Ability of Canine Termite Detectors to Locate Live Termites and Discriminate Them from Non-Termite Material

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ABSTRACT Dogs were trained to detect Eastern subterranean termites, *Reticulitermes flavipes* (Kollar), using the United States Customs method of scent detection dog training modified with a food reward. Dogs were tested with various numbers of Eastern subterranean termites placed in vented PVC containers. Trained dogs were 95.93% accurate in finding ≥40 Eastern subterranean termite workers (positive indications) and incorrectly indicated the presence of termites in 2.69% of the containers without termites. Multiple species of termites [dark southern subterranean, *R. virginicus* (Banks); Formosan subterranean, *Coptotermes formosanus* Shiraki; powderpost, *Cryptotermes cavifrons* Banks; and southeastern drywood termites, *Incisitermes snyderi* (Light)], were similarly evaluated. Dogs trained to locate Eastern subterranean termites were also 100% accurate in finding dark southern subterranean termites, 98.89% accurate in finding Formosan subterranean termites, 97.33% accurate in finding powderpost termites, and 88.89% accurate in finding southeastern drywood termites. Dogs were able to discriminate live termites from non-termite material. Trained dogs' false response rate was 25.33% to Eastern subterranean termite–damaged wood, 6.67% to American cockroaches, *Periplaneta americana* (L.), and 2.67% to Florida carpenter ants, *Camponotus floridanus* Buckley.

KEY WORDS subterranean termites, drywood termites, termite-damaged wood, American cockroach, termite detection, dog

AMONG THE PEST SPECIES of termites currently found in the United States, subterranean termites, *Reticulitermes* spp., *Coptotermes* spp., and *Heterotermes* spp., are responsible for ≈95% of the termite damage to wood and wood products (Mauldin 1986, Su and Scheffrahn 1990). Drywood, powderpost, and dampwood termites, as well as the termitid, *Amitermes floridensis* Scheffrahn, Su, and Mangold, are also structural pests of economic importance (Potter 1997). Su (1991) estimated that all termite infestations (subterranean, drywood, and dampwood) in the United States cost ≈$1.5 billion to control annually.

The cryptic behavior of termite pests often results in infestations that are concealed from view, making them difficult to detect. Construction and landscaping practices that do not consider subterranean termite prevention create areas conducive to subterranean termite infestations (Forschler 1999). Once subterranean termite infestations are established, a pest management professional conducting a visual inspection relies on finding live termites, mud tubes, and/or damaged wood to confirm a suspected infestation.

Drywood termites are difficult to detect visually because the establishment and maturation of the colony is confined entirely within the wood (Scheffrahn et al. 1997). Because drywood termite colonies start from only a pair of alates, it can take many years for them to produce noticeable structural damage. The most common sign of a drywood termite infestation is the presence of six-sided fecal pellets that are expelled through kick-out holes that the termites create in the wood surface (Scheffrahn et al. 1993, Potter 1997).

Evidence of a termite infestation is not always visible; therefore, relying on visual inspection alone limits the inspector to finding infestations that may have already caused substantial damage. To enable inspectors to locate termite infestations before substantial damage has occurred, the pest management industry has begun to use several tools to inspect areas inaccessible to visual inspection. Canine termite detectors are among these tools (Scheffrahn et al. 1993).

Dogs rely on olfaction, not vision, to detect a wide array of materials, including explosives, narcotics, missing people, brown tree snakes, and agricultural quarantine items (Wallner and Ellis 1976, Welch 1990, Lewis et al. 1997, Waggoner et al. 1997, Engeman et al. 1998). Dogs can be trained to a high level of accuracy. For example, dogs used to detect explosives must be tested to 100% accuracy before being assigned to field operations (S.E.B., personal communication).

While there are many testimonials regarding the use of dogs by the pest management industry, there is only

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one published account on the ability of dogs to detect termites (Lewis et al. 1997). Five beagles tested in that study were 81% accurate at finding ≥5 *R. hesperus* Banks workers. However, the usefulness of termite-detecting dogs to the pest management industry was doubtful because the dogs had a 28% false positive indication rate, which was considered an unacceptably high error rate. False positives are usually the result of poor training techniques or the use of training materials scented with nontarget odors; however, neither the techniques nor materials used to train the dogs used in the Lewis et al. (1997) study were presented, so the cause of the high percentage of false positives could not be determined.

Training materials contaminated with nontarget odors may teach dogs to respond to both target and nontarget odors, increasing the number of false positives (United States Customs Service 1979, Hallowell et al. 1997). Nontarget odors from ants and cockroaches are examples of odors that could be inadvertently included in training materials. Ants are known to compete with termites for nesting sites (Cornelius and Grace 1996), and peridomestic cockroaches are known to inhabit areas, such as woodpiles (Cornwell 1968), which are conducive to termite infestations. Our experience with dog trainers indicates that dogs are routinely trained with materials contaminated with nontarget odors.

The purpose of our study was to determine the ability of dogs to detect varying numbers of Eastern subterranean termites, *Reticulitermes flavipes* (Kollar), when trained with live Eastern subterranean termites. We also wanted to determine whether dogs could differentiate between five species of termites, discriminate termites from termite-damaged wood, and distinguish American cockroaches, *Periplaneta americana* (L.), and Florida carpenter ants, *Camponotus floridanus* Buckley, from Eastern subterranean termites.

Materials and Methods

Termites. Termites from three colonies of Eastern subterranean termites were collected from PVC collection tubes (11.5 cm diameter by 30.5 cm long) at the University of Florida, Gainesville, FL, and used for dog training and testing. The PVC collection tubes were buried ≈12 cm in the ground and covered with a PVC cap (12.5 cm diameter; NIBCO, Elkhart, IN), according to the procedure outlined by Powell (2000). The PVC tubes were filled with two single-faced, rolled corrugated cardboard strips (236.0 cm long by 15.2 cm wide; Gainesville Paper Co., Gainesville, FL) and left in the ground at areas where termites were active. Cardboard rolls in the tubes were replaced weekly, and termites in rolls removed from the tubes were transported back to the laboratory, separated from the rolled cardboard and debris, and placed on damp, clean corrugated cardboard strips. Termites were sealed in plastic containers (26 cm long by 19 cm wide by 10 cm deep; Pioneer Plastics, Dixon, KY) and held at ≈23°C.

Formosan subterranean termites, *C. formosanus* Shiraki, were obtained from private residences in Mobile, AL, and Hallandale, FL, transported to the laboratory, and stored in plastic containers as described previously. Dark southern subterranean termites, *R. virginicus* (Banks), were collected from infested logs in wooded areas on the University of Florida campus in Gainesville, FL. Powderpost termites, *C. cavifrons* Banks, and drywood termites, *Incisitermes snyderi* (Light), were obtained from private residences in Spring Hill, FL, and Gainesville, FL, respectively. Both the drywood and powderpost termites were held in plastic containers (26 cm long by 19 cm wide by 10 cm deep; Pioneer Plastics) at ≈23°C. Powderpost termites were used 5 mo after being transported to the laboratory. All other termites were used within 10 d of being transported to the laboratory.

To produce uncontaminated training and testing material, it was necessary to separate termites from debris. Termites were displaced from rolled corrugated cardboard strips into plastic containers that were tilted ≈45° and tapped until termites and debris had accumulated on the bottom. The container was then placed on a level surface. As the termites moved away from the debris that had accumulated in the plastic container, they were aspirated into a clean glass vial. All dogs, with the exception of Dog B, were trained with termites aspirated from contaminants. Termites used to train Dog B were prepared by breaking infested wood open over a screen (0.175 mm diameter) to allow small particles to sift through and large particles to be removed from the training sample by hand. This method of separating termites produced training samples that consisted of ≈1:85 (W:W) Eastern subterranean termites to termite-damaged material and debris.

Non-Termite Material. Termite-damaged wood was produced by placing pieces of kiln-dried pinewood (*Pinus* spp.; 8.5 by 3.5 by 0.5 cm) inside plastic containers with Eastern subterranean termites. Termites were allowed to feed on the wood for 1 mo. Termites were then separated from the wood, as above. The wood was dried in an oven (Precision Scientific, Winchester, VA) at 38 ± 1°C for 24 h before use in detection experiments.

Adult male and female American cockroaches of mixed ages were obtained from a laboratory-reared colony (Gulf strain) at the University of Florida Entomology and Nematology Department in Gainesville, FL. Cockroaches were reared in glass jars (25 tall by 21.5 cm diameter), fed laboratory rat chow (23% crude protein; Lab Diet 5001 Rodent Diet; PMI Nutrition International, Brentwood, MO), and provided water. The rearing room was kept at ≈23°C with a 12 L:12 D photoperiod. Food and water were replenished, and dead cockroaches were removed weekly.

Adult worker Florida carpenter ants were obtained from a laboratory-reared colony at the University of Florida Entomology and Nematology Department in Gainesville, FL. Carpenter ants were reared in plastic trays (52 by 41 by 8 cm) and fed fresh water, sugar water, and dead crickets. The rearing room was kept

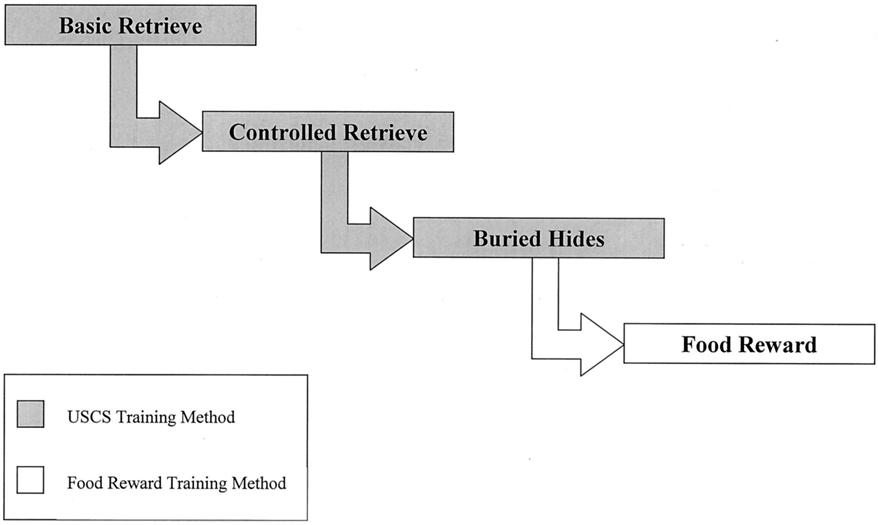

Fig. 1. Training steps used to teach dogs to locate termites.

at ≈27°C with a 12 L:12 D photoperiod. Water and food were replenished weekly.

Canine Training Methods. Six dogs (*Canis familiarius*), one German Shepherd (Dog A) and five beagles (Dogs B–F), were trained by experienced dog trainers to locate Eastern subterranean termites using the method outlined by the United States Customs Service (1979). Dogs B–F were trained with a combination of the USCS method and food reward method to reinforce correct behavior (Fig. 1). A PVC tube (1 cm diameter by 17 cm long) was drilled with 10 holes (3 mm diameter) and capped at both ends. Termite workers (≈300) were aspirated from damaged material with the method described above and placed in the PVC tube, which was then rolled into a (30 by 20 cm) terry cloth towel and secured with packaging tape. Rolled towels were stored overnight in an airtight food container (37 by 21 by 12 cm; Rubbermaid, Wooster, OH). Nonlatex gloves (Best Manufacturing Co., Menlo, GA) were used during the preparation process to prevent human scent from being transferred onto the terry cloth material. Dog B was trained with a mixture of Eastern subterranean termites and termite-damaged debris (1:85 [W:W] described above), while the remaining dogs were trained with Eastern subterranean termites alone.

The USCS method of dog training uses a retrieval exercise to teach the dog to associate a retrieve toy with the target odor. This method of training teaches the dog to search for the retrieve toy and to use its paws to dislodge the toy from where it is hidden. The advantage to this method is that the dog will go to where the strongest concentration of odor exists because that is where it believes the toy is hidden.

The first step of the USCS method is the basic retrieve, which teaches the dog to associate the scented terry cloth towel with the scent of termites. The towel was waved in front of the dog until he lunged for it. The handler then threw the towel ≈15 m. As the towel reached the apex of the throw, the dog was released. Once the dog picked up the towel, a tug-of-war game was initiated to reward the dog. To avoid discouraging the dog from working, the handler released the towel during the tug-of-war game, allowing the dog to have it before he tired.

The second step, called the "controlled retrieve," was used to teach the dog to use the scent of termites instead of sight to locate the terry cloth towel. The towel was waved in front of the dog until he lunged for it. The handler then threw the towel into high grass, which concealed its location. The handler verbally encouraged the dog to find the towel and guided the dog into the plume of termite scent. After the dog found the towel and picked it up, a tug-of-war game was initiated to reward him. Before the dog tired, the handler released the towel, allowing the dog to play with it.

When the dog demonstrated an ability to find the termite scented towel by odor alone, the third step, "buried hides," was used to teach the dog to search and actively indicate the presence of a termite-scented towel by digging with its paws. A termite-scented towel was hidden under a small amount of gravel or sand. A pine board (17 by 48 by 4 cm) was placed over the hidden termite-scented towel. An assistant teased the dog with an unscented towel while the handler restrained the dog. The assistant ran to the board and pretended to bury the towel under the board in several locations. The dog was encouraged to search under each board. When the dog located the buried termite-scented towel, he was encouraged to dig under the board to dislodge the towel. After the dog picked up the dislodged towel, a tug-of-war game was initiated to reward him. Before the dog tired, the handler released the towel, allowing the dog to have it.

After completing buried hides (the final step of the USCS method used in this study), the dogs were

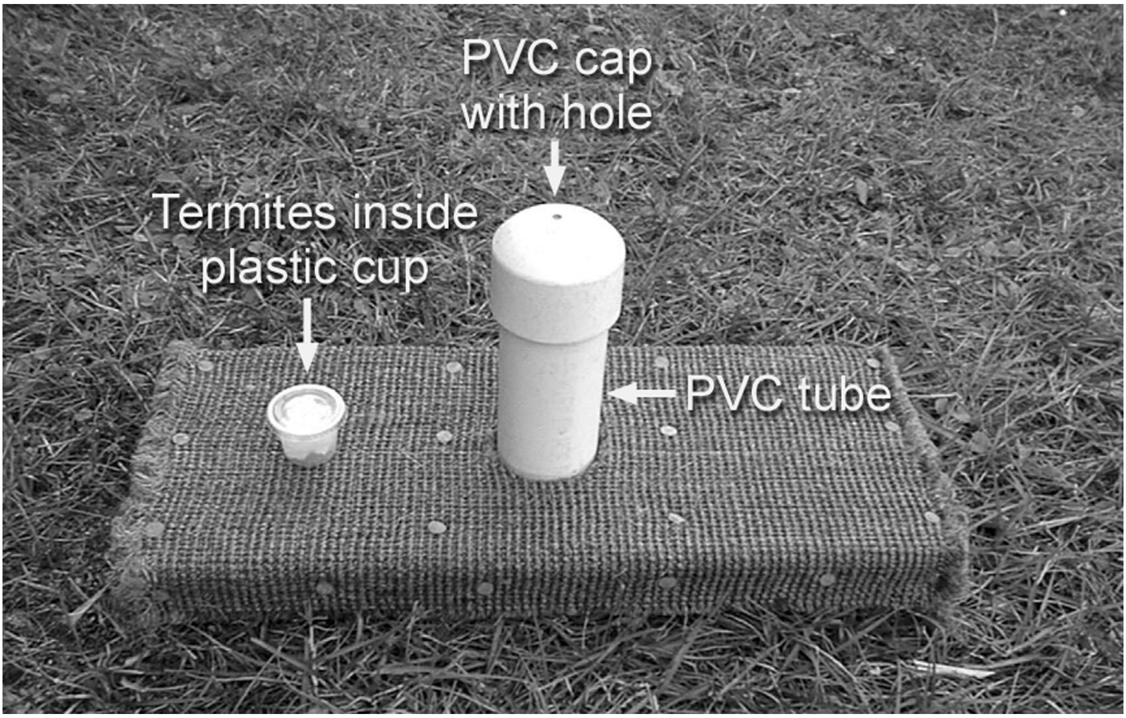

Fig. 2. PVC vented termite container.

taught to receive a food reward from the handler. This technique is taught to the dogs so they can be rewarded for correct behavior when the surroundings do not permit the handler to reward the dog with a tug-of-war game. To do this, four saucers, each with an empty plastic cup (29.5 ml; Prairie Packaging, Bedford Park, IL) and one saucer containing ≈300 termite workers in an identical plastic cup were placed on the ground. The dog was led to each of the saucers. When the dog responded to the presence of termites by digging, food was placed in the saucer as a reward. The dog was then taught to turn to the handler for a food reward after indicating the presence of termites.

To prevent the dog from responding to nontermite odors, the towels were washed after each training session in clean hot water (≈41°C) and dried in a dryer. No detergents, soaps or fabric softeners were used, so towels would not be contaminated with odors of these cleaning products. Daily training lasted from 3 wk to 3 mo depending on the individual dog. Each dog began the bioassay after consistently reaching 100% accuracy in locating ≈100 termite workers buried under gravel.

Detection of Various Numbers of Eastern Subterranean Termites. Containers used to hold termites were constructed by drilling the tops of pine boards (*Pinus* spp.; 17 by 48 by 4 cm) in the center to allow a PVC pipe (5 cm diameter by 15 cm) fitted with a cap to be secured onto the surface (Fig. 2). A hole (3 cm diameter) was drilled in the center of the PVC cap to allow scent to escape. Termites from three colonies of Eastern subterranean termites were collected from the field, separated into groups of 40, 80, and 160 with the method described previously, and placed inside plastic cups (29.5 ml; Prairie Packaging) using an aspirator. Each plastic cup contained a moistened section of paper towel (2 by 2 cm). The plastic cup lids were perforated with 30 holes (1 mm diameter) by a probe to allow the scent to permeate out. The plastic cups were placed inside the PVC tubes. The PVC tubes were placed onto the boards and allowed to sit for 12–14 h before being inspected by the dog.

Five PVC containers were placed on the ground linearly, 3 m apart. The handler led the dog to each of the five PVC containers for inspection. The dogs responded to the presence of termites in individual containers by digging. Responses were categorized as "positive indications," which is defined as a dog responding correctly to containers with termites, and "false positives," which is defined as the dog incorrectly responding to containers without termites.

To eliminate a testing pattern, more than one, one, or none of the PVC containers held termites. The order of the PVC containers with termites was rearranged for each replicate. However, data presented here are for the situation where one PVC container held termites. Testing was conducted over a period of several months. The dogs' level of proficiency was maintained by daily training sessions.

To evaluate the dogs' ability to detect varying numbers of termites, six dogs were tested using three densities of termites with 15 repetitions each. An experimental unit consisted of one set of five PVC containers. This experiment was a two-factor factorial design, with the main effects being dog identity and number of termites. Responses from dogs to the five PVC containers were categorized by response variable (positive indication or false positive), number of termites, and dog identity. Percentages of positive indications and false positives were rank-transformed (Conover and Iman 1981). Each response variable was subjected to a two-way analysis of variance (ANOVA) with termite numbers and dog identity as class variables. Means were separated by Student-Newman-Keuls tests ($P = 0.05$; SAS Institute 2001).

Detection of Five Species of Termite. The same experimental design was used to test the dogs' ability to differentiate between Eastern subterranean, dark southern subterranean, Formosan subterranean, drywood, and powderpost termites, except tests were conducted with 80 workers of each species because termite infestations usually have >40 termites. Percentages of positive indications and false positives were rank-transformed (Conover and Iman 1981). Each response variable was subjected to a two-way ANOVA, with termite species and dog identity as class variables. Means were separated by Student-Newman-Keuls tests ($P = 0.05$; SAS Institute 2001).

Responses to Non-Termite Material. The same experimental design described above was also used to test five dogs' reactions to termite-damaged wood, American cockroaches, and Florida carpenter ants. For this experiment, either one piece of termite-damaged wood, American cockroach adults ($n = 6$) of mixed age and sex, or Florida carpenter ant workers ($n = 118$) were placed in PVC containers. In this experiment "no indication" was defined as dog not responding to termite-damaged wood, American cockroaches, carpenter ants, or empty PVC containers. "False positive" was defined as the dog responding to non-termite material. Percentages of no indications and false positives were rank-transformed (Conover and Iman 1981). Each response variable was subjected to a two-way ANOVA, with non-termite test material and dog identity as class variables. Means were separated by Student-Newman-Keuls tests ($P = 0.05$; SAS Institute 2001).

Results

Detection of Various Numbers of Eastern Subterranean Termites. Dogs trained daily for 3 wk to 3 mo were able to accurately locate Eastern subterranean termite workers in 95.93% (Table 1) of PVC containers for all termite groups tested. For positive indications, the interaction between the main effects (dog identity and termite numbers) was not significant (df = 10; $F = 0.60$; $P = 0.8155$). There was also no significant difference between individual dog's ability to positively indicate the presence of termites (df = 5; $F = 0.99$; $P = 0.4248$; Table 1). Also, positive indications to varying densities (40, 80, and 160) of termites were not significantly different (df = 2; $F = 1.49$; $P = 0.2266$; Table 2).

Dogs were also able to discriminate containers with termites from empty containers, falsely indicating the presence of termites in only 2.69% (Table 1) of the empty containers. For false positives, the interaction between the main effects (dog identity and termite numbers) was not significant (df = 10, $F = 0.76$, $P = 0.6712$). However, there was a significant difference between individual dogs' responses to empty PVC containers (df = 5; $F = 2.41$; $P = 0.0371$; Table 1). Dog E had a significantly lower proportion of false positives than Dog D.

Detection of Five Species of Termites. Once trained with Eastern subterranean termites, the dogs' ability to locate four other species of termites was tested. The dogs reliably located termites in 96.67% of the containers (positive indications). The dogs responded to 1.73% of the empty containers (false indications). After training and testing with Eastern subterranean termites, the dogs' ability to reliably locate termites (positive indications) did not significantly increase or decrease when testing was conducted with Eastern subterranean, Formosan subterranean, or powderpost termites. For positive indications, the interaction between the main effects (dog identity and termite species) was not significant (df = 16; $F = 0.93$; $P = 0.5307$); however, false positives (df = 16; $F = 2.44$; $P = 0.0016$) were significantly affected. Individual dogs did not differ in their ability to locate Eastern subterranean,

Table 1. Mean percentage of positive indications and false positives by canine termite detectors when allowed to inspect empty containers or containers with termites

Dog	Positive indications[a] (mean % ± SE)	False positives[b] (mean % ± SE)
A	95.56 ± 3.11a	2.22 ± 1.07ab
B	95.56 ± 3.11a	3.33 ± 1.28ab
C	91.11 ± 4.29a	3.89 ± 1.37ab
D	95.56 ± 3.11a	5.56 ± 1.93a
E	100 ± 0.0a	0.0 ± 0.0b
F	97.78 ± 2.22a	1.11 ± 0.78ab
Mean	95.93 ± 1.21	2.69 ± 0.51

[a] Positive indication = response to container with Eastern subterranean termites.

[b] False positives = response to containers without Eastern subterranean termites.

Means within a column followed by the same letter are not significantly different ($P = 0.05$; Student-Newman-Keuls on rank transformed data; SAS Institute 2001).

Table 2. Mean percentage of positive indications and false positives by canine termite detectors when allowed to inspect empty containers or containers with 160, 80, and 40 Eastern subterranean termites

No. of Eastern subterranean termites	No. of dogs tested	Positive indications[a] (mean % ± SE)	False positives[b] (mean % ± SE)
160	6	98.89 ± 1.11a	2.22 ± 0.75a
80	6	94.44 ± 2.43a	2.22 ± 0.85a
40	6	94.44 ± 2.43a	3.61 ± 1.01a

[a] Positive indication = response to container with Eastern subterranean termites.

[b] False positives = response to containers without Eastern subterranean termites.

Means within a column followed by the same letter are not significantly different ($P = 0.05$; SAS Institute 2001).

Table 3. Mean percentage of positive indications and false positives by canine termite detectors when allowed to inspect empty containers or containers with varying species of termites

Termite species	Number of dogs tested	Positive indications[a] (mean % ± SE)	False positives[b] (mean % ± SE)
Eastern subterranean	6	94.44 ± 2.43ab	2.22 ± 0.85a
Dark southern subterranean	6	100 ± 0.0b	2.50 ± 0.89a
Formosan subterranean	6	98.89 ± 1.11b	1.39 ± 0.61a
Powderpost	6	97.33 ± 1.87b	1.33 ± 0.65a
Drywood	6	88.89 ± 4.74a	0.56 ± 0.56a
Mean	—	96.67 ± 0.91	1.73 ± 0.35

[a] Positive indication = response to container with termites.

[b] False positives = response to containers without termites.

Means within a column followed by the same letter are not significantly different ($P = 0.05$; Student-Newman-Keuls on ranked transformed data; SAS Institute 2001).

dark southern subterranean, Formosan subterranean, or powderpost termites (positive indications; df = 5; $F = 1.05$; $P = 0.3893$). However, the dogs' ability (positive indications) to reliably locate southeastern drywood termites was significantly lower than for the dark southern subterranean, Formosan subterranean, and powderpost termites (df = 4; $F = 2.88$; $P = 0.0227$; Table 3).

Responses to Non-Termite Material. Responses to termite-damaged wood, American cockroaches, and Florida carpenter ants from dogs trained with Eastern subterranean termites were tested by all dogs except Dog A. The rate of false positives for dogs trained with Eastern subterranean termites was 25.33% when termite-damaged wood was tested, 6.67% for American cockroaches, and 2.67% for carpenter ants. The dogs' rate of false positive responses to termite-damaged wood was significantly higher than their rate of false positive responses to American cockroaches and Florida carpenter ants (df = 2; $F = 15.30$; $P < 0.0001$; Table 4). The significantly higher rate of false positives to termite-damaged wood was attributed to Dog B, who was trained with a mixture of Eastern subterranean termites and termite-damaged debris. Dog B had a significantly higher rate of indications to termite-damaged wood than the other four dogs (df = 8; $F = 5.85$; $P < 0.0001$; Table 5).

Table 4. Mean percentage of no indications and false positives by canine termite detectors when allowed to inspect containers with termite-damaged wood, American cockroaches, or Florida carpenter ants

Material or insect	Number of dogs tested[a]	No indications[b] (mean % ± SE)	False positives[c] (mean % ± SE)
Termite-damaged wood	5	74.67 ± 5.06a	25.33 ± 5.06a
American cockroach	5	93.33 ± 2.90b	6.67 ± 2.90b
Florida carpenter ant	5	97.33 ± 1.87b	2.67 ± 1.87b

[a] Dog A was not tested.

[b] No indication = no response to containers with termite-damaged wood, American cockroaches, or Florida carpenter ants.

[c] False positives = response to containers with termite-damaged wood, American cockroaches, or Florida carpenter ants.

Means within a column followed by the same letter are not significantly different ($P = 0.05$; Student-Newman-Keuls on ranked transformed data; SAS Institute 2001).

Discussion

The value of detector dogs is defined by their ability to locate hidden objects when the target odor is present and to not respond when the target odor is not present. Several studies have documented the accuracy of scent detection dogs trained to locate narcotic constituents and insects. Dogs tested with methyl benzoate, a degradation product of cocaine hydrochloride, at concentrations of ≥50 ppb had a 90% positive indication rate and 9.6% false positive rate (Waggoner et al. 1997). Wallner and Ellis (1976) successfully trained three German shepherd dogs to locate gypsy moth, *Lymantria dispar* (L.), egg masses with a 95% positive indication rate. Welch (1990) trained a German wirehaired pointer dog to locate screwworms, *Cochliomyia hominivorax* (Coquerel), with a 99.7% positive indication rate. The positive indication rate for dogs trained to detect termites was 96%, which was similar to previous studies. Therefore, it is not unreasonable to expect a properly trained dog to meet a minimum acceptable standard with a positive indication rate of ≥90% and a false positive rate of ≤10%.

However, other studies have documented positive indication rates <90%. Jack Russell Terriers trained and deployed to locate brown tree snakes in shipping cargo on Guam had a positive indication rate of 70–80% (Engeman et al. 1998). The lower rates of positive indications observed by Engeman et al. (1998) could have resulted from several factors not defined in the Materials and Methods, which include the amount of maintenance training, length of search time, and environmental influences (Dravnieks 1975, Moulton 1975b, Wallner and Ellis 1976, Welch 1990, Johnston et al. 1993, Prestrude and Ternes 1998, Sandia National Laboratories 1998). Welch (1990) ensured search proficiency at >99% by daily maintenance training. Sandia National Laboratories (1998) notes scent detection dogs can search for 40–60 min before search proficiency decreases significantly, but providing a rest period maintains search proficiency. Environmental influences such as handler error, temperature extremes, and wind speed can also decrease the accuracy of dogs (Dravnieks 1975, Moulton 1975b, Johnston et al. 1993, Sandia National Laboratories 1998). The positive indication rate in our study was possible because each dog received two training sessions daily to maintain accuracy, and the length of time each dog was tested was kept under 40 min to eliminate fatigue from affecting their ability to detect termites. To eliminate environmental influences, a single blind study was used to eliminate handler error, and testing was not conducted during extremes of temperature or wind speed.

High false positive rates may result from using cross-contaminated training materials containing both target odor and nontarget or extraneous odor (United States Customs Service 1979, Hallowell et al. 1997). Lewis et al. (1997) observed high false positive rates

Table 5. Mean percentage of no indications and false positives by canine termite detectors when led by containers with termite-damaged wood

Training material	Dog[a]	n	No indications[b] (mean % ± SE)	False positives[c] (mean % ± SE)
Termites, wood, and debris	B	15	26.67 ± 11.82a	73.33 ± 11.82a
Termites only	C	15	100.00 ± 0.00b	0.00 ± 0.00b
Termites only	D	15	80.00 ± 10.69b	20.00 ± 10.69b
Termites only	E	15	93.33 ± 6.67b	6.67 ± 6.67b
Termites only	F	15	73.33 ± 11.82b	26.67 ± 11.82b

[a] Dog A was not tested.

[b] No indication = no response to containers with termite-damaged wood.

[c] False positives = response to containers with termite-damaged wood.

Termites, Eastern subterranean termites.

Means within a column followed by the same letter are not significantly different ($P = 0.05$; Student-Newman-Keuls on ranked transformed data; SAS Institute 2001).

(28%) that were not repeated in our study. Training methods and materials for the dogs used in the Lewis et al. (1997) study were not included. Training with contaminated materials may be the cause of the high rate of false positives. Our study, with the exception of Dog B, prevented contamination with nontarget or extraneous odors by aspirating the termites from the damaged material, possibly reducing the number of false positives. Dog B was 2 yr older than the other dogs and was initially trained on termites and wood debris before the study began, but maintenance training during the study used only termites.

Target odors that meet or exceed a threshold concentration will elicit a response from dogs trained to respond to that odor (Moulton 1975a, b, Waggoner et al. 1997, Johnston et al. 1998). Lewis et al. (1997) reported a positive indication rate of only ≈60% for dogs tested with five termites compared with a positive indication rate of ≈98% when termite numbers were increased from 5 to ≥50. The results from our study are similar to Lewis et al. (1997) with ≥50 termites. We did not test the dogs' ability to locate <40 termites because termites rarely forage in small numbers and can have foraging populations of ≈0.2–5.0 million individuals (Su et al. 1993).

Dogs trained with a particular target odor will respond to all substances that contain that target odor in concentrations equal to or greater than the dogs' odor detection threshold for that odor. The ability of dogs to locate four additional species of termites, after being trained with Eastern subterranean termites, suggests the dogs are detecting a common odor among the species of termites used in this study. This common odor could be cuticular components, which are common among closely related species of termites (Howard et al. 1982, Bagneres et al. 1990, 1991), or gases such as methane, which is abundantly emitted from termite colonies (LaFage and Nutting 1978, Zimmerman et al. 1982, Collins et al. 1984, Hackstein and Stumm 1994, Lewis et al. 1997), and carbon dioxide (Hoffman and Downer 1974, Lewis et al. 1997, Vogt and Appel 2000).

Our study has shown that dogs can be trained to reliably locate native subterranean with positive indication rates ≥90% and false positive rates ≤10%. The olfactory threshold for dogs trained to locate termites is <40 termites. The dogs tested demonstrated that, once trained to locate Eastern subterranean termites, they will also locate Formosan subterranean, drywood, and powderpost termites. Dogs can also discriminate termites from other orders of insects and termite-damaged wood. Although termites have a cryptic lifestyle, trained dogs are capable of detecting infestations by locating their signature odor.

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References Cited

Bagneres, A., J. L. Clement, M. S. Blum, R. F. Severson, C. Joulie, and C. Lange. 1990. Cuticular hydrocarbons and defensive compounds of *Reticulitermes flavipes* (Kollar) and *R. santonensis* (Feytaud): polymorphism and chemotaxonomy. J. Chem. Ecol. 16: 3213–3245.

Bagneres, A., A. Killian, J. L. Clement, and C. Lange. 1991. Interspecific recognition among termites of the genus *Reticulitermes:* Evidence for a role for the cuticular hydrocarbons. J. Chem. Ecol. 17: 2397–2420.

Collins, N. M., T. G. Wood, P. R. Zimmerman, J. P. Greenberg, and J.P.E.C. Darlington. 1984. Termites and atmospheric gas production. Science. 224: 84–86.

Conover, W. J., and R. L. Iman. 1981. Rank transformations as a bridge between parametric and non parametric statistics. Am. Statist. 35: 124–129.

Cornelius, M. L., and J. K. Grace. 1996. Effect of two ant species (Hymenoptera: Formicidae) on the foraging and survival of the Formosan subterranean termite (Isoptera: Rhinotermitidae). Environ. Entomol. 25: 85–89.

Cornwell, P. B. 1968. The cockroaches, vol. I. Hutchinson & Co., London, United Kingdom.

Dravnieks, A. 1975. Instrumental aspects of olfactometry, pp. 1–61. *In* D. G. Moulton, A. Turk, and J. W. Johnston Jr. (eds.), Methods in olfactory research. Academic, New York.

Engeman, R. M., D. S. Vice, D. V. Rodriquez, K. S. Gruver, W. S. Santos, and M. E. Pitzler. 1998. Effectiveness of the detector dogs used for deterring the dispersal of brown tree snakes. Pac. Conserv. Biol. 4: 256–260.

Forschler, B. T. 1999. Biology of subterranean termites of the genus *Reticulitermes.* Part II: National Pest Control Association research report on subterranean termites. National Pest Control Association Publications, Dunn Loring, VA.

Hackstein, J.H.P., and C. K. Stumm. 1994. Methane production in terrestrial arthropods. Proc. Nat. Acad. Sci. USA. 91: 5441–5445.

Hallowell, S. F., D. S. Fischer, J. D. Brasher, R. L. Malone, G. L. Gresham, and C. Rae. 1997. Effectiveness of quality control aids in verifying K-9 team explosive detection performance. Proc. SPIE. 2937: 227–234.

Hoffman, A. D., and R. H. Downer. 1974. Evolution of $^{14}CO_2$ from 1-^{14}C acetate in the American cockroach, *Periplaneta americana.* Comp. Biochem. Physiol. 48: 199–204.

Howard, R. W., C. A. McDaniel, D. R. Nelson, G. J. Blomquist, L. T. Gelbaum, and L. H. Zalkow. 1982. Cuticular hydrocarbons of *Reticulitermes virginicus* (Banks) and their role as potential species- and caste-recognition cues. J. Chem. Ecol. 8: 1227–1239.

Johnston, J. M., L. J. Meyers, P. Waggoner, and M. Williams. 1993. Determination of canine thresholds using operant laboratory methods. Proc. SPIE. 2092: 238–243.

Johnston, J. M., M. Williams, L. P. Waggoner, C. C. Edge, R. E. Dugan, and S. F. Hallowell. 1998. Canine detection odor signatures for mine-related explosives. Proc. SPIE. 3392: 490–501.

LaFage, J. P., and W. L. Nutting. 1978. Nutritional dynamics in termites, pp. 165–232. *In* M. V. Brian (ed.), Production ecology of ants and termites. Cambridge University Press, London, United Kingdom.

Lewis, V. R., C. F. Fouche, and R. L. Lemaster. 1997. Evaluation of dog-assisted searches and electronic odor devices for detecting western subterranean termite. For. Prod. J. 47: 79–84.

Mauldin, J. K. 1986. Economic importance and control of termites in the United States, pp. 138–141. *In* S. B. Vinson (ed.), Economic impact and control of social insects. Praeger Publishers, New York.

Moulton, D. G. 1975a. Factors influencing odor sensitivity in the dog. Grant AFOSR-73-2425. Air Force Office of Scientific Research, Bolling AFB, Washington, DC.

Moulton, D. G. 1975b. Laboratory methods for obtaining olfactory discrimination in rodents, pp. 1–32. *In* D. G. Moulton, A. Turk, and J. W. Johnston Jr. (eds.), Methods in olfactory research. Academic, New York.

Potter, M. F. 1997. Termites, pp. 233–333. *In* S. A. Hedges (ed.), Handbook of pest control: the behavior, life history, and control of household pests. Mallis Handbook & Technical Training Company, Cleveland, OH.

Powell, T. E. 2000. Eastern subterranean termite (Isoptera: Rhinotermitidae) tunneling in soil treated with non-repellant termiticides. M. S. thesis, University of Florida, Gainesville.

Prestrude, A. M., and J. W. Ternes. 1994. Optimising substance detection by integration of canine-human team with machine technology. Proc. SPIE. 2093: 633–643.

SAS Institute. 2001. PROC user's manual, version 6th. SAS Institute, Cary, NC.

Scheffrahn, R. H., W. P. Robbins, P. Busey, N. Y. Su, and R. K. Mueller. 1993. Evaluation of a novel, hand-held, acoustic emissions detector to monitor termites (Isoptera: Kalotermitidae, Rhinotermitidae) in wood. J. Econ. Entomol. 86: 1720–1729.

Scheffrahn, R. H., N. Y. Su, and P. Busey. 1997. Laboratory and field evaluations of selected chemical treatments for control of drywood termites (Isoptera: Kalotermitidae). J. Econ. Entomol. 90: 492–502.

[SNL] **Sandia National Laboratories. 1998.** Explosives detection equipment. Sandia National Laboratories, Albuquerque, NM.

Su, N.-Y. 1991. Termites of the United States and their control. SP. World. 17: 12–15.

Su, N. -Y., and R. H. Scheffrahn. 1990. Economically important termites in the United States and their control. Sociobiology. 17: 77–94.

Su, N. -Y., P. M. Ban, and R. H. Scheffrahn. 1993. Foraging populations and territories of the eastern subterranean termite (Isoptera: Rhinotermitidae) in southeastern Florida. Environ. Entomol. 22: 1113–1117.

[USCS] **United States Customs Service. 1979.** U.S. Customs narcotics detector dog training. U.S. Customs Service, Washington, DC.

Vogt, J. T., and A. G. Appel. 2000. Discontinuous gas exchange in the fire ant, *Solenopsis invicta* Buren: caste differences and temperature effects. J. Insect Physiol. 46: 403–416.

Waggoner, L. P., J. M. Johnston, M. Williams, J. Jackson, M. Jones, T. Boussom, and J. A. Petrousky. 1997. Canine olfactory sensitivity to cocaine hydrochloride and methyl benzoate. Proc. SPIE. 2937: 216–226.

Wallner, W. E., and T. L. Ellis. 1976. Olfactory detection of gypsy moth pheromone and egg masses by domestic canines. Environ. Entomol. 5: 183–186.

Welch, J. B. 1990. A detector dog for screwworms (Diptera: Calliphoridae). J. Econ. Entomol. 83: 1932–1934.

Zimmerman, P. R., J. P. Greenberg, S. O. Wandiga, and P. J. Crutzen. 1982. Termites: a potentially large source of atmospheric methane, carbon dioxide, and molecular hydrogen. Science. 218: 563–565.

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