and efficiently in their respective working environment.

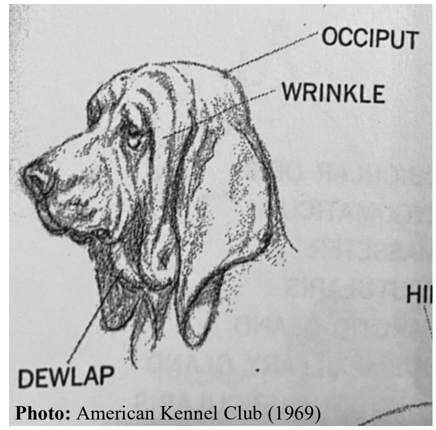

Photo: American Kennel Club (1969)

Figure 10: Illustration of the dewlap and large hanging ears on a bloodhound.

Since roughly 50% of dogs in training never qualify to become actual working dogs. This is a significant waste of resources, so using each dog to their fullest potential means selecting the most reliable dogs to train. Determining which dog will be the better scent dog is not an easy task. So, this analysis used a series of statistical test to determine if the dogs' gender, age, and breed to see if they were predisposed to becoming a reliable scent detection dog; or if accuracy came as a result of experience and training, or if the handler influenced the outcome of a search. According to this analysis, gender and age had no impact on a dog's accuracy. A dog's breed can affect a dog's accuracy, but the statistical test only indicated that dogs originally bred for herding make more accurate scent dogs than dogs bred for hunting. A dog's level of experience did not impact their success rate of a search. There are some target scents that the dogs were not as accurate in locating, like narcotics, explosives, and other chemical mixtures. Whether or not the handler was blind during the searches had the highest impact on a dog's accuracy. Scent dogs will find their target based on their handler's behavior during the search. More research is needed for more conclusive results with a larger sample and more complete dataset, but the dataset used here can be a good starting point.

Appendix A

Table listing the different breeds included in this dataset and what category they were placed in.

Table A: *List of breeds that this analysis included and what category they were placed in.*

Companion *N = 14*	**Herding** *N = 19*	**Hunting** *N = 73*	**Mix Breeds** *N = 23*	**Scent/Tracker** *N = 18*	**Utility/Other** *N = 8*	**Wolf** *N = 12*
- Bichon Bolognese	- Australian Shepherd	- Afghan Hound	- American Bulldog-Boxer	- Basset Hound	- American Staffordshire Terrier	- Gray Wolf
- Bichon Havanese	- Belgian Malinois	- Bracco Italiano	- Beagle Mix	- Beagle	- Boxer	
- Boston Terrier	- Border Collie	- Brittany Spaniel	- Beagle-Jack Russel	- Bloodhound	- Bullmastiff	
- Cavalier King Charles	- German Shepherd	- Dachshund	- Beagle-Pug	- Grand Basset Griffon Vendéen	- English Bulldog	
- Chinese Crested	- Herder	- Duck Tolling Retriever	- Bloodhound Mix	- Transylvanian Hound	- Grosspitz	
- Miniature Pincher	- Rough Collie	- English Greyhound	- Coonhound-Pointer Mix		- Rottweiler	
- Pug		- English Springer Spaniel	- German Shepherd Mix		- Siberian Husky	
		- German Pointer	- Goldendoodle			
		- German Shorthaired Pointer	- Greyhound Mix			
		- German Wirehaired Pointer	- Lab-Collie Mix			
		- Golden Retriever	- Lab-Lieka Mix			
		- Hungarian Greyhound	- Lab-Russian Spaniel Mix			
		- Labrador Retriever	- Labrador Retriever Mix			
		- Poodle	- Mutt			
		- Springer Spaniel	- Pit Bull Mix			
		- Whippet	- Terrier-Pointer Mix			
		- Wirehaired Vizsla				

Appendix B

SPSS 20.0 results for the statistical analyses.

Males vs. Females

Table B: *Descriptive group statistics for the independent t-test for the males vs. females test.*

Groups Statistics

	Gender:	N	Mean	Std. Deviation	Std. Error Mean
Accuracy:	M	79	72.7415%	21.92251%	2.46648%
	F	58	75.4648%	20.12981%	2.64317%

Table C: *The results of the independent t-test for the males vs. females analysis. Equal variances are assumed since the p-value for Levene's Test is >.05.*

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Accuracy:	Equal variances assumed	.417	.515	-.743	135	.458	-2.72331%	3.66305%	-9.96770%	4.52108%
	Equal variances not assumed			-.753	128.362	.453	-2.72331%	3.61523%	-9.87646%	4.42984%

Age and Success Rates

Table D: *Descriptive group statistics of the dogs' age and their accuracies.*

Descriptive Statistics

	Mean	Std. Deviation	N
Age:	4.83	2.73327	135
Accuracy:	76.516%	18.971%	135

Table E: *The results of the Pearson's correlation test comparing the age of the dogs and their accuracies.*

Correlations

		Age:	Accuracy:
Age:	Pearson Correlation	1	-.025
	Sig. (2-tailed)		.775
	N	135	135
Accuracy:	Pearson Correlation	-.025	1
	Sig. (2-tailed)	.775	
	N	135	135

Breed of Dog

Table F: *The breed groups' descriptive statistics for the one-way ANOVA analysis.*

Descriptive Statistics

Dependent Variable: Accuracy:

Breed Category:	Mean	Std. Deviation	N
Companion	75.9286%	11.32366%	14
Herding	82.7533%	13.22021%	21
Hunting	64.7044%	29.26397%	79
Mix	68.2348%	21.25151%	27
Scent/Tracker	83.1567%	24.41426%	18
Utility/Other	69.9789%	22.05689%	9
Wolf	72.3333%	14.16996%	12
Total	70.8302%	24.69934%	180

Table G: *Results of the one-way ANOVA comparing the averages of the seven breed categories.*

Tests of Between-Subjects Effects

Dependent Variable: Accuracy:

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	9264.230[a]	6	1544.038	2.673	.017	.085
Intercept	638535.289	1	638535.289	1105.373	.000	.865
Breed Category	9264.230	6	1544.038	2.673	.017	.085
Error	99936.014	173	577.665			
Total	1012245.913	180				
Corrected Total	109200.244	179				

a. R Squared= .085 (Adjusted R Squared = .053)

Table H: *Results of the Tukey HSD identifying which breed categories are statistically different.*

Multiple Comparisons

Dependent Variable: Accuracy:

Tukey HSD

(I) Breed Category:	(J) Breed Category:	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Companion	Herding	-6.8248%	8.29275%	.982	-31.5649%	17.9154%
	Hunting	11.2241%	6.96950%	.676	-9.5683%	32.0166%
	Mix	7.6938%	7.91560%	.959	-15.9213%	31.3088%
	Scent/Tracker	-7.2281%	8.56471%	.980	-32.7796%	18.3235%
	Utility/Other	5.9497%	10.26873%	.997	-24.6856%	36.5849%
	Wolf	3.5952%	9.45518%	1.000	-24.6129%	31.8034%
Herding	Companion	6.8248%	8.29275%	.982	-17.9154%	31.5649%
	Hunting	18.0489%*	5.90085%	.040	0.4446%	35.6532%
	Mix	14.5185%	6.99306%	.372	-6.3442%	35.3813%
	Scent/Tracker	-0.4033%	7.72013%	1.000	-23.4352%	22.6285%
	Utility/Other	12.7744%	9.57564%	.835	-15.7931%	41.3419%
	Wolf	10.4200%	8.69750%	.894	-15.5277%	36.3677%
Hunting	Companion	-11.2241%	6.96950%	.676	-32.0166%	9.5683%
	Herding	-18.0489%*	5.90085%	.040	-35.6532%	-0.4446%
	Mix	-3.5304%	5.35791%	.995	-19.5149%	12.4542%
	Scent/Tracker	-18.4522%	6.27732%	.056	-37.1797%	0.2752%
	Utility/Other	-5.2745%	8.45560%	.996	-30.5005%	19.9516%
	Wolf	-7.6289%	7.44654%	.948	-29.8446%	14.5868%
Mix	Companion	-7.6938%	7.91560%	.959	-31.3088%	15.9213%
	Herding	-14.5185%	6.99306%	.372	-35.3813%	6.3442%
	Hunting	3.5304%	5.35791%	.995	-12.4542%	19.5149%
	Scent/Tracker	-14.9219%	7.31351%	.393	-36.7406%	6.8969%
	Utility/Other	-1.7441%	9.25094%	1.000	-29.3429%	25.8548%
	Wolf	-4.0985%	8.33869%	.999	-28.9758%	20.7787%
Scent/Tracker	Companion	7.2281%	8.56471%	.980	-18.3235%	32.7796%
	Herding	0.4033%	7.72013%	1.000	-22.6285%	23.4352%
	Hunting	18.4522%	6.27732%	.056	-0.2752%	37.1797%
	Mix	14.9219%	7.31351%	.393	-6.8969%	36.7406%
	Utility/Other	13.1778%	9.81211%	.831	-16.0952%	42.4508%
	Wolf	10.8233%	8.95719%	.890	-15.8991%	37.5458%
Utility/Other	Companion	-5.9497%	10.26873%	.997	-36.5849%	24.6856%
	Herding	-12.7744%	9.57564%	.835	-41.3419%	15.7931%
	Hunting	5.2745%	8.45560%	.996	-19.9516%	30.5005%
	Mix	1.7441%	9.25094%	1.000	-25.8548%	29.3429%
	Scent/Tracker	-13.1778%	9.81211%	.831	-42.4508%	16.0952%
	Wolf	-2.3544%	10.59829%	1.000	-33.9729%	29.2640%
Wolf	Companion	-3.5952%	9.45518%	1.000	-31.8034%	24.6129%
	Herding	-10.4200%	8.69750%	.894	-36.3677%	15.5277%
	Hunting	7.6289%	7.44654%	.948	-14.5868%	29.8446%
	Mix	4.0985%	8.33869%	.999	-20.7787%	28.9758%
	Scent/Tracker	-10.8233%	8.95719%	.890	-37.5458%	15.8991%
	Utility/Other	2.3544%	10.59829%	1.000	-29.2640%	33.9729%

Based on observed means.
The error term is Mean Square(Error) = 577.665.

*. The mean difference is significant at the .05 level.

Experience and Success Rates

Table I: *Descriptive group statistics of the dogs' years of experience and their success rates.*

Descriptive Statistics

	Mean	Std. Deviation	N
Years Exp.	1.143	1.91172	95
Accuracy:	74.4%	19.968%	95

Table J: *The results of the Pearson's correlation test comparing the number of years' experience of the dogs and their success rates.*

Correlations

		Years Exp.:	Accuracy:
Years Exp.	Pearson Correlation	1	-.126
	Sig. (2-tailed)		.224
	N	95	95
Accuracy:	Pearson Correlation	-.126	1
	Sig. (2-tailed)	.224	
	N	95	95

Target Scents

Table K: *The descriptive statistics for the five target scent categories.*

Descriptive Statistics

Dependent Variable: Accuracy:

Target Scent:	Mean	Std. Deviation	N
Animal Scent	78.5114%	18.15233%	65
Chemicals	47.4706%	27.33577%	32
Human Remains	76.5050%	24.12206%	36
Human Scent	74.9200%	15.41352%	25
Plant/Bugs	75.4674%	25.83992%	38
Total	72.0267%	24.64475%	196

Table L: *Results of the one-way ANOVA comparing the averages of the five target scent categories.*

Tests of Between-Subjects Effects

Dependent Variable: Accuracy:

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	23410.467[a]	4	5852.617	11.764	.000	.198
Intercept	884828.642	1	884828.642	1778.496	.000	.903
Target Scent	23410.467	4	5852.617	11.764	.000	.198
Error	95025.410	191	497.515			
Total	1135254.577	196				
Corrected Total	118435.877	195				

a. R Squared= .198 (Adjusted R Squared = .181)

Table M: *Results of the Tukey HSD identifying which target scent categories are statistically different.*

Multiple Comparisons

Dependent Variable: Accuracy:

Tukey HSD

(I) Target Scent:	(J) Target Scent:	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Animal Scent	Chemicals	31.0408%*	4.81679%	.000	17.7753%	44.3063%
	Human Remains	2.0064%	4.63400%	.993	-10.7557%	14.7685%
	Human Scent	3.5914%	5.24926%	.960	-10.8651%	18.0479%
	Plant/Bugs	3.0440%	4.55484%	.963	-9.5001%	15.5881%
Chemicals	Animal Scent	-31.0408%*	4.81679%	.000	-44.3063%	-17.7753%
	Human Remains	-29.0344%*	5.41915%	.000	-43.9588%	-14.1100%
	Human Scent	-27.4494%*	5.95382%	.000	-43.8463%	-11.0525%
	Plant/Bugs	-27.9967%*	5.35162%	.000	-42.7352%	-13.2583%
Human Remains	Animal Scent	-2.0064%	4.63400%	.993	-14.7685%	10.7557%
	Chemicals	29.0344%*	5.41915%	.000	14.1100%	43.9588%
	Human Scent	1.5850%	5.80693%	.999	-14.4074%	17.5774%
	Plant/Bugs	1.0376%	5.18771%	1.000	-13.2494%	15.3247%
Human Scent	Animal Scent	-3.5914%	5.24926%	.960	-18.0479%	10.8651%
	Chemicals	27.4494%*	5.95382%	.000	11.0525%	43.8463%
	Human Remains	-1.5850%	5.80693%	.999	-17.5774%	14.4074%
	Plant/Bugs	-0.5474%	5.74396%	1.000	-16.3663%	15.2716%
Plant/Bugs	Animal Scent	-3.0440%	4.55484%	.963	-15.5881%	9.5001%
	Chemicals	27.9967%*	5.35162%	.000	13.2583%	42.7352%
	Human Remains	-1.0376%	5.18771%	1.000	-15.3247%	13.2494%
	Human Scent	0.5474%	5.74396%	1.000	-15.2716%	16.3663%

Based on observed means.

The error term is Mean Square (Error) = 497.515.

*. The mean difference is significant at the .05 level.

Blind- vs. Known-Experiment

Table N: *Descriptive group statistics for the independent t-test for the blind- vs. known-experiment analysis.*

Groups Statistics

	Blind?:	N	Mean	Std. Deviation	Std. Error Mean
Accuracy:	yes	150	79.5460%	18.61917%	1.52025%
	no	11	83.6364%	14.00195%	4.22175%

Table O: *Results of the independent t-test for the blind- vs. known-experiment analysis.*

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Accuracy:	Equal variances assumed	.147	.702	-.713	159	.477	-4.09034%	5.73608%	-15.41907%	7.23840%
	Equal variances not assumed			-.912	12.747	.379	-4.09034%	4.48713%	-13.80376%	5.62309%

Table P: *Descriptive group statistics for the paired t-test for the blind- vs. known-experiment analysis.*

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Blind-Experiment	69.5743%	7	13.54219%	5.11847%
	Known-Experiment	83.8571%	7	16.00446%	6.04912%

Table Q: *Results of the paired t-test for the blind- vs. known-experiment showing the r-value and p-value.*

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Blind-Experiment: & Known-Experiment:	7	.935	.002

Table R: *Results of the paired t-test for the blind- vs. known-experiment showing the mean difference and t-value.*

Paired Samples Correlations

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Blind-Experiment: - Known-Experiment:	-14.28286%	5.85198%	2.21184%	-19.69503%	-8.87068%	-6.457	6	.001

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