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The effect of breed on age-related changes in behavior and disease prevalence in cognitively normal older community dogs, *Canis lupus familiaris*

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Abstract Variation in breed longevity in the dog has led to the inference that large dogs age at a faster rate than small dogs, possibly because of an increased oxidative load. Potential differences in behavioral aging (the rate of age-related decline in cognito-behavioral performance) across breeds represent a significant challenge to veterinarians and scientists. Using data from a large cross-sectional survey of older dog owners, we aimed to identify breed differences in behavioral aging in successfully aged dogs ≥ 8 years of age. Differences based on longevity (short-lived, <11 years; medium-lived, 11-13 years; and long-lived, >13 years), size (small-sized, <35 cm; medium-sized, 35-55 cm; and large-sized, >55 cm), and breed (pure vs. crossbred) were identified using binary logistic regression. Significant breed differences across longevity group were seen in 2 behavioral responses: dogs drinking >1 L/d ($P = 0.001$, maximum difference between groups = 16.4%) and dogs showing aggression ($P = 0.006$, maximum difference between groups = 15.1%). In purebred dogs, 8 responses ($P < 0.001$ -0.008, maximum difference between groups = 8.4%-20%) showed significant differences across size group compared with 1 response, in crossbred dogs ($P = 0.008$, max difference between groups = 28.4%). Significant differences were observed across longevity group in the prevalence of arthritis ($P = 0.014$) and across size group in the prevalence of arthritis ($P < 0.001$) and blindness ($P = 0.014$). In medium-sized dogs, 2 age \times breeding group interactions were seen in ingestive behavior ($P = 0.037$) and aggression ($P = 0.028$). In large-sized dogs, 1 age \times breeding group interaction was seen in abnormal locomotion ($P = 0.025$). A consistent direction in the differences identified was not seen across all analyses. In general, these data did not suggest an increased rate of behavioral aging in large, short-lived dogs. It is possible that size-dependent aging affects body systems differently or, alternatively, owner's management may differ between small and large dogs, resulting in differences in behavior.

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Introduction

Dogs (*Canis lupus familiaris*) display the largest variation in morphology of any mammal (Neff and Rine, 2006) and, perhaps unsurprisingly, also a large variation in life expectancy (Patronek, et al., 1997; Kraft, 1998; Michell, 1999; Proschowsky et al., 2003b; Egenvall et al., 2005; Galis et al., 2007). Large dogs have shorter lifespan than small dogs, with weight rather than height suggested as the main contributing factor (Greer et al., 2007). Based on these longevity differences, it has been proposed that large dogs age at a faster rate than smaller dogs (Egenvall et al., 2005). For example, Austad (2005) states, "The differences in longevity among dog breeds of different sizes seemingly reflect not just survival per se but also real differences in aging rate." Using mathematical modeling, Patronek et al. (1997) estimated that for dogs weighing 15-30 lbs (6.8-13.6 kg), 1 dog year equates to 12.2 human years, but for dogs weighing >100 lbs (>45.4 kg), 1 dog year equates to 20 human years. Despite these inferences, no one has, to date, established the effect of breed differences in longevity and size on several important indicators of aging. In particular, age-related decline in cognitive-behavioral performance in different dog breeds (i.e., the rate of behavioral aging) has not been investigated.

Potential breed differences in rates of behavioral aging may represent a significant challenge for both, veterinarians treating older dogs and scientists interested in the canine as a model for human cognitive aging. Because behavioral changes are often used as an indicator of underlying neurodegenerative disease, it is important for clinicians to first establish which behavioral changes are normal with age and which, if any, of these changes may be breed-specific. There are also other breed-specific hereditary conditions, such as late-onset canine ceroid-lipofuscinosis, that may mirror age-related cognitive decline in specific breeds; thus, baseline data for normal dogs of these breeds are vital. In a research setting, it is easy to control for breed variation by using a single breed, but then it cannot be assumed that these findings are transferable to the rest of the domestic dog population. Similarly, single-breed data cannot be fully used by the clinician unless the effect of breed differences is better understood.

Crossbred dogs also present a significant problem when establishing norms for changes that may occur during aging. Patronek et al. (1997) showed that in purebred dogs, age at death was significantly lower than in crossbred dogs across weight groups; however, other studies suggest the relationship is not so straightforward, with some purebreds appearing to have a greater longevity than crossbreeds (Proschowsky et al., 2003b; Michell, 1999; Switzer and Nolte, 2007). Again, differences in longevity have led to the inference that crossbred dogs age at a rate different from that in purebred dogs (Patronek et al., 1997).

Several theories have been proposed to explain differences in longevity in species of different sizes. The

oxidative stress theory proposes that smaller animals have a higher metabolic rate than larger animals (e.g., the mouse vs. the elephant), and thus generate a higher oxidative load leading to earlier cell death and reduced longevity. However, this theory deals predominantly with interspecies variation and is less applicable to intraspecies variation. For example, large-breed dogs have a lower mass-specific metabolic rate than their small-breed counterparts, yet exhibit a reduced life expectancy. A similar effect is also seen within other species, such as mice (Miller et al., 2000), horses (Brosnahan and Paradis, 2003), and humans (Samaras and Elrick, 1999). One adaptation of the oxidative stress theory is that animals with faster growth rates have an increased rate of reactive oxygen species (ROS) production when young and therefore have reduced life expectancies. This could help to explain the pattern in dogs, given that large breeds have considerably higher growth rates than small breeds. This theory is supported by evidence from giant breeds in which we see an increased frequency of diseases with suspected links to ROS production, such as bone cancer (Phillips et al., 2007) and age-related cataracts (Urfer et al., 2010). Oxidative stress and ROS production have also been heavily implicated as factors in cognitive aging in both humans (Trollor and Valenzuela, 2001) and dogs (Head et al., 2008). Given the suspected relationship between breed size and oxidative load, it would be expected that short-lived (large) dogs would show a faster rate of cognitive-behavioral aging than long-lived (small) dogs.

Our aim was to identify any breed differences in behavioral aging in the dog. In particular, we investigated the effect of breed longevity, size, and breeding (crossbred vs. purebred) on a range of behavioral responses. On the basis of previous literature, we first hypothesized that a greater proportion of short-lived, large breeds would exhibit age-related behaviors than long-lived, small breeds after correction for age. Second, we hypothesized that a greater proportion of purebred dogs would exhibit age-related behaviors than crossbred dogs after correction for age.

Dogs, materials, and methods

The Senior Dog Survey consisted of 83 items of which 13 covered dog and owner details, general management practices, and health. The remaining 60 items covered the dog's behavior. Each behavior ($n = 30$) was addressed by 2 items, the first quantified the frequency or severity of a particular response (scored from 1 to 5), and the second determined the level of change in that response over a 6-month period (scored from 1 to 5 as improved, unchanged, or deteriorated). The 30 behaviors were further categorized into 5 subsets: ingestive behaviors ($n = 6$), locomotory and arousal behaviors ($n = 5$), human-dog interactions ($n = 4$), memory and learning behaviors ($n =$

10), and problem behaviors ($n = 5$). Surveys were distributed in *DogsLife* magazine (Universal Magazines, North Ryde, NSW, Australia, Issue 86, 2007) and online. For further details on the scoring system and survey distribution, refer the study by Salvin et al. (2010).

Sample selection

To isolate a sample population of “successfully aging” dogs, dogs with a veterinary diagnosis of canine cognitive dysfunction (CCD) ($N = 18$) or neurological disease ($N = 23$) were excluded from the sample. An additional subpopulation ($N = 97$) of dogs was excluded because they had a neurobehavioral profile consistent with CCD, based on the classification using the recently described CCD rating scale (Salvin et al., 2011). Crossbred dogs with unreported parentage (e.g., terrier cross) could not be designated a size group and were therefore excluded from any analysis investigating size-group associations. All crossbred dogs were also excluded from any longevity-group analysis because of our inability to assign them to groups of a given life expectancy. The resulting sample of “successfully aging” dogs was grouped in 2 ways.

Longevity groups

Purebred dogs were split into 3 longevity groups based on their breed’s estimated life expectancy (Michell, 1999). Short-, medium-, and long-lived breeds had an estimated life expectancy of ≤ 11 , 11-13, and >13 years, respectively (Supplementary Table S1, online).

Size groups

Purebred dogs were split into 3 size groups based on the average height of the breed provided in the Australian breed standard, or the U.S. breed standard if an Australian standard was not available. Average heights for males and females were calculated from the ranges provided in the standard, and then the average of males and females was taken to provide the breed average. Small, medium, and large dogs had an average height of <35 , 35-55, and >55 cm, respectively. If height was not available, average weight from the breed standard was used to group dogs of that breed into an appropriate size group, with dogs <11 kg grouped in the small size group (Table S1, online). All breeds ($N = 9$) without a height measurement in either the U.S. or Australian breed standards were placed in the small size group based on their weight. A total of 29 dogs were categorized in this way.

Crossbred dogs, for whom one or more parent breed included in the cross was identified (by the owner), were also split into the 3 size groups. Dogs, for whom a single parent breed was mentioned (i.e., Labrador cross), were placed in the size group corresponding to that breed. Dogs,

for whom multiple parent breeds were mentioned (i.e., German shepherd cross kelpie), were placed in the size group corresponding to the average of the 2 (or more) breeds’ heights.

Statistical analysis

PASW v.18 (SPSS Inc, NY) was used for all statistical analyses, and the significance threshold was maintained at 0.05. Univariate analysis of variance was used to identify any age differences in the longevity or size groups. Binary logistic regression was then conducted on each behavioral item to identify any associations between longevity group, purebred size group, or crossbred size group after correction for age. Correction for age was achieved by including age group (≤ 10 , 10-12, and >12 years) as a covariate in the regression model. Longevity or size group was included as a categorical covariate with a simple contrast, using the first group (small-sized or short-lived) as the reference category. To identify any significant contrasts between large- and medium-sized or long- and medium-lived dogs, a second analysis was also run using the last group (large-sized or long-lived) as the reference category.

To facilitate the use of binary analysis, all behavioral responses were collapsed into 2 categories. Items relating to the change in the frequency or severity of a response were separated into the following: category 1, “the response had stayed the same or improved”; or category 2, “the response had deteriorated.” In most instances, items reporting the frequency or severity of a response were separated into the following: category A, “never displays that response”; or category B, “sometimes displays that response.” Exceptions to this system of categorization are outlined in Table 1. Reported age was also categorized, forming 3 groups: ≤ 10 years ($n = 253$), 10-12 years ($n = 275$), and >12 years ($n = 263$).

Binary logistic regression (correcting for age) was used to assess any association of longevity group and size group with the prevalence of owner-reported arthritis, blindness, and deafness. In addition, the association between breeding (pure vs. crossbred) and the prevalence of those diseases was analyzed correcting age- and size-group differences.

Finally, binary logistic regression was used to identify any age \times breeding-group (pure vs. crossbred) interactions for small-, medium-, and large-sized dogs separately after correction for age- and breeding-group main effects.

To correct for multiple comparisons error, the significance threshold within each subset of related behaviors was revised using a Bonferroni correction. The resulting significance thresholds for each subset were as follows: ingestive behaviors ($P \leq 0.0083$), locomotory and arousal behaviors ($P \leq 0.01$), human-dog interactions ($P \leq 0.0125$), memory and learning behaviors ($P \leq 0.005$), and problem behaviors ($P \leq 0.01$).

Table 1 Classification of atypical response categories used in the binary regression analysis of successfully aging dogs

Response	Response category for binary regression analysis	
	A	B
Time spent eating per day	10 minutes or less	More than 10 minutes
Still hungry after a meal	Once a month or more	Never
Time spent chewing	Once a week or more	Once a month or less
Amount drunk per day	Less than 1.0 L	More than 1.0 L
Time spent active per day	More than 2 hours	2 hours or less
Percentage of active time spent playing	More than 30% of the time	30% of the time or less
Excitement for walks	More than 90% of the time	90% of the time or less
Number of wakes during the night	1-5 times or less	5-10 times or more
Time spent in contact or close proximity to owner	90% of the time or less	More than 90% of the time
Enthusiastic to greet returning owner	More than 90% of the time	90% of the time or less
Responds immediately to oral commands	More than 60% of the time	Less than 60% of the time
Displays breed typical behaviors	More than once a fortnight	Once a month or less
Time taken to learn new tasks	Fewer than 8 attempts	8 attempts or more

Results

Sample characteristics

Sample characteristics have been reported in detail elsewhere (Salvin et al., 2010). In brief, a total of 1,100 surveys were obtained from 11 countries, of which 956 were eligible for inclusion. Within this sample, 821 dogs (85.8%) were classified as successfully aging, and data from these dogs are the subject of the current report. The majority of responses were from Australia (N = 428) and the United States (N = 299), with significant number of responses also from New Zealand (N = 45) and the United Kingdom (N = 35). Data on a total of 60 behavioral items were collected, 30 items pertaining to the frequency or severity of a behavior and 30 items pertaining to the degree of change in a behavior in the previous 6 months.

Six hundred fifty-one purebred dogs were described, representing more than 100 breeds (Table S1, online). One hundred seventy crossbred dogs were also represented. Arthritis, blindness, and deafness were the most commonly reported diseases, with 51.3%, 17.2%, and 24.2% of dogs affected, respectively.

When grouped by estimated life expectancy (N = 661), there were 135 short-lived, 157 medium-lived, and 199 long-lived dogs. Dogs in the short-lived, medium-lived, and long-lived groups had an average age of 10 years 10 months, 11 years 4 months, and 11 years 5 months, respectively. There was a significant group effect for age ($P = 0.017$, $F = 4.108$). Within-group contrasts showed a significant difference in the average age of short- and medium-lived dogs ($P = 0.042$, confidence interval [CI] = 0.197-11.198) and short- and long-lived dogs ($P = 0.005$, CI = 2.263-12.714) but not in medium- and long-lived dogs ($P = 0.482$, CI = -6.793 to 3.211). When grouped by breed size (N = 803), there were 171 small, 289

medium, and 343 large dogs. The average age of small, medium, and large dogs was 11 years 10 months, 11 years 6 months, and 11 years 1 month, respectively. There was a significant group effect for age ($P = 0.001$, $F = 7.598$). Within-group contrasts showed a significant difference in the average age of small- and large-sized dogs ($P = 0.021$, CI = -13.19 to -1.057) and medium- and large-sized dogs ($P < 0.001$, CI = 4.122-13.456) but not in small- and medium-sized dogs ($P = 0.611$, CI = -4.756 to 8.078). When further grouped as being pure or crossbred, there were 143 small, 220 medium, and 287 large purebred dogs and 28 small, 69 medium, and 56 large crossbred dogs.

Longevity group effects

Significant associations between longevity and the frequency of a behavior were seen in 6 response items (Table 2). Two responses, "Amount drunk per day" ($P = 0.001$) and "aggression" ($P = 0.006$), remained significant after correction for multiple comparisons. For the frequency of drinking behavior, 23.7%, 29.9%, and 13.6% of short-, medium-, and long-lived dogs drank more than 1 L per day, respectively. Significantly less long-lived dogs drank more than 1 L of water per day than short-lived ($P = 0.017$, odds ratio [OR] = 0.497, CI = 0.280-0.882) and medium-lived dogs ($P < 0.001$, OR = 2.746, CI = 1.613-4.673). There was no significant difference between short- and medium-lived dogs ($P = 0.246$). For the frequency of aggressive behavior, 37.8%, 23.6%, and 38.7% of short-, medium-, and long-lived dogs showed aggressive behavior, respectively. Significantly less medium-lived dogs showed aggression than short-lived ($P = 0.009$, OR = 0.509, CI = 0.306-0.846) or long-lived dogs ($P = 0.003$, OR = 0.489, CI = 0.306-0.779). There was no significant difference in the percentage of short- and long-lived dogs that showed aggression ($P = 0.864$).

Table 2 Significance outcomes of binary logistic regression analysis for 30 behavioral items assessing both the frequency of a behavior and the level of deterioration in that behavior in the previous six months

Group analysis Response	Longevity		Size in purebreds		Size in crossbreds	
	Frequency	Deterioration	Frequency	Deterioration	Frequency	Deterioration
Ingestive behaviors						
Time spent eating per day	0.062	0.448	0.198	0.049 ^a	0.062	0.435
Still hungry after a meal	0.070	0.421	0.800	0.997	0.970	0.585
Fails to finish a meal	0.066	0.688	0.015 ^a	0.023 ^a	0.319	0.453
Time spent chewing (toys and bones)	0.813	0.246	0.566	0.346	0.378	0.166
Amount drunk per day	0.001 ^b	0.198	NA	NA	NA	NA
Stands over bowl but does not drink	0.059	0.095	0.377	0.237	0.733	0.986
Multiple comparisons threshold $P < 0.0083$						
Locomotory and arousal behaviors						
Time spent active per day	0.120	0.666	0.087	0.869	0.617	0.596
Percentage of active time spent playing	0.520	0.297	0.170	0.441	0.756	0.035 ^a
Excitement for walks	0.025 ^a	0.257	0.124	0.494	0.036 ^a	0.197
Number of wakes during the night	0.098	0.331	0.395	0.276	0.976	0.762
Pacing, circling or wandering without purpose (abnormal locomotion)	0.049 ^a	0.072	0.863	0.679	0.752	0.778
Multiple comparisons threshold $P < 0.01$						
Human-dog interactions						
Time spent in contact or close proximity to owner	0.709	0.669	0.093	0.865	0.008 ^b	0.300
Oral behavior directed at other pets or people	0.563	0.871	0.007 ^b	0.252	0.225	0.981
Avoids contact or petting	0.128	0.159	0.005 ^b	0.007 ^b	0.697	0.786
Enthusiastic to greet returning owner	0.597	0.464	0.138	0.081	0.589	0.850
Multiple comparisons threshold $P < 0.0125$						
Memory and learning						
Stares blankly at the walls or floor	0.498	0.345	0.430	0.470	0.955	0.253
Failure to recognize familiar people	0.827	0.524	0.307	0.309	0.230	0.530
Responds immediately to verbal commands	0.044 ^a	0.854	0.075	0.012 ^a	0.306	0.024 ^a
Displays breed-typical behaviors	0.368	0.339	0.007 ^a	0.036 ^a	0.112	0.512
Time taken to learn new tasks	0.977	0.624	0.000 ^b	0.568	0.014 ^a	0.592
Gets stuck behind objects or furniture	0.010 ^a	0.386	0.996	0.586	0.170	0.994
Walks into walls or doors	0.579	0.116	0.441	0.030 ^a	0.908	0.770
Goes to the hinge side of the door to be let out	0.616	0.855	0.054	0.410	0.345	0.716
Difficulty finding dropped food	0.599	0.731	0.312	0.147	0.924	0.392
Fails to shake when wet	0.112	0.741	0.262	0.433	0.057	1.000
Multiple comparisons threshold $P < 0.005$						
Problem behaviors						
Oral behavior directed at objects	0.264	0.161	0.395	0.038 ^a	0.254	0.973
Vocalizes at no apparent stimuli	0.362	0.298	0.024 ^a	0.233	0.429	0.912
Aggression	0.006 ^b	0.133	0.000 ^b	0.008 ^b	0.119	0.635
House soiled	0.841	0.989	0.004 ^b	0.076	0.135	0.372
Fears/phobias	0.406	0.992	0.039 ^a	0.003 ^b	0.336	0.963
Multiple comparisons threshold $P < 0.01$						

Note: The effects of longevity group (short, ≤ 11 years, $N = 135$; medium, 11-13 years, $N = 157$; long-lived, >13 years, $N = 199$) and size group (small, <35 cm; medium, 35-55 cm; and large-sized, >55 cm) in purebreds ($N = 650$) and crossbreds ($N = 153$) on behavior were investigated.

^aSignificant at a statistical threshold of $P = 0.05$.

^bSignificant after Bonferroni correction for multiple comparisons within behavioral subsets. The significance thresholds used for these corrections are given at the bottom of each subset. NA—the effect of size group on the amount drunk per day was not investigated due to the established relationship between body mass and water requirement.

There was a significant difference in the prevalence of owner-reported arthritis ($P = 0.014$) but no difference was noted in owner-reported deafness ($P = 0.069$) or blindness ($P = 0.736$). Owners reported arthritis in 55.6%, 53.5%, 44.2% of short-, medium-, and long-lived

dogs, respectively. Significantly fewer long-lived dogs were reported to have arthritis as compared with short-lived ($P = 0.006$, OR = 0.519, CI = 0.326-0.825) and medium-lived dogs ($P = 0.041$, OR = 1.579, CI = 1.020-2.445). There was no significant difference in

owner-reported arthritis in short- and medium-lived dogs ($P = 0.416$).

Size group effects

Table 2 shows the 18 responses for which there was a significant size effect in purebred dogs. Of these, 8 responses remained significant after correction for multiple comparisons. Five responses showed a significant association between size group and the proportion of dogs that displayed a behavior (Figure 1).

Three behaviors showed a significant association between size group and the proportion of dogs that had deteriorated in the past 6 months (Figure 2).

In crossbred dogs, Table 2 shows the significant size effects for 5 responses of which one, “>90% of the time spent in contact or close proximity to their owner,” remained significant after correction for multiple comparisons ($P = 0.008$). Of small-, medium-, and large-sized dogs, 42.9%, 14.5%, and 16.1% spent >90% of the time in contact or close proximity to their owners, respectively. Significantly, more small-sized dogs spent >90% of the time in contact or close proximity to their owners than medium-sized ($P = 0.004$, OR = 0.224, CI = 0.081-0.618) and large-sized dogs ($P = 0.012$, OR = 0.259, CI = 0.091-0.741). There was no significant difference in the frequency of this behavior between medium- and large-sized dogs ($P = 0.768$).

Figure 3 shows the significant increase in the prevalence of arthritis with size group ($P < 0.001$) and significant decrease in the prevalence of blindness with size ($P = 0.014$). There was no significant association between size group and the prevalence of deafness ($P = 0.495$).

Breeding (pure vs. crossbred) effects

After correction for age and size, there was no significant difference between the prevalence of arthritis

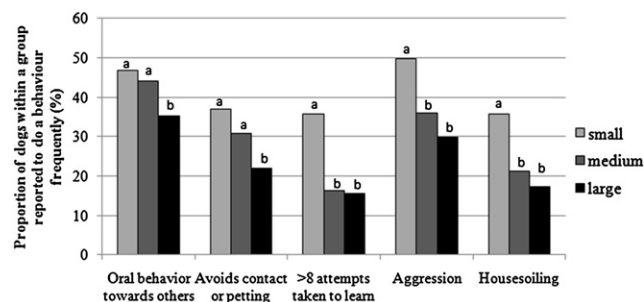


Figure 1 Behavioral responses in only purebred dogs ($n = 650$) that, after correction for age, showed a significant main effect of size group (small: <35 cm; medium: 35-55 cm; and large-sized: >55 cm) on the proportion of dogs that performed a behavior frequently. For each behavior, frequency bars with different letters indicate a significant specific difference between size groups, $P < 0.05$.

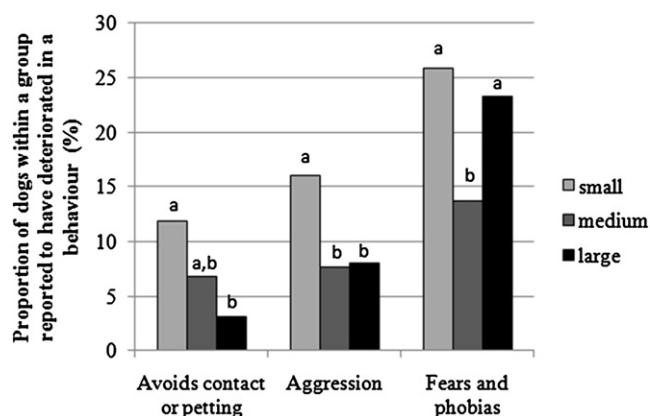


Figure 2 Behavioral responses in only purebred dogs ($n = 650$) that, after correction for age, showed a significant main effect of size group (small: <35 cm; medium: 35-55 cm; and large-sized: >55 cm) on the proportion of dogs that have deteriorated in a behavior. For each behavior, frequency bars with different letters indicate a significant specific difference between size groups, $P < 0.05$.

($P = 0.418$), blindness ($P = 0.134$), or deafness ($P = 0.071$) in purebred compared with crossbred dogs.

In small-sized dogs, there were no significant differences in age-dependent response frequencies between purebred and crossbred dogs for any behavior, that is, no significant age \times breeding (pure vs. crossbred) interactions. There were 2 significant age \times breeding (crossbred vs. purebred) interactions seen in medium-sized dogs for “change in time spent eating” ($P = 0.037$) and “aggression” ($P = 0.028$). Figure 4 shows the different response frequencies for medium-sized purebred and crossbred dogs in the proportion of dogs that had increased the amount of time spent eating per day in the previous 6 months.

Figure 5 shows the different response frequencies seen for medium-sized purebred and crossbred dogs in the proportion of dogs showing aggression.

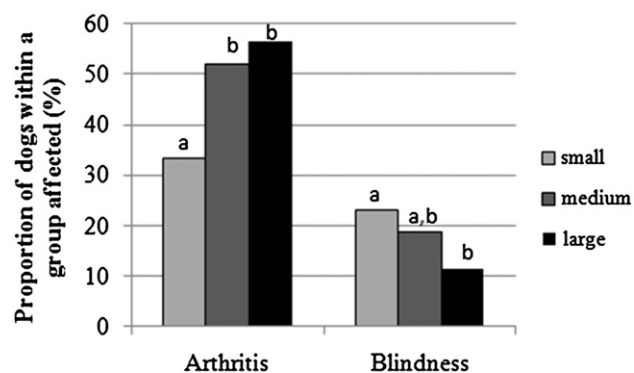


Figure 3 Diseases in both purebred ($N = 650$) and crossbred ($N = 153$) dogs combined that, after correction for age, showed a significant main effect of size group (small, <35 cm; medium, 35-55 cm; and large-sized, >55 cm) on the proportion of dogs reportedly affected. For each behavior, frequency bars with different letters indicate a significant specific difference between size groups, $P < 0.05$.

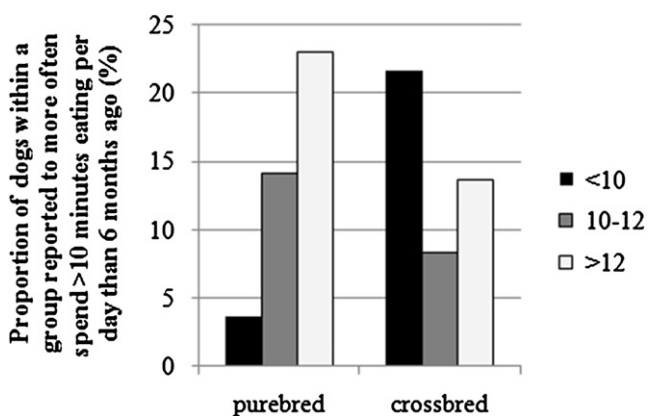


Figure 4 Response curves across age group (<10, 10-12, and >12 years) for only medium-sized (35-55 cm), purebred (N = 220), and crossbred (N = 69) dogs that had increased the time they spend eating in the previous 6 months.

There was one significant age × breeding (crossbred vs. purebred) interaction for large dogs (*P* = 0.025). **Figure 6** shows the different response frequencies seen for large-sized purebred and crossbred dogs in the proportion of dogs showing abnormal locomotion, that is, circling, pacing, or wandering with no apparent direction or purpose.

None of these interactions remained significant after correction for multiple comparisons.

Discussion

Although there has been much speculation about breed differences in the aging process (Patronek et al., 1997; Austad, 2005), the current report represents the first investigation of the effect of breed on canine behavioral aging. Our large cross-sectional survey of owners of aged dogs has identified that few behavioral responses show a size (8 responses in purebreds, 3 in crossbreds) or longevity (2 responses) effect. We have also isolated a small number

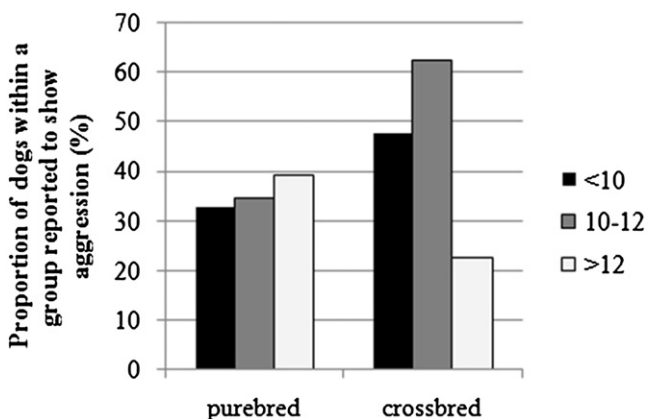


Figure 5 Response frequencies across age group (<10, 10-12, and >12 years) for only medium-sized (35-55 cm), purebred (N = 220), and crossbred (N = 69) dogs showing aggression.

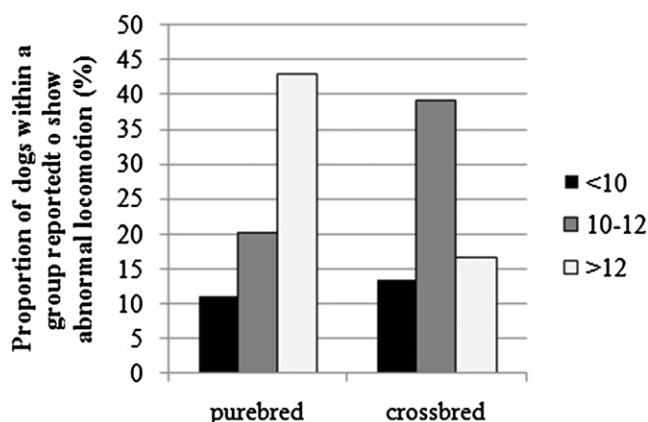


Figure 6 Proportion of dogs across age groups (<10, 10-12, and >12 years) for only large-sized (>55 cm), purebred (N = 287), and crossbred (N = 56) dogs showing abnormal locomotion, pacing, circling, and wandering with no apparent direction or purpose.

of differences in the age-dependency of aging behavior between purebred and crossbred dogs (3 responses), although these did not remain significant after correction for multiple comparisons. Interestingly, many behaviors that we studied (58 responses out of 60 [96.7%] for longevity analysis; and 52 [86.7%] and 57 [95%] responses out of 60 for size analysis in purebreds and crossbreds, respectively) exhibited no breed effects.

If we consider first the link between longevity or size and behavior in purebred dogs, several responses displayed group differences. There was a significant association between longevity and 3.3% of the responses investigated, and between size and 13.3% of the responses. There were also significant longevity associations in 1, and size associations in 2 of the 3 diseases reported. Given the hypothesis that large-sized or short-lived dogs have reduced life expectancies because of increased oxidative damage and a faster rate of aging, group differences were expected. What was unexpected is that for only one behavior in the longevity analysis, and no behaviors in the size analysis, do short-lived or large-sized dogs show an increased severity or level of deterioration compared with long-lived or small-sized dogs. In addition, the decreased “proportion of dogs that drink >1 L water/day” in long-lived dogs is likely to reflect a body mass rather than aging relationship. The association between size and longevity on arthritis did follow predictions, with large-sized, short-lived dogs showing a higher prevalence. In contrast, blindness had a lower prevalence in large- compared with medium- and small-sized dogs. These findings partially support the findings of Proschowsky et al. (2003a) who found that the prevalence of ear, eye, and skeletal diseases significantly differed between breeds.

We attempted to restrict our analysis to cognitively intact animals by excluding those with a possible CCD diagnosis (Salvin et al., 2011). Despite this, several

behaviors that are used to inform this diagnosis (such as, house soiling, increased time taken to learn, and avoiding contact) showed a response pattern contrary to that predicted by the oxidative load hypothesis of aging such that small-sized dogs showed a higher frequency or level of deterioration. This suggests that the increased oxidative load in large-sized dogs may not negatively affect all body systems equally. Beyond oxidative stress, there are probably also a large number of other contributors to the overall aging process, which may not affect cognitive function.

Several longevity and size differences in canine behavioral aging have been shown, not all of which are in the same direction. Hence, there is conflicting evidence as to whether large-sized or short-lived dogs show an increased rate of aging. If large-sized, short-lived dogs were “physiologically older” than small-sized, long-lived dogs of the same chronological age, they would show a general increased prevalence of age-related disease and increased rate of behavioral signs of cognitive deterioration. Instead, 3 cognitive deterioration indicators were more prevalent in small-sized dogs, as was blindness which is a strongly age-related disease. One possible explanation is that the increased prevalence of some of these behaviors in small-sized dogs was not age-dependent per se, but rather a management-related effect. Some unwelcome behaviors may be more tolerated in a small-sized dog because of the ability to physically manipulate them, whereas the same behaviors may have more profound implications for owners of a large-sized dog. Further investigation into the owner’s management of unwelcome behaviors and data on a larger range of age-related diseases will help to clarify these issues.

The suggestion that crossbred dogs age more successfully than their purebred counterparts (Patronek et al., 1997) was also investigated. To assess this, we separated purebred and crossbred dogs, and then further segregated them into 3 size groups. Although 13.3% of behaviors were sensitive to size group in purebred dogs ($N = 650$), only 5% of behaviors were sensitive to size group in crossbred dogs ($N = 153$). This could suggest that crossbred dogs are less susceptible to size variations in aging or, more likely, that there was insufficient power to identify significant differences because of the lower number of crossbreeds included. Also, there were no significant behaviors common to both purebred and crossbreeds, making direct comparison difficult. Further investigation is needed to clarify the differences in behavioral aging between crossbred and purebred dogs.

As with all owner-sourced data, owner’s assessment of their dog’s parentage and pedigrees is prone to error. Unless both parents are purebreds and are definitively known, it is extremely difficult to assess the makeup of a crossbreed without complex genetic analysis. For the purpose of this study, this possible source of error was minimized by grouping crossbreeds by size and not specific parent breed

groups. Even if the correct parent breeds were not identified, it is likely that they would be of a size similar to the crossbred’s actual size, and therefore more probable that they were categorized correctly. Age data are also likely to be less accurate in crossbred than purebred dogs as the exact birthdates of crossbreeds are often not known. Another shortcoming of this study is that it focuses primarily on behavioral changes that may be indicative of cognitive decline and fails to assess other aspects of aging, particularly physical changes. It is possible that the hypothesized differences between purebreds and crossbreeds are more evident in aspects of aging not investigated here, such as other age-related diseases.

There was a considerable bias in this study toward desexed/neutered dogs, with only 5.9% of females and 15.7% of males being entire/intact. This bias is not consistent with that seen in other countries, such as in Sweden (Egenvall et al., 2000), Spain (Azkona et al., 2009), and Italy (Golini et al., 2009), which report much higher proportions of entire/intact dogs. However, because of the low numbers of intact dogs in the current study, a comparison of the effects of normal aging on desexed/neutered and intact dogs was not possible. Given the previously reported link between desexing and an increased risk of cognitive impairment (Azkona et al., 2009), it is possible that neutering may also increase the cognitive changes associated with successful aging. Care must therefore be taken when extrapolating the findings of this study to other populations, which may have different proportions of neutered dogs. Variability in sexual status demographics between countries might also result in potential confounders when looking at other diseases that are potentially influenced by ROS damage.

These data suggest that there is considerable variation in the cognitive aging process, particularly between breeds of different sizes. However, they provide no consistent evidence for the expected cognitive aging advantage of small-sized, long-lived, and crossbred dogs. This surprising finding supports the need for further research into breed differences in aging and the processes behind them. However, it should be noted that these findings do not detract from the established advantages of small-sized dogs in longevity and some age-related diseases. The use of breed longevity data alone should therefore not be accepted uncritically as evidence that larger dogs age at a faster rate. Instead, it may be possible that particular load-dependent body systems, such as the cardiovascular or skeletal system, are more susceptible to size-dependent aging, whereas other systems are spared. The data presented here therefore provide a preliminary insight into the interaction of various breed-specific behavioral responses with aging. However, they also raise a multitude of questions that only further prospective studies in this area can address. A greater understanding of the breed differences in aging will facilitate canine research and improve the generalization of breed-specific data on aging for veterinary and community stakeholders.

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Supplementary data

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