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Fear of noises affects canine problem solving behavior and locomotion in standardized cognitive tests

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ABSTRACT

As part of a larger problem solving study, 22 dogs who were identified by owners/clients as reacting to noise and 13 identified by owners/clients as not reacting to noise that had been previously compared for auditory function were compared with respect to their reported noise reactions, performance on a puzzle box test, response to a provocative noise recording, and movement. Each dog was evaluated using a standardized, validated, semi-quantitative objective questionnaire from which an Anxiety Intensity Rank (AIR) score was calculated. AIR score calculations reflect the number of categories of noise to which the dog reacts, the behaviors exhibited, and the intensity of the reaction. Each dog underwent a 13 item problem-solving test (The Canine Intelligence Test Protocol; CITP) designed to evaluate 4 standardly evaluated cognitive domains. We report on two of the 13 tests – the puzzle box test and the provocative noise test – for this group of dogs. During testing most dogs wore collars containing accelerometers using custom firmware which provided second-by-second 3D movement data. AIR scores for the 2 groups differed significantly (Welch's t tests; $t = 4.34$, $df = 19.23$, $P < 0.0004$), although the affected group was only mildly affected. Affected dogs took longer to solve the tasks and, overall, did more poorly ($P < 0.5$). Accelerometry revealed that during testing, movements of affected dogs were more erratic, less continuous and subject to greater extreme deviations and longer pauses than were the movements of unaffected dogs. Even dogs mildly affected with fear of noises differed from unaffected dogs, and performed more poorly on problem-solving tests possibly, in part, because their movements were characterized by a high degree of physical and behavioral/emotional reactivity. Reactions to noise affect how these dogs move, which may affect every investigatory and interactive aspect of their lives. Combining AIR scores with movement measures may be a useful method to assess welfare in pet dogs.

1. Introduction

Distressed reactions to noise, ranging from alterations in attentiveness through fears and phobias, are common pathological behavioral conditions in pet dogs. Many surveys report that up to 50% of dogs may be affected by some extreme reaction to some noise during their lifetime (Blackshaw et al., 1990; Dale et al., 2010; Blackwell et al., 2013; Storengen and Lingaas, 2015; Tiira and Lohi, 2015, 2016). True prevalence levels are unknown for any population (although see Dinwoodie et al., 2019). Reactions are most commonly reported for storms, fireworks and guns, but noises associated with vehicles, machines, alarms, et cetera can also trigger fearful, anxious or phobic responses in dogs (McCobb et al., 2001; King et al., 2003; Ley et al., 2007).

A number of terms are often used to describe an adverse reactive, fearful or phobic response, including noise aversion, noise fear, noise stress, storm or thunderstorm phobia and noise sensitivity. Criteria for labeling a dog 'noise reactive' or 'phobic' or any of these other terms are not usually included in most studies (but see Overall et al., 2001; Dreschel and Granger, 2005; Overall et al., 2016; Scheifele et al., 2016), nor are the range of behaviors potentially displayed by the afflicted dog often noted (but see Overall et al., 2001; Crowell-Davis et al., 2003; Tiira and Lohi, 2014, 2016; Overall et al., 2016). Diagnostic criteria require that noise phobic dogs exhibit a profound, non-graded, extreme response to noise, manifest as intense avoidance, escape, or anxiety and associated with the sympathetic branch of the autonomic nervous system (Overall et al., 2001). Dogs who are continuously and characteristically distressed when exposed to specified noises, including

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storms, but who do not meet the criteria for a 'phobia' may be classified as 'reactive' (Overall, 2013) or 'sensitive' (Sherman and Mills, 2008; Tiira and Lohi, 2016; Franzini de Souza et al., 2018; Lopes Fagundes et al., 2018).

Confusingly, 'noise sensitivity' is defined differently both in audiology and in human medicine/psychiatry. In audiology, 'noise sensitivity' is commonly used to describe the range of upper and lower limits of auditory capability (a sensitivity to certain frequencies and volume ranges of sounds), and often refers to hyperacusis (Eggermont, 2013). 'Noise sensitivity' has also been defined in human 'annoyance' contexts: sensitivity to annoyance (expression of more annoyance than those around you for any given level of noise) and general susceptibility to noise (annoyance over a wide range of noises). In human psychiatry, the term 'noise sensitivity' has been used to characterize a relatively stable personality trait, independent of noise exposure (Belojevic et al., 2003; Stansfeld, 1996; Stansfeld et al., 1985, 2000; Milenković and Paunović, 2015).

We lack data to support any of these definitions for 'noise sensitivity' in dogs, so for those individuals who do not meet the diagnostic criteria for phobia, we have chosen to use the term 'noise reactive', which implies no underlying mechanism. This decision acknowledges that multiple underlying mechanisms may be contributory to the pathology, and uses 'reactive' within the context it is commonly used in experimental psychology and psychiatry to reflect a range of responses to a number of stimuli, which is applicable here (Epstein et al., 1978; Siniscalchi et al., 2013).

The behavioral signs of distress associated with noise reactivity and phobia may include trembling, freezing, panting, social withdrawal, pacing, salivating, urinating, defecating, destruction (with or without self-injury), hiding/crouching and escape/running away behaviors (Shull-Selcer and Stagg, 1991; Beerda et al., 1997, 1998; Overall et al., 2001; Crowell-Davis et al., 2003; Hydbring-Sandberg et al., 2004; Sherman and Mills, 2008; Sheppard and Mills, 2003; Tiira and Lohi, 2016), which are all classic responses to anxious states.

Noise stress (105 dB SPL) has been shown to impair higher order, pre-frontal cortex, delayed–response performance in cognitive trials in monkeys (Arnsten and Goldman-Rakic, 1998). Exposure to acute or chronic noise, itself, can distract from cognitive tasks (Söderlund et al., 2010). Noise reactivity and phobia interferes with performance in working dogs (Tomkins et al., 2011, 2012; Gazzano et al., 2007; Batt et al., 2008; Asher et al., 2013; Arvelius et al., 2014; Sherman et al., 2014; Evans et al., 2015), and interferes routine patterns of daily life in pet dogs (Overall et al., 2001, 2016).

We asked whether noise-reactivity, as scored from client reports using a standardized, validated questionnaire (Working Dog Questionnaire – PET version; WDQ-PET), was reflected in performance on the puzzle box test, one of 13 tests (Canine Intelligence Test Protocol; CITP) we used to evaluate the 4 commonly recognized cognitive domains (Social learning; Spatial learning/memory; Executive function/sustained attention/perseverance/inhibition; Spontaneous behavior (Lezak et al., 2004; Strauss et al., 2006; Gabowitz et al., 2008)). We also evaluated whether client reports and calculated Anxiety Intensity Rank (AIR) scores matched behavioral responses during a test using a custom designed 3.5 min noise recording. We hypothesized that reactivity to noise would adversely affect the puzzle box and noise test performance, and that client evaluations would contain false negatives, but no false positives, as has been shown elsewhere (Overall et al., 2016; Bellamy et al., 2018).

2. Materials and methods

2.1. Study design

We reported on the pet dogs used in this study in an earlier paper where we asked whether auditory function, including auditory middle-latency response (AMLR), a measure of higher order cortical function, differed between dogs that were affected with noise reactivity and those that were not (Scheifele et al., 2016). These dogs were participants in a large study comparing problem solving ability of working dogs to that of pet dogs.

All dogs in all studies were assessed using either the Working Dog Questionnaire (WDQ) or the WDQ-PET and a battery of 13 problem solving tests (CITP). The WDQ/WDQ-PET seeks information on source, demographics, early history, exposure, behavioral history and behavioral responses to standardized circumstances, as evaluated through a series of objective questionnaires used in clinical situations. The CITP is designed to identify how dogs use information from the environment, including human and nonhuman signals, to solve various problems across all 4 cognitive domains (Overall and Dunham, 2013; Scheifele et al., 2016; Bryant et al., 2018).

Dogs recruited for the pet dog study, from which the subset of dogs reported on here were derived, were recruited through local trainers, veterinarians and dog training or sport clubs and could be any age or breed, although puppies at least 8 weeks of age and breeds that work (Labrador retrievers, German shepherds, Border collies, Australian shepherds, Jack Russell terriers, and Belgian malinois) were especially solicited. Aggression and fear were exclusion criteria. We ensured that these dogs were excluded using client responses to the WDQ-PET, which includes an aggression and fear screen, and visual inspection of the dog at the test. Because the effects of reactivity to noise on performance was one of the foci of the study, we specifically solicited dogs who reacted with concern to common environmental noises (storms, guns, fireworks). A subset of those dogs, determined by timing and funding, comprise the dogs in this study and the earlier auditory study (Scheifele et al., 2016).

Of 39 dog dogs available, 35 dogs of 13 breeds (Labrador retriever, golden retriever, cocker spaniel, Jack Russell terrier, Australian shepherd, standard poodle, miniature dachshund, keeshond, bull terrier, German shepherd, basenji, borzoi, greyhound), 3 known breed mixes (French bulldog mix, Border collie x Labrador retriever x golden retriever mix) and 2 unknown breed mixes who had already undergone CITP testing, and whose owners were willing to have them undergo an hour long auditory test during a 6 week period, were easily handled and recruited for the auditory study (Scheifele et al., 2016). Of these 35 dogs, 22 were reported by the clients to react to noise and 13 were reported to not react to noise. For the dogs that were reported to react to noise, the mean age was 6.17 years, the median 5.08 years, the SD 3.38 years and the range 1.38–12.99 years. For the dogs that were reported to not react to noise, the mean age was 5.25 years, the median 5.92 years, the SD 3.97 years and the range 0.5–12.08 years.

2.2. Subjective assessment of behavioral responses to noise

All dogs had anxiety intensity ranks (AIRs scores) for noise calculated based a section of a much longer behavior and life-style questionnaire (WDQ-PET), completed by owners of all study dogs (Overall et al., 2006). We used this questionnaire to classify dogs as noise phobic or reactive or not reactive. The 11 behavioral signs evaluated within the questionnaire were salivate, defecate, tremble, urinate, vocalize, destroy, pace, escape, freeze, pant, and hide (includes crouching). Anxiety intensity rank (AIR) were calculated by multiplying the number of signs any dog showed by a weight determined by frequency of reaction, with the frequencies above receiving a weight of 4, 2.5, 1.5, 1, and 0, respectively, and summed for all provocative stimuli (see Supplemental materials).

2.3. CITP puzzle box testing

For the research reported here we evaluated 2 of the 13 CITP tests, one quantitative and one qualitative. The puzzle box test (test 11) evaluated 'boldness', tenacity and problem-solving style and had as its outcome measures number of successes of 3 tries to extract a tennis ball

Fig. 1. The puzzle box being used by a dog (not a dog reported on in this paper). Note the 9 holes on the top of the box that accommodate paws and mouths, and the 1 hole on the side through which the ball is initially rolled.

from a box in 5 min and time to extract the ball (quantitative measures).

For the puzzle box test, dogs were presented with a custom designed box built of finely finished ¼ inch (0.64 cm) Lexan that had 9 holes in the top and one on one side (Fig. 1). Two versions of the box were made, one each with medium (5 inch/12.7 cm diameter) or large sized (7 inch/17.8 cm diameter) top holes to accommodate jaw width. The box was placed on a marked, standardized spot on a yoga mat. While the dogs sat off-lead 2 m from the box, a researcher assistant calmly called the dog by name. Once the dog was looking at the assistant, she bounced a new, unused tennis ball 3 times. Upon catching it the final time, the assistant rolled the ball into the box from the end hole. She then stepped completely away from the box while saying, ‘Okay, go!’. At this point, the client, who had been gently manually restraining the sitting dog behind the marked start line, released the dog. The dog had 5 min to extract the ball from the box using any method. The test was repeated 3 times. All tests were videotaped using 2 stationary, tripod mounted, Sony Handicam video cameras, DCR-SR87. At the end of each test the dogs were told that they were good, leashed, and removed from the room until the room had been cleaned and set up for the next test. Boxes were sanitized between uses with medical grade, anti-viral and anti-bacterial sanitizing wipes (PDI Sani Cloths). Data collected included time for extraction (in seconds) and success/fail in ball extraction for the 3 tests. Dogs who did not complete extraction were given a score of 300 s. Dogs who refused to try or continue to try to extract the ball were labeled “na” (no score applicable). If the dog failed to show interest in or interact with the tennis ball, it was replaced with an equivalently sized food ball. All of the dogs discussed here used the tennis ball.

2.4. Activity/accelerometer testing

All dogs greater than 15 pounds (6.8 kg) and with necks at least 13 in. (33 cm) in circumference were fitted with a VOYCE band (i4C) which contained an accelerometer which they wore throughout testing. The accelerometer used custom firmware which provided second-by-second 3D movement data, integrated over every minute, allowing us to compare relative activity of the dogs during and across all tests. Accelerometer data were characterized by mean activity (milli g) and maximum deviations.

The puzzle box test was chosen as a benchmark for the present study because in a comparison of dozens of dogs across all 13 tests, this test best discriminated movement (standard deviation to median ratio) during each test (See explanation in Fig. 2) and involved a great range of behaviors and activities.

2.5. Objective assessment of behavioral responses to noise

For the noise test, clients sat facing away from the researchers on a chair placed on a large yoga mat in the middle of the room. Two Kongs were stuffed with food treats of the client’s choosing (whipped Philadelphia brand cream cheese, cooked and sliced Nathan’s all beef hot dogs, Maggio brand low fat mozzarella sticks, Merrick’s Texas Hold ‘Ems dehydrated lamb lung, JIF peanut butter). The dog was loose in the room. One stationery, tripod mounted video camera was focused on the client, mat and dog at the beginning of the test, and one was hand-held by a research assistant to follow the dog during the test. A custom made, 3.5 min noise recording was played through a Dell computer equipped with portable, USB connected speakers. Noises included a range of environmental sounds ranging from softly running water to a serious thunderstorm, fireworks, equipment and weapon noises, including those associated with rocket launchers. Loudness was measured at the computer between the speakers using an Extech Instruments Sound Level Meter (407730) and background noise in the room was measured each testing day.

Prior to starting the recording, the stuffed Kongs were placed on the yoga mat in front of the clients and the dogs were allowed to do whatever they wished for 1 min. After the 1 min baseline period, the recording was started at low volume. The first sounds were that of water running in a stream. The volume was increased until the dog began to show a change in behavior where they attended to the noise and/or showed signs of anxiety or distress. If that level was reached, the volume was extremely slowly decreased until the dog no longer reacted. This means that dogs who did not react experienced the recording at full volume, and that the occasional dog required that the recording was turned completely off prior to its completion. The noise exposure test had as its outcome measure the behavioral reaction to the recording (a qualitative measure).

All dogs were video recorded for the full 4.5 min (1 min no recording plus the 3.5 min recording) of the test. The background noise in the room during testing hours was routinely ∼56 dB SPL. The dB range of the recording had considerable dynamic range (81.2–105.4 dB SPL; 60–70 dB SPL is considered comfortable for normal conversation). It should be noted that this dB range is not what the dog or humans heard, but was the only standardization we could implement given the test constraints. The researcher administering the test and controlling the recording volume wore noise cancelling headphones (Bose). Videos were reviewed and, for the purposes of this study, dogs were classified only as reacting to the recording or not reacting to the recording. At the end of the test, the dogs were told they were good, petted, and had Voyce bands removed. As this was the last test in the 13-item sequence, they then were leashed and went home.

All Kongs and all tennis balls used were sent home with the dog. Yoga mats were changed between dogs and laundered at the end of every testing day.

2.6. Statistical tests and analysis

AIR scores, performance, reactivity to noise, and mean activity were analyzed using R (R Core Development Team, 2009) and https://www.socscistatistics.com.

Parametric procedures were used whenever the data met the assumptions of the test. Randomization (permutation) procedures (Good, 2005) were used to compute significance levels for all nonparametric comparisons to eliminate the need for distribution assumptions (e.g., normality). The significance levels for these tests were calculated on the basis of 10,000 permutations. All AIR score comparisons were done using Kruskal-Wallis, χ^2, Welch’s t and Fisher’s exact tests. Minimum time (of 3 attempts) to complete the box test as a function of mean activity was analyzed using linear regression. Time to complete the box test on the initial attempt as a function of mean activity was also analyzed using linear regression. Statistical significance for all

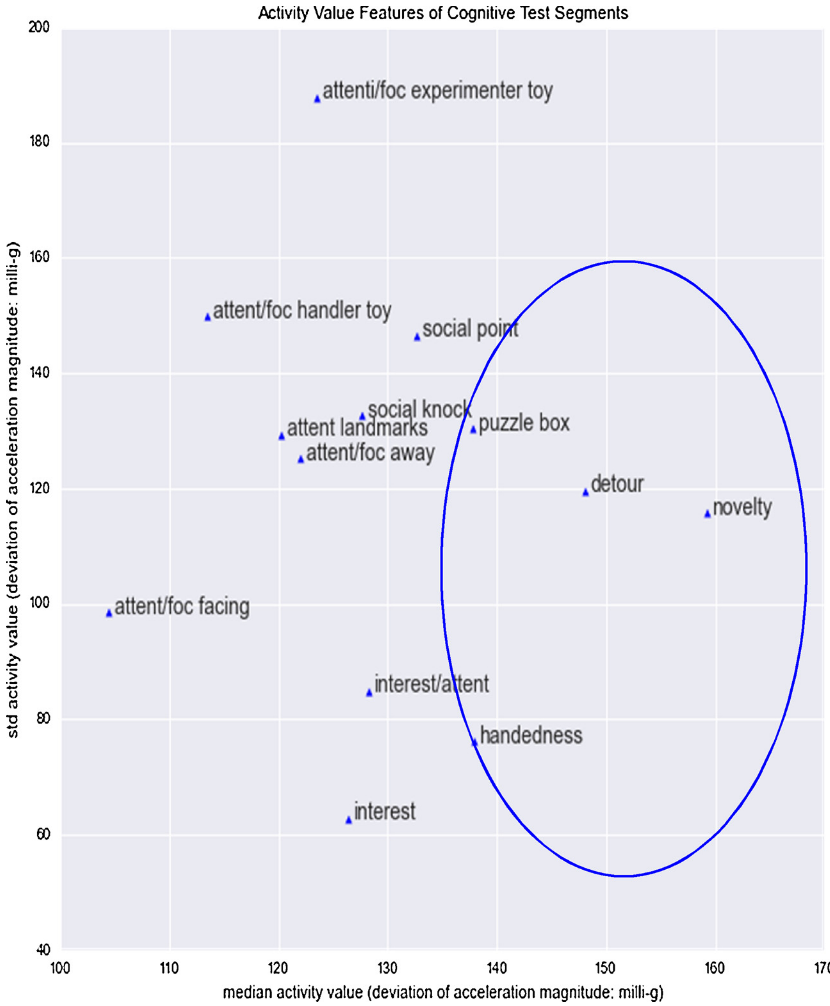

Fig. 2. Activity and standard deviation of activity values for the 13 test in the problem solving battery across all dogs who fit Voyce bands for all 13 tests. The X axis represents the median activity value (deviation in mill g) and the Y axis represents the standard deviation of the activity value in milli g. The 4 tests in the oblong do the best job of separating the performance of the dogs with respect to activity level (median activity). The puzzle box test is slightly preferred to the detour test for discriminating movement during performance because the standard deviation to median activity ratio is higher.

statistical tests was taken to be an attained *a priori* level of significance (p) of $\leq$ 0.05.

For analysis of acceleration values, Voyce data arrive as (x-,y-,z-) triples at a 30 Hz sampling rate in milli-g units. X, y and z are positions of the dog on an orthogonal grid. From these data an acceleration magnitude m can be computed as:

$$m(x, y, z) = \sqrt{x^2 + y^2 + z^2}$$

The second-by-second activity value is computed as the standard deviation of acceleration magnitude, at 30 Hz, for every 30 samples that arrive.

The fluidity metric of an acceleration magnitude time series is the proportion of seconds in the series where there is a change between successive states. Fluidity is measured as follows:

$$a_t = \sqrt{\sum_{t}^{t+30} \frac{(m_t - \bar{m})^2}{30}}$$

Where $\bar{m}$ is the mean acceleration magnitude for a given second. Higher scores are indicative of more divergent movements (e.g., less consistent, coordinated action).

3. Results

3.1. Analysis of AIR scores for dogs with auditory testing

Of the 35 dogs recruited from dogs already tested with the CITP, 22 were identified by clients completing the WDQ-PET as noise reactive and 13 were not. Of the 22 that were classified as noise reactive, 2 clients had said that their dogs did not react to noise upon enrollment but changed their minds once they completed the WDQ-PET with the detailed categories used to calculate AIR scores.

Of the 22 original noise reactive dogs, 5 were behaviorally too reactive to start or complete the auditory test (G test; P $<$ 0.03). Of the 13 non-noise reactive dogs, 1 had a disease that rendered the test unreliable (otitis media) and 1 dog's data had a significant recording artefact. Accordingly, 17 noise reactive dogs and 11 non-noise reactive dogs who had undergone the CITP also underwent auditory assessment (Fig. 3).

For dogs whose auditory ability was tested, dogs identified as affected by clients completing the WDQ-PET had a mean AIR score = 19.92 (N = 15; SD = 14.70; maximum score of 64 (maximum = 132 for the storm, fireworks and gun categories)) and unaffected dogs had a mean AIR score of 0.36 (N = 11; SD = 1.20) (Welch's *t-test*; t = 3.32022; p = 0.003; effect size/Hedges' g = 1.213912).

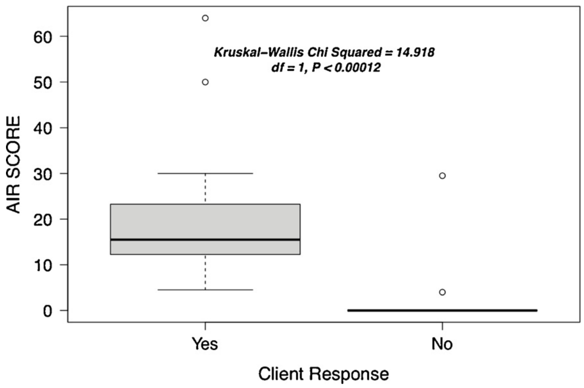

Fig. 3. Comparison of AIR scores based on *owner/client assessment* on questionnaire. The X axis is the binary client assessment about whether the dog reacted to noise. “Yes” means the dog was identified by the client as noise reactive (N = 22); “No” means the dog was identified by the client as not noise reactive (N = 17). The Y axis is the AIR score. The heavy lines represent the median; the whiskers represent 2 SD. Circles represent individual dogs that are outliers. “Yes” means the dog was identified by the client as noise reactive (N = 22); “No” means the dog was identified by the client as not noise reactive (N = 17).

3.2. Analysis of AIR scores for all dogs

AIR scores calculated for all dogs classified by the clients as reactive ranged from 1.5 to 64.0 with a mean of 17.45 (N = 22; SD = 17.68), and for non-reactive dogs ranged from 0 to 4.0 with a mean of 0.31 (N = 13, SD = 1.11) (t = 3.47833; p = 0.001; effect size/Hedges' g = 1.213912; Kruskal-Wallis Chi-squared = 14.918; $p < 0.0001$) (Fig. 3). The mean AIR scores of the non-reactive group based on the client completed WDQ-PET was low but not non-zero due to one dog who was said not to react to guns, storms or fireworks, but reacted to a house smoke alarm associated with the kitchen fan with a score of 4. The labeling this dog by the owner as non-reactive is likely a false negative (see Fig. 4).

When all dogs with non-zero AIR scores were considered noise-reactive, the mean AIR score was 16.91 (N = 23; SD = 17.74; range 1.5–64), compared with 0 for non-reactive dogs (N = 12; SD = 0) (Welch’s *t-test*; t = 3.32149; p = 0.002).

3.3. Analysis of AIR scores and reaction to the recording

The range of AIR scores for dogs who reacted to the recording (AIR = 1.5–64) mirrored those of noise reactive dogs who did not react to the recording (AIR = 3–64) suggesting that both groups were relatively mildly affected compared to clinical populations.

AIR scores were compared for dogs who reacted to the recording in the last test of the CITP and those who did not. The mean AIR score for dogs who reacted to the recording was 25.42 (N = 6; SD = 22.83). The mean AIR score for all dogs who did not react to the recording – including dogs with an AIR score of 0 - was 8.16 (N = 29; SD = 13.25). Dogs who reacted to the recording had significantly higher AIR scores when compared with those that did not react to the recording (Kruskal-Wallis Chi-square 5.1937, df = 1; $P < 0.023$) (effect size/Hedges' g = 1.143239)

(Fig. 5), when all dogs – including the dog not labeled as noise reactive by the client - were considered (see Fig. 5).

All dogs except one who reacted to the recording had been identified as noise reactive by clients. The dog who was not identified as such but who had a non-zero AIR score is likely a false negative. The AIR scores of dogs who reacted to the recording (mean AIR score = 25.42; N = 6; SD = 22.83) were statistically significantly higher than those for dogs identified as noise reactive (non-zero AIR score) who did not react to the recording (mean AIR score = 13.91; N = 17; SD = 14.91) (Kruskal-Wallis Chi squared = 16.05, df = 1, $P < 0.001$). The effect size here is smaller than for the comparison including unaffected dogs (effect size/Hedges' g = 0.671877), but still notable given the small dataset (Fig. 5).

When comparing those dogs who reacted to the recording with those who had a non-zero AIR score, in this sample, the specificity of the recording response as a test is 27.7%, the sensitivity is 100%, the negative predictive value (NPV) of the test is 42.86% and the positive predictive value (PPV) of the test is 100%. Without knowing true prevalence of noise reactivity in the overall population of dogs and recalling how we solicited these dogs, we cannot know whether our values are reflective of the population at large, but in this selected test population, prevalence of noise reactivity is 64.71%.

3.4. Puzzle box results – completion rate, time to completion and accelerometry results

Dogs were compared for their time to completion on their initial puzzle box attempt (Fig. 6) and on their fastest of 3 puzzle box attempts (Fig. 7). Of the 35 dogs recruited for the auditory component of the study 6 were too small to wear a Voyce band and 5 of these 6 dogs were noise reactive. Accordingly, data presented in Figs. 6 and 7 include only 17 noise reactive dogs. Noise reactive dogs were statistically less likely to complete 2/3 rounds of puzzle box testing (Yates corrected Chi-square = 6.4215; $p < 0.011$).

With respect to the slower dogs, of the 9 dogs who took 150 s or more to complete the puzzle box during the first attempt, 6 were noise reactive, and 3 were not (Fisher exact test 0.1059; $p > 0.05$). When the fastest of 3 trials were compared, 5/6 dogs taking 150 s or more were noise reactive (Fisher exact test 0.0276; $p < 0.05$). Dogs who could learn to do so became faster with experience, and dogs who were not noise reactive were statistically over-represented in this group, and success may help them more than it does noise reactive dogs (Fig. 7).

Dogs who solved the puzzle box quickly on the first or best trial were significantly more active than dogs who solved it slowly or not at all (Figs. 6 and 7; $p < 0.0001$ and $p < 0.0004$, respectively). Fast dogs with low activity were lucky in where the ball landed and simply plucked it from the box. Fast dogs with high activity had few to no breaks in their activity, had continuous activity with less erratic and more consistent movement and fewer deviations from the mean and extreme movements (Fig. 8). In other words, dogs who solved this test quickly and were not lucky did so by coordinating their movements to those of the ball. Dogs with AIR scores = 0 (non-noise reactive) demonstrated more continuous, coordinated movement than do dogs with AIR scores > 0 (Welch two sample *t-test*; t = −2.9227, df = 21.982, $P < 0.0079$) (Fig. 9). The per-subject fluidity metric shows that the puzzle box test is useful for measuring fluidity, and that fluidity reflects condition.

A. Accelerometry results across all tests for one dog with an AIR score of 0

4. Discussion

Problem solving ability is known to be affected by anxiety and fear. In dogs, separation anxiety/separation-related distress has been correlated with a negative cognitive bias (Mendl et al., 2010), and clinical anxieties have been shown to impair performance on solvable and insolvable tests (Passalacqua, Marshall-Pescini et al., 2013). The effects of noise, itself, may be important and somewhat separate from general fear. Noise reactivity affects the presentation of clinical signs of other conditions when co-morbid (Overall et al., 2001), but can also occur (Tiira and Lohi, 2016; Dinwoodie et al., 2019) and be inherited separately (Overall et al., 2016) from other conditions based in fear.

The sensation of sound/noise induces structural and functional changes in both the central auditory system and, relevant for this study, in regions involved in overall arousal and learning, including the

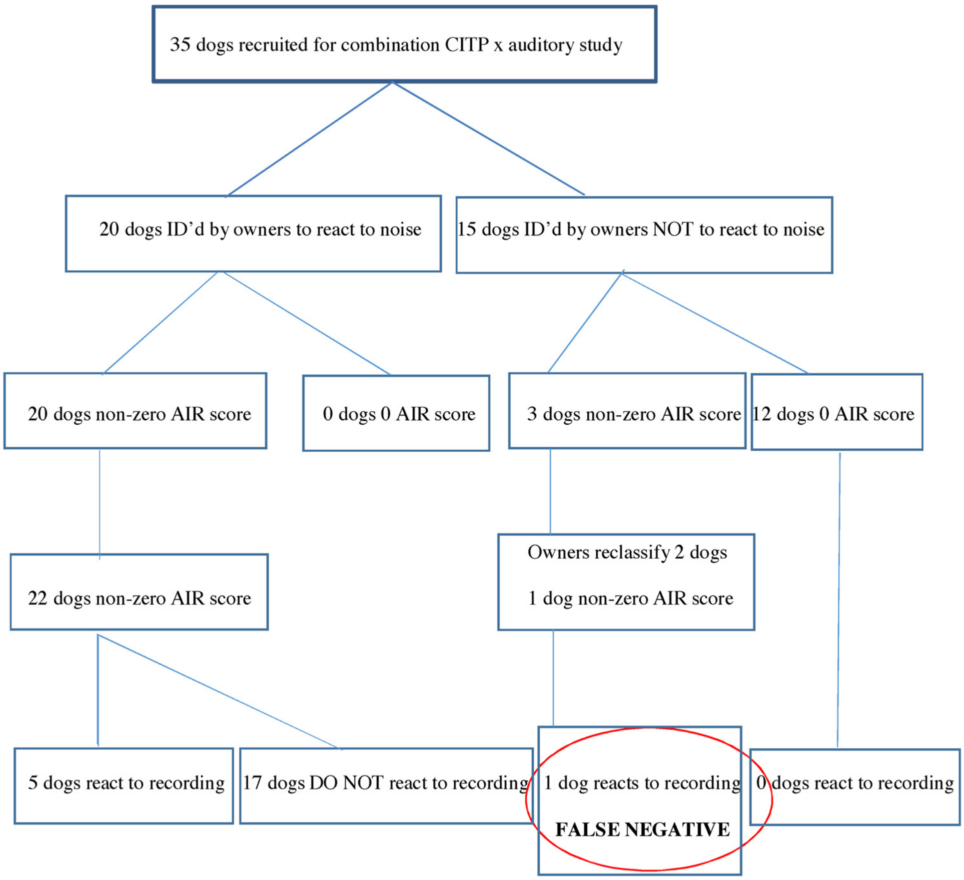

Fig. 4. The effect of the addition of the dog's reaction to the recording on the classification of dogs. One dog that the client classified as not reacting to noise ("No") did react to the recording and so was deemed a false negative. The client had noted that this dog reacted to only 1 class of an alarm, but to no other sounds. There were no alarms on the recording.

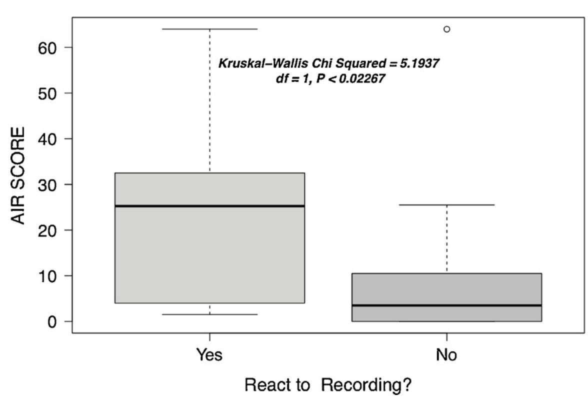

Fig. 5. Comparison of AIR score and reaction to recording for *all dogs* in the study, including those who had AIR scores of 0. The X axis is the binary response to the recording. "Yes" means the dog reacted to the recording (N = 6); "No" means the dog did not react to the recording (N = 29). The Y axis is AIR score. No dogs with an AIR score of zero reacted to the recording. Not all dogs with non-zero AIR scores reacted to the recording. The heavy lines represent the median; the whiskers represent 2 SD. Circles represent individual dogs that are outliers.

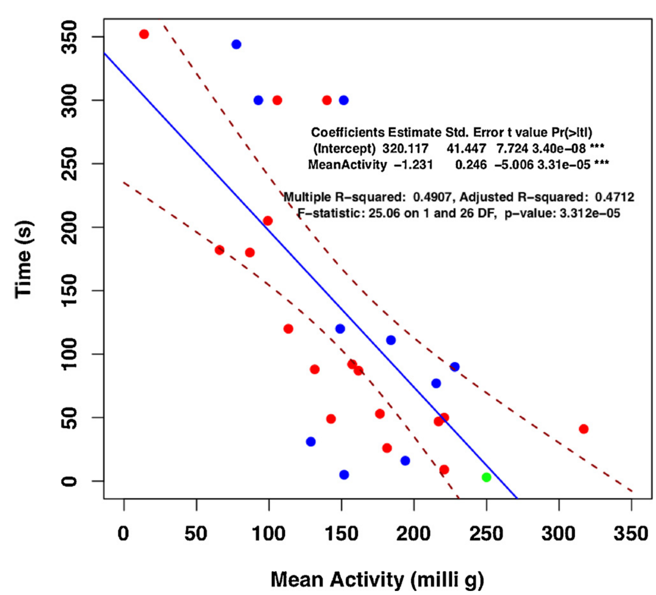

Fig. 6. Regression of time to completion in seconds (s) of the initial puzzle box attempt (Y axis) on mean activity (milli g) (X axis) for the first of 3 attempts to extract the ball from the puzzle box. The blue line is the regression line and the dashed red lines represent the 95% CI. Blue symbols indicate dogs for which owners indicated that their dogs did not react to noise on the questionnaire (N = 11). Red symbols indicate dogs for which owners indicated that their dogs did react to noise on the questionnaire (N = 17). The green symbol is the false negative (a dog that the owner indicated was only rarely reactive on the questionnaire (AIR score 4 for an alarm) but which reacted on the noise test). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

amygdala and hippocampus (Kraus and Canlon, 2012). If the noise response is perceived/processed by the individual as stressful, an amygdala-mediated release of stress hormones follows activation of the hypothalamic-pituitary-adrenal axis (Burow et al., 2005), resulting in the physical and physiological signs of distress. Babisch (2003) noted that noise activates sympathetic responses and stimulates epinephrine, norepinephrine and cortisol in laboratory dogs (Engeland et al., 1990). Exposure to acute or chronic noise, itself, can distract from cognitive tasks (Söderlund et al., 2010), and acute noise stress in humans has been shown to impair cognitive control (Banis and Lorist, 2012).

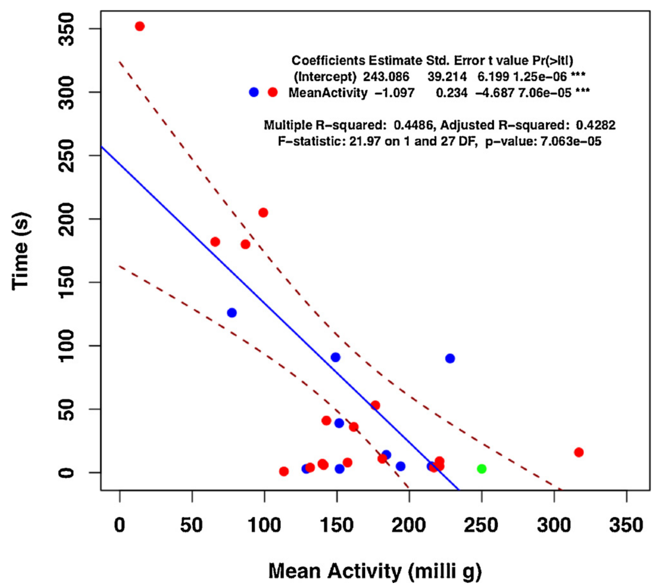

Fig. 7. Regression of time to completion in seconds (Y axis) on mean activity (millig) (X axis) for the fastest of 3 puzzle box attempts. The blue line is the regression line and the dashed red lines represent the 95% CI. Symbols/sample sizes are as in Fig. 6. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

In this study AIR scores were calculated based on client reports using a standardized and validated noise questionnaire embedded in the WDQ-PET (Overall et al., 2006, 2016; Tiira and Lohi, 2016; Bellamy et al., 2018). It is notable that two clients (~10%) who responded 'no' to a 'yes/no/unknown' question, changed to 'yes' when they could reflect on the affiliated behaviors and their frequencies across the contexts of noises queried. This result strongly suggests that veterinarians should be asking clients about specific contextual behavioral outcomes and frequencies and not rely on clients to make their own diagnoses (Hammerle et al., 2015). One dog whom the client classified as reacting only to an occasional household alarm noise, reacted profoundly to the recording. These results confirm our hypothesis that this questionnaire, based on client reports, can produce false negatives, but not false positives.

All dogs who reacted to the recording were identified as noise reactive, but not all identified noise reactive dogs reacted to the recording, likely reflecting the mild nature of the affliction in this population. Dogs who reacted to the recording had statistically significantly higher AIR scores than did the noise reactive dogs who did not respond adversely to the recording, validating the questionnaire to identify noise reactive dogs with AIR scores range in this study. The range of AIR scores for dogs who reacted to the recording (1.5–64) mirrored those of noise reactive dogs who did not react to the recording (3–64) suggesting that both groups were relatively mildly affected compared to clinical populations and that clients may not be recognizing all the signs of noise reactivity in their dogs, given the differential response.

The data from our study suggest that noise reactivity potentially adversely affects all aspects of a dog's life. In this study, which used AIR scores and exposure to a custom made recording of a range of noises, the dogs were mildly affected compared to those in clinical specialty populations. Yet, of the 22 dogs enrolled in the audiology portion of the study, 5 were too reactive to undergo testing with their owners present (Scheifele et al., 2016). It is important to adequately screen a dog's behavior at or before a veterinary consultation, so that their needs can be met and so that adequate prophylactic and interventional pharmaceutical treatment can be implemented to reduce fear during examination (Overall, 2017).

AIR scores differed significantly between noise reactive dogs and non-noise reactive dogs, and are a reliable and valid way to assess noise reactivity in dogs. Dogs with higher AIR scores could not tolerate the recording, suggesting that a repeated study of more profoundly affected dogs may yield more dramatic results.

Accelerometer data revealed that noise reactivity dogs had more periods of stillness, more erratic and less consistent movement and higher deviations from the mean in extreme movements when engaged in testing than did non-noise reactive dogs. A statistically significant number of dogs who were noise reactive could not complete 2/3 replications of the puzzle box test, a rare event for non-noise reactive dogs. When noise reactive dogs did complete the puzzle box test they did so, on average, more slowly. It is important to note that not all dogs like these tests and some non-reactive dogs were not truly interested in participating.

The dogs who were most successful in solving the puzzle box test had the ability to move deliberately and coordinate their movements with those of the ball. These dogs had more movements and more continuous and consistent movements as they interacted with the box. Non-noise reactive dogs were significantly more common in this performance group. This is an interesting finding given that during an active listening task in humans, functional segregation of whole brain networks change relative to the resting state, and the more modular the process, the more selective the information gleaned from the cues (Alavash et al., 2018). Such findings may further suggest that pathological responses to noise alter such functional segregation and impair other cognitive processes.

4.1. Study limitations

This is a small study. The dogs studied are unlikely to be representative of the dog population, as a whole, and are not a random sample of the pet population or of dogs who react to noise. Given the time commitment involved, the owners/clients may be more observant than average. If so, the logic that that veterinarians should take detailed, standardized behavioral histories at every visit (Overall, 2013) is even more compelling. Without elucidation of contextually relevant behavior patterns, using discrete categorization of behaviors and their frequencies, it is likely pet welfare suffers for lack of veterinary evaluation.

Because of the time period in which we were constrained to do the study, we chose dogs who had already undergone the CITP, were available during the required times and who were identified as simply affected with noise reactivity or not. We did not search for our most affected participants. Accordingly, we had a mildly affected population. It is entirely possible that the outcome would be different with a more severely affected population – for which AIR scores permit objective and valid assessment – but we would hypothesize that the direction of the findings would be the same, while the magnitude may differ. Our sample size was reduced due to loss of data due to dogs being too reactive to wear the Voyce band and due to equipment malfunction (Fig. 10). While effect sizes for our results are encouraging, this study should be viewed with caution.

4.2. Use of AIR scores

The AIR scores are a reliable and valid tool to evaluate noise reactivity in dogs, and we recommend routine use for all dogs. Dogs who reacted to the noise recording had higher AIR scores, on average, than did dogs with non-zero AIR scores who did not react to the recording, although the range of AIR scores did not differ. This finding may suggest that the types of noises to which dogs react may matter. Knowing that AIR score is associated with how dogs move and engage in problem solving tasks that require movement is evidence that this particular set of sensory-related fears affects canine behavior more globally than is usually appreciated. Any dog with any noise reactivity should be screened for cormorbid behavioral and medical conditions, since such

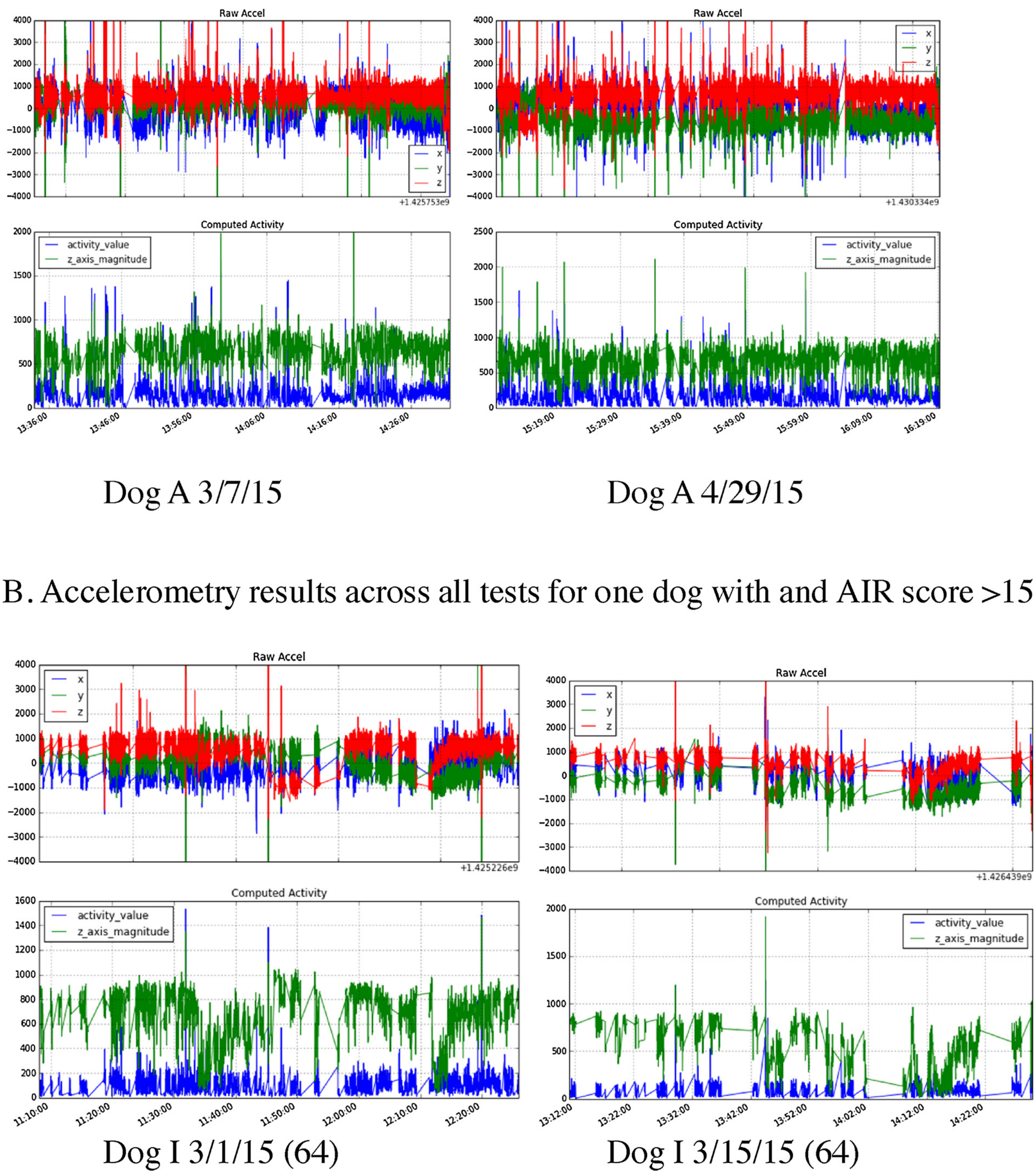

Fig. 8. Examples of movement patterns across all tests; A is a representative dog with an AIR score of 0; B is a representative dog with an AIR score > 15. For each of these dogs 2 sets of CITP accelerometer results are shown. The X axis is time by minute. The Y axis is activity counts summed over each minute. The top graph for each dog represents movement in 3 axes (X/blue and Y/green are both linear (back/forward and left/right) directions measured from the initial reference position at rest and Z/red represents vertical movement). These are the raw data. The bottom graphs show the average linear activity value (blue) and deviations from this average value (green). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

comorbidity is common in dogs (Overall et al., 2001; Storengen and Lingaas, 2015; Tiira and Lohi, 2014, 2015, 2016; Lopes Fagundes et al., 2018; Dinwoodie et al., 2019). We cannot say that noise reactivity is causal in any comorbid condition, but the patterns of responses it generates suggest that it may act as an endophenotype that marks some shared, underlying pathology (Gottesman and Gould, 2003; Gould and Gottesman, 2006) that drives and/or modulates other pathological conditions. Unlike many of the other affiliated conditions, problematic and fearful reactions to noises can start quite young and can be fully developed by 2 years (Overall et al., 2016). By screening for and treating noise reactivity as soon as it appears, we may decrease the risk or severity of other commonly comorbid conditions, especially if they share endophenotypes.

4.3. Recommendations for practice

Despite arguments that mild noise reactivities require no treatment (Sheppard and Mills, 2003) our data strongly contradict this approach and suggest that noise reactivity/phobia changes under-appreciated aspects of dogs' lives and behaviors, and essentially functions to turn off

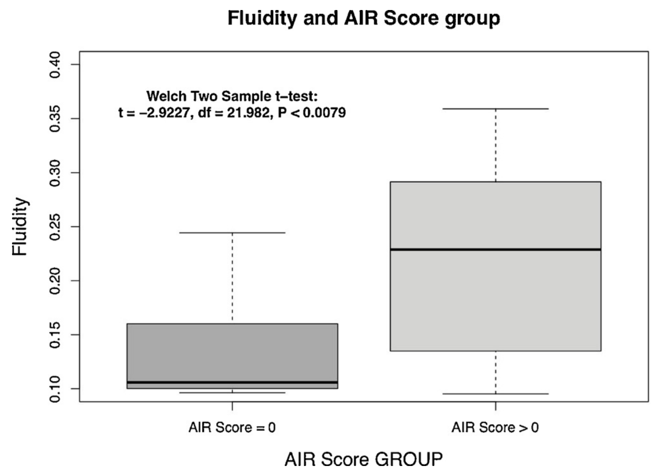

Fig. 9. Calculated fluidity for dogs with AIR scores = 0 (N = 9) and those with AIR scores > 0 (N = 15). The X axis shows the 2 groups of dogs by AIR score. The Y axis shows the calculated fluidity using the equation in the text. The heavy lines represent the median; the whiskers represent 2 SD. The groups are significantly different in their fluidity, with the dogs with AIR scores = 0 showing more continuous, coordinated movement ($P < 0.0079$; Welch two sample *t-test*).

the plastic, problem solving canine brain. Every veterinary visit should involve a screening for noise reactivity/phobia as recommended by AAHA Behavior Guidelines (https://www.aaha.org/professional/resources/behavior_management_guidelines.aspx; See supplemental material for the tool used here and calculations). Furthermore, intervention at the first signs of noise reactivity should be the standard of care: early treatment with proven pharmaceuticals plus behavioral strategies to teach the dog to manage their responses should be recommended. Continued treatment should be dictated by the dog's behaviors and be as aggressive and prophylactic as needed. All dogs should be screened multiple times a year for any physical or behavioral comorbid condition and treated when these are found.

5. Conclusions

We compared noise reactive and non-reactive dogs with respect to AIR scores calculated from the WDQ-PET, reaction to a provocative noise recording, accelerometry and performance in a puzzle box test. There was an important association between performance on the noise section of the WDQ-PET and pattern/dimensions of movement as measured accelerometry. Movement across all aspects of the tests for noise reactive/phobic dogs was, on average, more erratic, subject to more starts and stops, and had more extreme deviations from mean.

The dogs who solved the problems fastest and most accurately most often did not react to noise and were deliberative and consistent in their movements across all tests. Within the puzzle box test, the most active dogs during the test were the fastest.

Together these findings suggest that noise reactivity may be linked to cognitive performance and locomotion, so we recommend that dogs are screened early and repeatedly for their response to various noises

The positive predictive value (PPV) of the noise recording was 100% for reported outcomes on the WDQ-PET noise assessment. Not all dogs who reacted to noises reacted to the test recording, but all dogs who reacted to the recording had non-zero AIR scores.

Noise reactive dogs who reacted to the recording had higher average AIR scores than did these dogs who did not react to the recording, providing further validation of the clinical noise reactions section of the WDQ-PET questionnaire (Overall et al., 2001). However, even within this mildly affected population of dogs, the range of AIR scores for the noise reactive dogs who reacted to the recording mirrored those who did not (AIR = 1.5–64; 3–64, respectively), suggesting that any dog with any AIR score may be as risk for suffering in some noise environments. This is a startling conclusion and suggests that even the

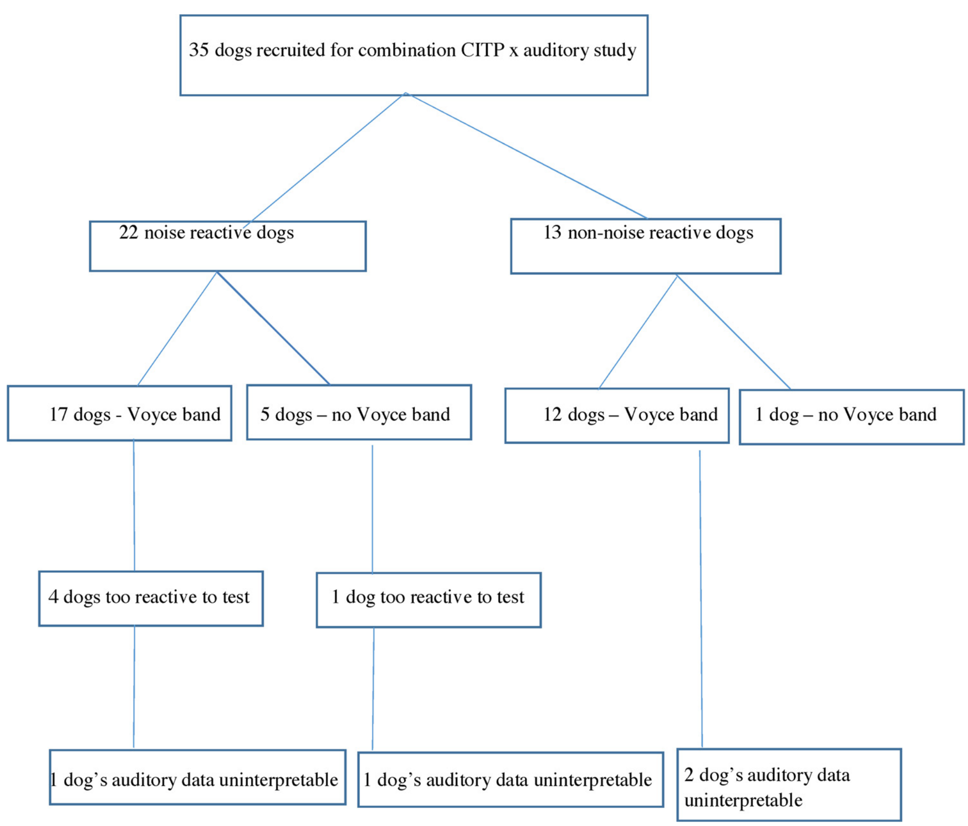

Fig. 10. Ultimate data collection design showing distribution of dogs over evaluations (accelerometers were contained in the Voyce bands).

best clients may miss or underestimate their dog's signs of behavioral distress when exposed to noise.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.applanim.2019.104863.

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