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Age-related changes in the propensity of dogs to bite

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ABSTRACT

This retrospective cohort study was aimed at describing the effects of age at acquisition, age, and duration of ownership of dogs on the risk of (1) bites during play and (2) non-play bites to humans. Data were collected on 110 dogs that had bitten during play with a person, 161 dogs that had bitten outside of play and 951 non-biting dogs from veterinary clients in Kingston (KGN), Jamaica and San Francisco (SF), USA. Modified Poisson regression was employed to model the relationships of both types of bites to each variable separately.

Effects of the variables on dog bite risk (1) during and (2) outside of play with the dog, differed from each other and by type of bite. Effects varied with the dog's age and age-related associations were strongest in dogs younger than 1 year old. Ages at acquisition of dogs at highest risk for bites during play were substantially lower than those at risk for non-play bites. Ages and durations of ownership of dogs at highest risk for bites during play were also lower than those of dogs at highest risk for non-play bites. The propensity of a dog to bite changes as it ages and relationships between dog bites occurring during and outside of play and the dog's age at acquisition, current age, and duration of ownership, differ from each other.

Introduction

Dog bites are frequent sequelae to human–canine interactions (Overall and Love, 2001; The American Veterinary Medical Association, 2001). This has led to much interest in identifying human and canine risk factors for both bites and aggression to humans in many parts of the world (Cornelissen and Hopster, 2010; Feddersen-Petersen, 1994; Georges and Adesiyun, 2008; Gershman et al., 1994; Guy et al., 2001; Maragliano et al., 2007; Messam et al., 2008; O'Sullivan et al., 2008; Rosado et al., 2009; Wake et al., 2009). While age is accepted as a risk factor for canine aggression (Borchelt and Voith, 1996a,b; Lockwood, 1995; Overall and Love, 2001), little is known about the age or ages at which dogs are most likely to bite (Overall and Love, 2001). Similarly, while a few studies have examined the association between the age of dogs at their acquisition and subsequent aggression (Appleby et al., 2002; Hsu and Sun, 2010; Petersen and Deddens, 2006), there is still need for an understanding of how age at acquisition is related to dog bites.

Knowledge of how a dog's age at acquisition and current age are related to its aggressive behavior will help veterinarians to contextualize properly for dog–owners both human-directed aggression in newly acquired dogs as well as aggression-related behavior changes in dogs as they age.

To investigate the relationships of dog age-related factors to the risk of dog bites, a retrospective cohort study was conducted in Kingston (KGN), Jamaica and San Francisco (SF), USA. The premise of the investigation was that if the effects of age-related factors on the risk of a dog biting were not constant over a dog's lifetime, then age–time periods corresponding to higher or lower dog bite risks should be identifiable using analytic methods which permit data to define the shape of the age–time–dog bite relationship.

The goals of the study were: (1) to describe the relationships of age at acquisition, dog age, and duration of ownership to the risks of bites occurring during and outside of play; (2) to identify the ranges of these variables corresponding to the highest risks of dog bites; (3) to identify the ranges of these variables during which the change in dog bite risk is greatest, and (4) for each variable, to compare its relationship to the risk of bites occurring during play to its relationship to the risk of non-play bites. Age, age at acquisition and duration of ownership were used as surrogate measures for (1) the cumulative effect of time-related social and biological changes occurring in the dog since its birth; (2) the effect of the timing of the most recent change in the dog's ownership and living environment occurring during this process of change, and (3) the cumulative effect of these changes in the dog since the most recent change in its ownership and living environment, respectively.

The bi-national component in this study provided an opportunity to investigate if the effects of dog age-related factors on dog bite-risk differed between the two countries. Previous research points to differences in cultural attitudes to dog rearing between

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the United States and the Caribbean (Davis et al., 2007; Deddens and Petersen, 2008; Fielding and Mather, 2001).

Materials and methods

Study protocol

This study constituted a part of a cohort study on dog bites approved by the University of California Davis Institutional Review Board. Most aspects of the materials and methods are identical to those previously described in detail (Messam et al., 2008, 2012) and so only a brief description is provided here.

Study participants

Study participants were clients interviewed in the waiting rooms of eight veterinary clinics in KGN and three veterinary clinics in SF from May 2003 to January 2004. Clients were eligible to participate if they were at least 18 years old. Additionally, the dog in question had to be present at the time of the interview, owned for at least 24 h and living 7 days/week in the same home as the client. Whenever more than one dog was present, their names were ranked alphabetically and the first ranked chosen for participation.

Outcome definition

Dog bite categories were determined using the following questions:

(a) During play, in the last 2 years, did the dog ever hold onto or catch a part of any person's body with its teeth and cause a wound?
(b) Not during play, in the last 2 years, did the dog ever hold onto or catch a part of any person's body with its teeth and cause a wound?
(c) Not during play, in the last 2 years, did the dog ever hold onto or catch a part of any person's body or clothes with its teeth but not cause a wound?

The outcome was considered a bite during play if the respondent answered 'yes' to (a) but 'no' to both (b) and (c); a non-play bite if the respondent answered 'yes' to (b) and/or (c) but 'no' to (a), and a non-bite if the respondent answered 'no' to all three questions. Bites occurring during play were restricted to those resulting in wounds to exclude cases of playful mouthing where a dog might grasp a person's body without applying sudden pressure (Messam et al., 2012). 'Bite during play,' instead of 'play bite' was used whenever the victim was playing with the dog at the time of the bite, as no distinction was made between when the dog was and was not playing. For dogs owned for 2 years or more, it was assumed that the dog bites occurred 1 year prior to the date of the interview. For dogs owned for less than 2 years, it was assumed that the bite preceded the day of the interview by a time period equal to half the duration of ownership.

Exposures of interest

The exposures of interest were the dog's age at acquisition, the dog's current age, and the duration of ownership (Table 1), with each recorded both as categorical and continuous variables. In the absence of exact dates of birth and acquisition, the following decision rules were used: when an exact age or time period was given, that number was used; when a range was provided, the midpoint of the range was used, and when fractions of weeks, months and years were given, the value was rounded to the nearest week, month or year, respectively. If a respondent could not provide one of the age or time periods, the value was estimated using the values of the other two variables of interest if possible. When no age or time period was obtained from the respondent, the value was omitted. Twenty-eight per cent of the ages at acquisition and 18% of dog ages were estimated, respectively, for the continuous variable analysis. No estimation of age–time variables was performed when these exposures were recorded as categorical variables.

Statistical analysis

For analyses, modified Poisson regression (Zou, 2004) in SAS version 8.2 was used. Initially, each exposure of interest was used as a continuous variable to model play and non-play bites with functional forms (of the exposures of interest) separately, determined using fractional polynomials (Royston et al., 1999). This was necessary to allow the data, in addition to the statistical model, to define the shape of each age (–time) variable–dog bite relationship. Directed acyclic graphs (DAGs; Greenland et al., 1999) were used to choose a set of potential confounders of the relationships of age at acquisition to bites occurring during and outside of play. This initial set included city of residence, presence of yard space, source of the dog and reason for the dog's acquisition (Table 2).

A priori, no canine characteristics were believed to be confounders of the relationships of current age or duration of ownership to either type of bites, as both these variables represent slightly different surrogates for aging in the dog. Since aging is an inherent characteristic of the animal, its effect was not believed to be confounded by other individual-level characteristics or variables. For model selection, the change-in-estimate criterion (Greenland, 1989) was employed to select confounders from the DAG-based subset with a $\geqslant$10% change in the estimated RR required for a potential confounder to be retained in the model. To detect differences in RRs attributable to city of residence, an interaction term consisting of the exposure of interest and city was added to each model and retained if the corresponding regression coefficient was statistically significant ($P < 0.05$). If no statisti-

Table 1
Distribution of biting and non-biting dogs by selected exposures and city of origin: Kingston (KGN), Jamaica and San Francisco (SF), USA.

Exposure	Exposure categories	Total	Bites during play		Non-play bites		Non-bites	
			KGN *n* (%)[a]	SF *n* (%)[a]	KGN *n* (%)[a]	SF *n* (%)[a]	KGN *n* (%)[a]	SF *n* (%)[a]
Age at acquisition	Birth	149	5 (3)	0 (0)	12 (8)	1 (<1)	129 (87)	2 (1)
	⩽2 months	481	35 (7)	28 (6)	38 (8)	22 (5)	242 (50)	116 (24)
	>2 months to ⩽6 months	317	8 (3)	21 (11)	19 (6)	27 (9)	111 (35)	131 (41)
	>6 months to ⩽1 year	84	0 (0)	4 (5)	4 (5)	9 (11)	24 (29)	43 (51)
	>1 year to ⩽2 years	48	0 (0)	2 (4)	1 (2)	8 (17)	10 (21)	27 (56)
	>2 years to ⩽5 years	43	0 (0)	3 (7)	0 (0)	5 (12)	7 (16)	28 (65)
	>5 years	34	0 (0)	3 (9)	1 (3)	6 (18)	3 (9)	21 (62)
	Total	1156[b]	48	61	75	78	526	368
Current age	⩽2 months	123	7 (6)	2 (2)	2 (3)	1 (<1)	106 (86)	5 (4)
	>2 months to ⩽6 months	326	28 (9)	30 (9)	9 (3)	4 (1)	200 (61)	55 (17)
	>6 months to ⩽1 year	145	9 (6)	7 (5)	15 (10)	9 (6)	65 (45)	40 (28)
	>1 year to ⩽2 years	153	3 (2)	8 (5)	15 (10)	16 (10)	58 (40)	53 (35)
	>2 years to ⩽5 years	184	1 (<1)	6 (3)	23 (12)	22 (12)	53 (29)	79 (43)
	>5 years	233	0 (0)	8 (3)	13 (6)	26 (11)	52 (22)	134 (58)
	Total	1164[b]	48	61	77	78	534	366
Duration of ownership	⩽2 months	425	27 (6)	29 (47)	10 (2)	8 (2)	273 (64)	78 (18)
	>2 months to ⩽6 months	183	13 (7)	12 (20)	8 (4)	8 (4)	97 (53)	45 (25)
	>6 months to ⩽1 year	139	4 (3)	8 (13)	16 (12)	18 (13)	48 (35)	45 (32)
	>1 year to ⩽2 years	95	3 (3)	2 (3)	7 (7)	7 (7)	42 (44)	34 (36)
	>2 years to ⩽5 years	154	1 (<1)	4 (7)	22 (14)	18 (12)	47 (31)	62 (40)
	>5 years	193	0 (0)	6 (10)	13 (7)	20 (10)	48 (25)	106 (55)
	Total	1189[b]	48	61	76	79	555	370

[a] Row percentages. Not all percentages sum to 100 due to rounding error.
[b] Differences in totals reflect differences in number of responses to each question.

Table 2
Distribution of biting and non-biting dogs by selected exposures and city of origin: Kingston (KGN), Jamaica and San Francisco (SF), USA.

Exposure	Exposure categories	Total	Bites during play		Non-play bites[a]		Non-bites[a]	
			KGN *n* (%)[b]	SF *n* (%)[b]	KGN *n* (%)[b]	SF *n* (%)[b]	KGN *n* (%)[b]	SF *n* (%)[b]
Respondent's age (years)	⩽20	45	2 (4)	2 (4)	6 (13)	0 (0)	30 (67)	5 (11)
	21–30	254	14 (6)	14 (6)	19 (7)	13 (5)	100 (39)	94 (37)
	31–40	338	14 (4)	25 (7)	21 (6)	31 (9)	136 (40)	111 (33)
	41–50	244	8 (3)	11 (5)	19 (8)	14 (6)	113 (46)	79 (32)
	51–60	175	9 (5)	6 (3)	12 (7)	12 (7)	91 (52)	45 (26)
	61–70	108	2 (2)	0 (0)	3 (3)	7 (6)	70 (65)	26 (4)
	⩾71	49	0 (0)	2 (4)	2 (4)	1 (2)	35 (71)	9 (18)
	Total	1213[c]	49	60	82	78	575	369
Respondent's gender	Male	533	18 (3)	35 (7)	32 (6)	28 (5)	270 (51)	150 (28)
	Female	689	31 (4)	26 (4)	50 (7)	51 (7)	308 (45)	223 (32)
	Total	1222[c]	49	61	82	79	578	373
Method of response	Alone	962	33 (3)	46 (5)	63 (7)	67 (7)	444 (46)	309 (32)
	Spouse/companion helped	105	5 (5)	7 (7)	4 (4)	5 (5)	45 (43)	39 (39)
	Child helped	99	8 (8)	5 (5)	12 (12)	4 (4)	59 (59)	11 (11)
	Other individual helped	56	3 (5)	3 (5)	3 (5)	3 (5)	30 (54)	14 (25)
	Total	1222[c]	49	61	82	79	578	373
Dog's sex and neuter status	Male (intact)	441	24 (5)	18 (4)	40 (9)	14 (3)	298 (68)	47 (11)
	Male (castrated)	222	1(<1)	15 (75)	4 (2)	33 (15)	19 (9)	150 (68)
	Female (intact)	336	23 (7)	18 (5)	34 (10)	11 (3)	221 (66)	29 (9)
	Female (spayed)	214	0 (0)	9 (4)	4 (2)	20 (9)	36 (17)	145 (68)
	Total	1213[c]	48	60	82	78	574	371
Housing	Yard space	1017	47 (5)	34 (3)	80 (8)	47 (5)	569 (56)	240 (24)
	No yard space	200	2 (1)	26 (13)	2 (1)	31 (16)	6 (3)	133 (67)
	Total	1217[c]	49	60	82	78	575	373
Reason for acquisition	Included protection[d]	173	6 (3)	1 (1)	16 (9)	1 (1)	144 (83)	5 (3)
	Included companionship[e]	623	31 (5)	44 (7)	38 (6)	56 (9)	194 (31)	260 (42)
	Included protection and companionship[f]	75	5 (7)	1 (1)	7 (9)	1 (1)	56 (75)	5 (7)
	Love dogs	208	2 (1)	4 (2)	15 (7)	10 (5)	126 (61)	51 (25)
	Take care of dog	49	1 (2)	5 (10)	0 (0)	5 (10)	8 (16)	30 (61)
	Other[g]	93	4 (4)	6 (16)	6 (6)	6 (6)	49 (53)	22 (24)
	Total	1221[c]	49	61	82	79	577	373
Dog's origin	Born at home	144	4 (3)	0 (0)	12 (8)	1 (1)	125 (87)	2 (1)
	Obtained from friend/acquaintance	423	19 (4)	14 (3)	38 (9)	22 (5)	259 (61)	71 (17)
	SPCA or shelter	158	1 (1)	12 (8)	0 (0)	25 (16)	11 (7)	109 (69)
	Purchased	455	22 (5)	33 (7)	31 (7)	28 (6)	166 (36)	175 (38)
	Stray/found	39	3 (8)	2 (5)	1 (3)	3 (8)	15 (38)	15 (38)
	Total	1219[c]	49	61	82	79	576	372

[a] Messam et al. (2008).
[b] Row percentages. Not all percentages sum to 100 due to rounding error.
[c] Differences in totals reflect differences in the number of responses to each question.
[d] Acquired for protection or for protection and other reasons excluding companionship.
[e] Acquired for companionship or for companionship and other reasons excluding protection.
[f] Acquired for both protection and companionship.
[g] Acquired for reasons which did not include those listed above.

cally significant interaction was detected, pooled RRs were calculated and city of residence retained in the final model if it caused a ⩾10% change in the estimated RR. Overall, from 110 biters during play, 161 non-play biters and 951 non-biters, data for 1061 and 1112 dogs were used for bite during play and non-play bite analyses, respectively. Thus the same group of non-biting dogs was used for both analyses.

Analyses, using data for the same dogs, were then repeated using age at acquisition and current age as categorical variables to compare results with the continuous variable analysis. Additionally, Spearman's rank correlation (r) between age of dog and duration of ownership for both play and non-play bites was estimated.

Finally, a sensitivity analysis was performed in order to determine the robustness of the choices of functional forms of the age–time variables (Table 3) by omitting the observations with estimated exposure values and repeating the fractional polynomial procedure.

From final models, RRs and 95% CIs for comparisons of interest (Tables 4 and 5) were estimated using model-based variances and covariances (Table 3). From each of the six final models, a range of dog bite risks corresponding to the range of its respective exposure of interest was generated. In this way, age–time values corresponding to the 95th percentile of dog bite risks were obtained for each exposure of interest.

Results

Approximately 50% of KGN respondents were 40 years or younger, compared to 60% of SF respondents, with most respondents in both countries being female (Table 2). Compared to dogs in SF, dogs in KGN were acquired at a younger age (92% vs. 77% <6 months of age), were younger (53% vs. 19% <6 months old) and owned for less time (46% vs. 23% owned for <2 months; Table 1). The relationships between the age–time variables and dog bites were non-linear, with the exception of the relationship of duration of ownership to bites during play (Figs. 1 and 3).

Age at acquisition

Dogs that bit while being played with were acquired at a younger age than non-play biters. Medians (M) and inter-quartile

Table 3
Final modified Poisson regression equations modeling the natural log relative risk, (ln(RR)), of (1) bites occurring during play and (2) non-play bites, as separate functions of age at acquisition (X_1), current age (X_2) and duration of ownership (X_3).

Exposure	Outcome	Regression equations[a]
Age at acquisition	Bites during play[b,c]	$\ln(RR) = -2.86 + 0.52(0.14)\left(\frac{X_1+1}{10}\right)^{-1} - 0.05(0.01)\left(\frac{X_1+1}{10}\right)^{-2} - 0.55(0.18)(C)$
	Non-play bites	$\ln(RR) = -0.99 - 0.07(0.03)\left(\frac{X_1+1}{10}\right)^{-1}$
Current age	Bites during play[c,d]	$\ln(RR) = -3.18 + 1.40(0.25)\left(\frac{X_2}{10}\right)^{-1} + 0.61(0.13)\left(\frac{X_2}{10}\right)^{-1}\ln\left(\frac{X_2}{10}\right) - 0.96(0.19)(C)$
	Non-play bites[e]	$\ln(RR) = -1.11 + 0.57(0.11)\ln\left(\frac{X_2}{10}\right) - 0.22(0.06)\left(\ln\left(\frac{X_2}{10}\right)\right)^2$
Duration of ownership	Bites during play[c]	$\ln(RR) = -1.47 - 0.22(0.06)\left(\frac{X_3}{10}\right) - 0.79(0.18)C$
	Non-play bites[c,f,g]	$\ln(RR) = -0.76 - 0.17(0.20)C + 0.07(0.07)\ln\left(\frac{X_3}{10}\right) - 0.10(0.04)\left(\ln\left(\frac{X_3}{10}\right)\right)^2 + 0.30(0.10)\ln\left(\frac{X_3}{10}\right)\times(C) - 0.02(0.06)\left(\ln\left(\frac{X_3}{10}\right)\right)^2\times(C)$

[a] Equations are of the form $\ln(RR) = \beta_1 + \beta_2A_2 + \cdots + \beta_n$, A_n, where β_n = nth regression coefficient in the equation (from left to right), A_n = variable in the equation, standard errors of regression coefficients are in parentheses and $\text{cov}(\beta_i, \beta_j)$ = covariance of the ith and jth parameters in the regression equation.
[b] $\text{cov}(\beta_2, \beta_3) = -0.002$.
[c] C = City (Kingston = 1, San Francisco = 0).
[d] $\text{cov}(\beta_2, \beta_3) = -0.032$.
[e] $\text{cov}(\beta_2, \beta_3) = -0.006$.
[f] $\text{cov}(\beta_3, \beta_4) = -0.0006$, $\text{cov}(\beta_3, \beta_5) = -0.005$, $\text{cov}(\beta_3, \beta_6) = -0.0006$, $\text{cov}(\beta_4, \beta_5) = -0.0006$, $\text{cov}(\beta_4, \beta_6) = -0.002$, $\text{cov}(\beta_5, \beta_6) = -0.001$.
[g] Interaction with city (C). $P = 0.0047$ and $P = 0.76$ for first and second interaction terms, respectively.

ranges (IQR) were M=2 months (IQR 6 weeks to 3 months) and M=2.25 months (IQR = 6 weeks to 5.75 months), respectively.

Dogs acquired at 6 weeks of age were at higher risk for biting during play than those born into their current owner's home. For dogs acquired between 6 weeks and approximately 1 year of age, the risk of biting while being played with decreased slightly with increasing age at acquisition, but for dogs acquired older than 1 year of age, risks were essentially the same (Fig. 1a). Correspondingly, while a dog acquired at 6 weeks was 3.4 (95% CI: 1.3–8.9) times as likely to bite while being played with, than one born into its owner's home, dogs acquired at 3 and 6 months were 2.6 (95% CI: 1.0–8.7) and 1.8 (95% CI: 0.7–4.9) times, respectively, as likely to bite during play than those born at their current home. Dogs acquired between 1 and 1.5 months of age had estimated risks of

Table 4
Adjusted relative risks (RRs) and 95% confidence intervals (CIs) for the associations between 6 month increases in age at acquisition, current age, and duration of ownership and (a) non-play bites and (b) bites occurring during play with the dog when the exposures are modeled as continuous variables, Kingston (KGN), Jamaica and San Francisco (SF), USA.

Exposure	Months	Non-play bites		Bites during play	
		RR	95% CI	RR	95% CI
Age at acquisition[a,b]	6 vs. 0	1.8	1.1–3.0	1.8	0.7–4.9
	8 vs. 2	1.2	1.0–1.3	0.5	0.4–0.8
	12 vs. 6	1.0	1.0–1.1	0.8	0.7–0.9
	18 vs. 12	1.0	1.0–1.03	0.9	0.8–0.9
	24 vs. 18	1.0	1.0–1.02	0.9	0.9–1.0
			$n = 1033$[h]		$n = 989$[h]
Current age[c,d]	8 vs. 2	3.8	2.1–6.9	0.6	0.4–1.0
	12 vs. 6	1.6	1.3–1.9	0.6	0.5–0.7
	18 vs. 12	1.2	1.1–1.2	0.7	0.7–0.8
	24 vs. 18	1.1	1.0–1.1	0.8	0.8–0.9
	30 vs. 24	1.0	1.0–1.1	0.9	0.86–0.93
			$n = 1029$[h]		$n = 986$[h]
Duration of ownership (SF)[e]	8 vs. 2	1.4	1.2–1.7	0.9[f,g]	0.8–0.9
	12 vs. 6	1.1	1.0–1.2	0.9[f,g]	0.8–0.9
	18 vs. 12	1.0	0.9–1.1	0.9[f,g]	0.8–0.9
	24 vs. 18	1.0	0.9–1.0	0.9[f,g]	0.8–0.9
(KGN)[e]	8 vs. 2	2.3	1.2–4.2		
	12 vs. 6	1.3	1.1–1.7		
	18 vs. 12	1.1	1.0–1.3		
	24 vs. 18	1.0	0.9–1.2		
			$n = 1029$[h]		$n = 986$[h]

[a] Unadjusted age at acquisition–non-play bite association. No variable caused ⩾10% change in RRs.
[b] Age at acquisition–bites during play association adjusted for city.
[c] Unadjusted current age–non-play bite association. No variable caused ⩾10% change in RRs.
[d] Current age–bites during play association adjusted for city.
[e] Duration of ownership–non-play bite association: interaction with city.
[f] Duration of ownership–bites during play association (linear model): RR. for each additional 6 months of ownership.
[g] Duration of ownership–bites during play association adjusted for city.
[h] Differences in totals reflect missing data for each exposure of interest.

Table 5
Adjusted relative risks (RRs) and 95% confidence intervals (CIs) for the associations between age at acquisition and non-play bites, age at acquisition and bites occurring during play, current age and non-play bites and current age and bites occurring during play, when the exposures are modeled as categorical variables: Kingston, Jamaica and San Francisco, USA.

Exposure	Non-play bites		Bites during play	
	RR	95% CI	RR	95% CI
Age at acquisition[a,b]				
Birth	1		1	
>0 months to ⩽2 months	1.4	0.8–2.6	3.6	1.4–9.4
>2 months to <6 months	1.5	0.8–2.9	2.5	1.0–6.8
⩾6 months to <2 years	1.5	0.8–3.0	1.0	0.3–3.4
⩾2 years to <5 years	1.4	0.6–3.3	1.2	0.3–5.2
>5 years	1.8	0.8–4.0	2.1	0.6–7.2
		$n = 1032$[e]		$n = 989$[e]
Current age[c,d]				
⩽2 months	1		1	
>2 months to <6 months	1.0	0.2–4.4	1.9	0.7–4.9
6 months to <2 years	3.6	0.9–14.6	1.3	0.5–3.5
⩾2 years to <5 years	5.3	1.3–20.9	0.5	0.2–1.6
>5 years	4.6	1.2–18.3	0.3	0.1–0.9
		$n = 1026$[e]		$n = 984$[e]

[a] Age at acquisition-non-play bite association adjusted for city.
[b] Age at acquisition–bites during play association adjusted for city and reason for acquisition.
[c] Unadjusted current age-non-play bite association. No variable caused ⩾10% change in RR.
[d] Current age–bites during play association adjusted for city.
[e] Differences in totals reflect missing data for each exposure of interest.

biting during play in the 95th percentile of the range of risks for bites during play.

The risk of non-play bites increased sharply with increasing age at acquisition for dogs acquired younger than 6 months old and then was constant (Fig. 1a). Thus, for dogs acquired older than 6 months of age, later ages at acquisition did not appreciably change the RR of a non-play bite (Tables 4 and 5; Fig. 2b) when compared to dogs acquired at 6 months. Compared to dogs born at the respondent's home, dogs acquired at 2 months, 6 months and 1 year old were 1.6 (95% CI: 1.1–2.4), 1.8 (95% CI: 1.1–3.0) and 1.9 (95% CI: 1.1–3.3) times as likely to bite outside of play, respectively. Dogs aged 1.5 years or older when acquired had estimated risks of non-play bites in the 95th percentile of the range of non-play bite risks.

Current age

Dogs that bit during play were younger than non-play biters with M = 4 months (IQR = 10 weeks to 1 year) and M = 2.5 years (IQR = 11 months to 6.5 years), respectively. The risk of bites during play increased sharply until approximately 3 months of age and declined thereafter with increasing age (Fig. 1b). Thus, dogs that were 6, 12 and 24 months old were 0.7 (95% CI: 0.6–0.8), 0.4 (95% CI: 0.3–0.5) and 0.3 (95% CI: 0.2–0.4) times as likely to bite during play as a 3 month old puppy, respectively. Two to 4 month old dogs had estimated risks of biting during play in the 95th percentile of the range of risks for bites during play.

Regarding non-play bites, the risk increased with age but at a diminishing rate from 2 months to approximately 3 years, after which it declined gradually (Fig. 1b). Correspondingly, while an 8 month old dog was 3.8 (95% CI: 2.1–6.9) times as likely to bite as a 2 month old dog, a 1 year old dog was 1.6 (95% CI: 1.3–1.9) times as likely to bite as a 6 month old dog. The most rapid increases in risk occurred in the age range 2–12 months (Figs. 1b and 2d), and 1–1.5 year old dogs had essentially the same risks of biting. Thus an 18 month old dog was just 1.2 (95% CI: 1.1–1.3) times as likely to bite as a 12 month old dog (Table 4). Dogs that were 21–65 months old had estimated risks of non-play bites in the 95th percentile of the range of non-play bite risks.

Age at acquisition vs. current age

For dogs acquired before 4–6 months of age, the effect of increases in age at acquisition on the magnitude of the risk of non-play bites was greater than the effect due to an increase in the dog's age (Fig. 3). For dogs acquired after 6 months of age, this tendency was reversed (Fig. 3).

Duration of ownership

Dogs that bit during play were owned for a shorter period before the bite took place than non-play biters, with M=2 months (IQR = 3 weeks to 7 months) and M = 21.5 months (IQR = 8 months to 4.5 years), respectively. Dogs owned for 3 months or less had estimated risks of biting during play in the 95th percentile of the range of risks for bites during play.

The risk of non-play bites, as a function of duration of ownership, showed a similar pattern to the risk of non-play bites as a function of current age. It was highest at 24–36 months and decreased gradually thereafter (Fig. 1b and c). There was evidence of differences in the association of duration of ownership on non-play bites between the two cities (Table 4 and Fig. 1c). After being owned for 6 months in SF, a further 6 months of ownership did not change the risk of biting. In KGN, this was the case after being owned for 1 year. In SF and KGN, dogs owned for 6–33 and 20–97 months, respectively, had estimated risks of non-play bites in the 95th percentile of the range of non-play bite risk.

Correlation between current age and duration of ownership

There were high correlations between the current age and duration of ownership for dogs that bit during play ($r = 0.88$; 95% CI 0.81–0.95) and for dogs that were non-play biters ($r = 0.89$; 95% CI 0.82–0.95).

Continuous vs. categorized exposures

The sensitivity analysis confirmed the choices of functional forms of the exposures of interest used for final models in the continuous variable analysis (Table 3). Results using the exposures of interest as categorical variables (Table 5) were similar to the continuous variable analysis. This was confirmed by the overlap in 95% CIs when the RR estimates for the continuous variable analyses calculated at the midpoints of each category were used for comparison with the categorical variable analyses (Fig. 4).

Discussion

In this study, age at acquisition, current age and duration of ownership have been used as surrogates for unspecified socio-biologic factors believed to be associated with dog bites. Thus, for instance, while canine age (which is simply the amount of time that has transpired since the birth of a dog), cannot in itself be a causative or protective factor with respect to dog bites, it is likely to be correlated with canine socio-biological changes which might be causative or protective.

Most biters during play were acquired younger than 6 months old and bites occurring during play with the dog occurred relatively soon after acquisition (75% within 6 months of ownership). If bites during play are likely to occur soon after acquisition, the increase in bite risk observed for dogs acquired at 1.5–2 months of

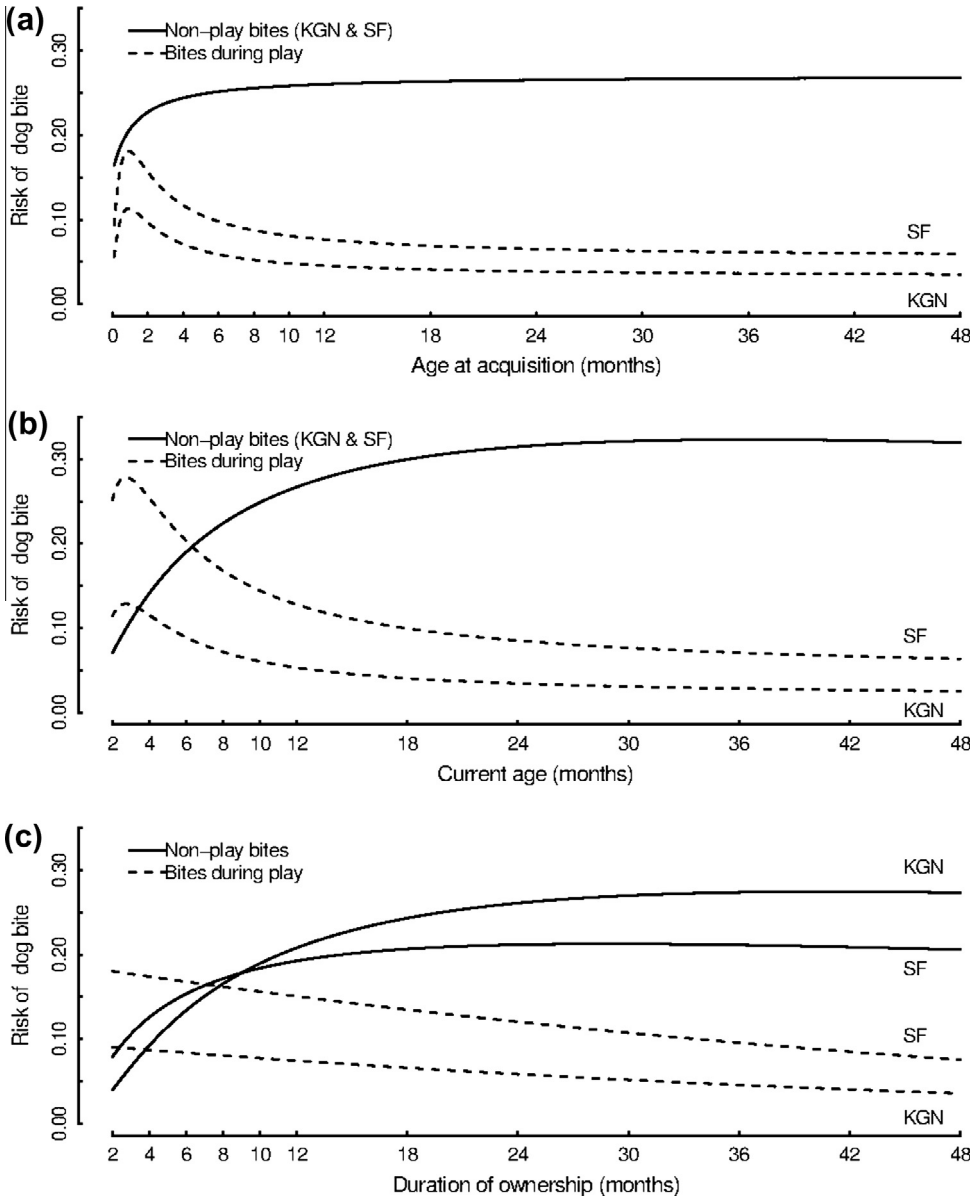

Fig. 1. Comparisons of the risk of non-play bites to bites during play plotted as separate functions of a dog's (a) age at acquisition, (b) current age and (c), duration of ownership.

age compared to those born at home might be attributable to more physical interaction between the owner and a newly acquired puppy than between the owner and a puppy that he/she has seen develop from birth. Additionally, increased responsiveness by a 2 month old puppy, the eruption of its teeth, its increased strength and tendency to playfully mouth are possible reasons for increasing risks of biting while being played with during the first 1.5–2 months after birth. Progressive decreases in the risk of bites occurring during play for dogs acquired older than 1.5–2 months of age and for dogs older than 3–4 months might be a consequence of a decreasing tendency of older dogs to play, or for their owners to play with them, or both. This is consistent with dog age being inversely associated with the frequency of owner–dog play (Rooney et al., 2000), as well as with a reported decline in social play in dogs after 6–7 months (Feddersen-Petersen, 1991).

Dogs that never changed homes being at the lowest risk for non-play biting is consistent with previous observations that dogs bred at home (Serpell and Jagoe, 1995), or which remained longer (adopted at 60 days vs. 30–40 days) with litter mates (Petersen and Deddens, 2006), were under-represented among dogs with behavior problems. It is also consistent with a previous report which found that while there was an overall positive association between being born outside in a kennel, garage or barn (as opposed to in the residential part of the home) and stranger-directed aggression, there was no association observed among that subset of the same dogs acquired before 8 weeks of age (Appleby et al., 2002). Recently, somewhat contradictory findings have been reported: dogs acquired as puppies (vs. as adults) were at higher odds of showing stranger-directed aggression (Hsu and Sun, 2010). However, the authors explain that people might not adopt aggressive adult dogs and also that they might be unable to recognize signs of future aggressive tendencies in puppies.

This study suggests that the association between age at acquisition and the risk of dog bites (both during and outside of play with the dog) primarily occurs over a limited time window, i.e. during the first 6–12 months of a dog's life. This lends support to the view

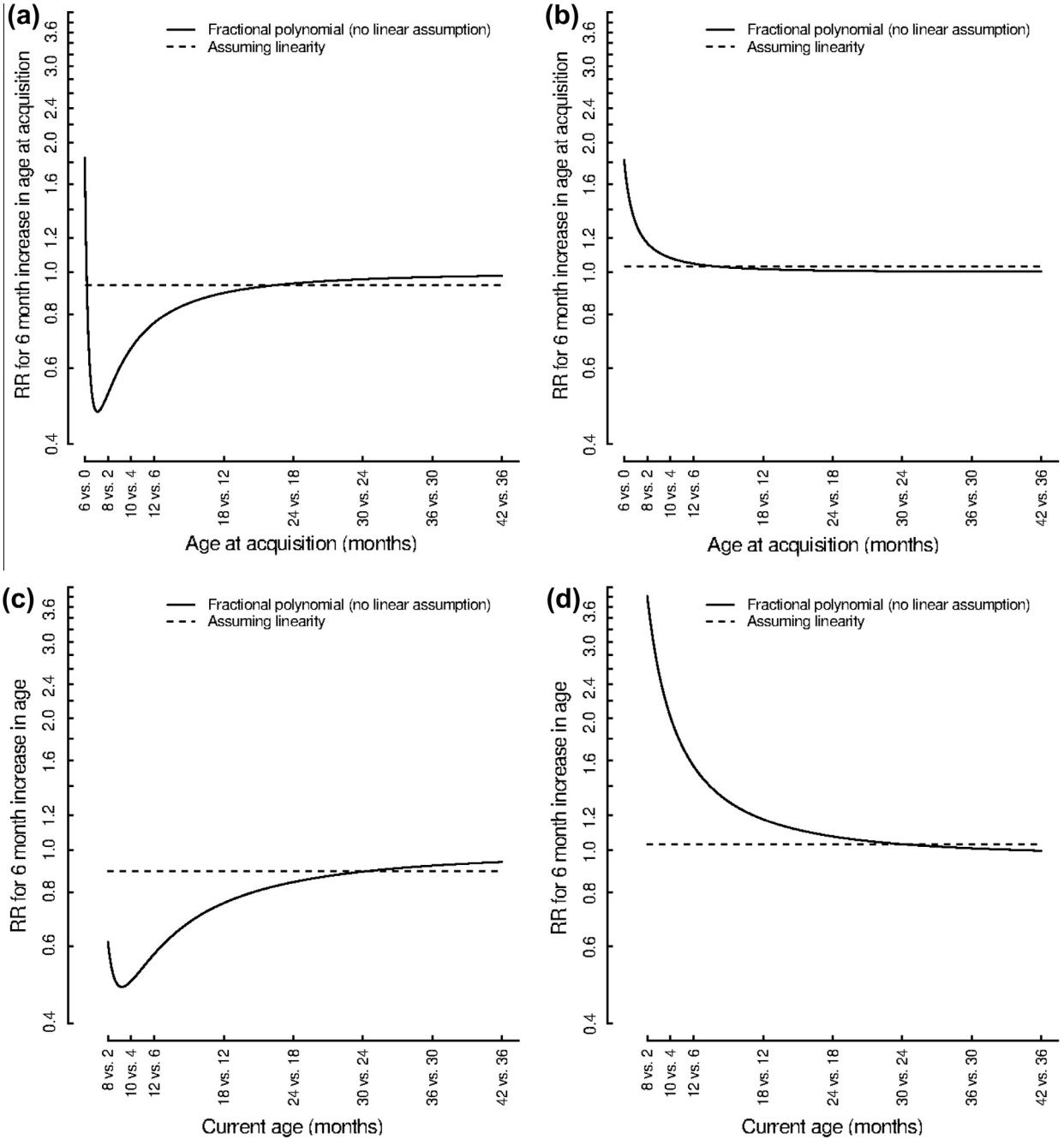

Fig. 2. Plots of the relative risk (RR) of bites for 6 month increases in ages at acquisition for (a) age at acquisition–bites during play; (b) age at acquisition–non-play bites, and for 6 month increases in current ages for (c) current age–bites during play, and (d) current age–non-play bites associations assuming both linear and non-linear (polynomial) relationships to dog bites. For example, in (a) the risk of biting while being played with for a dog acquired at age 12 months would be 0.8 times its risk of biting had it been acquired at age 6 months and in (d) a 12 month old dog's risk of non-play biting is 1.4 times that of a 6 month old dog. Regardless of which age categories are compared, RRs are constant when linearity is assumed (dashed lines).

that the timing of events in a dog's life is an important determinant of dog bites (Lockwood, 1995; Stein et al., 1994; Wright, 1996) and that early experiences are more important determinants of adult dog behavior than later ones (Serpell and Jagoe, 1995). For instance, it is possible that the trauma of changing both home and owner can have negative consequences on canine development and behavior, manifesting itself in an increased risk of biting outside of play. It is logical that this could still contribute to aggression in non-play biters, even if human-directed aggression caused previous relinquishment.

Previous studies assuming a constant effect of age on non-play bite risk have reported odds ratios of 0.96 (95% CI: 0.89–1.03) (Guy et al., 2001) and 1.1 (95% CI: 1.0–1.2) (Drobatz and Smith, 2003) for 1 year increases in age. When constant age effects were assumed, in this study, a similar result (RR = 1.1; 95% CI: 1.0–1.1) was obtained. This result suggests that for every 1 year increase in age, there is a 1.1-fold increase in the risk of biting, thus implying that the risk of dog bites increases by a constant multiple throughout the lifetime of the dog. These results differ from, and are less plausible, than the results obtained using fractional polynomials

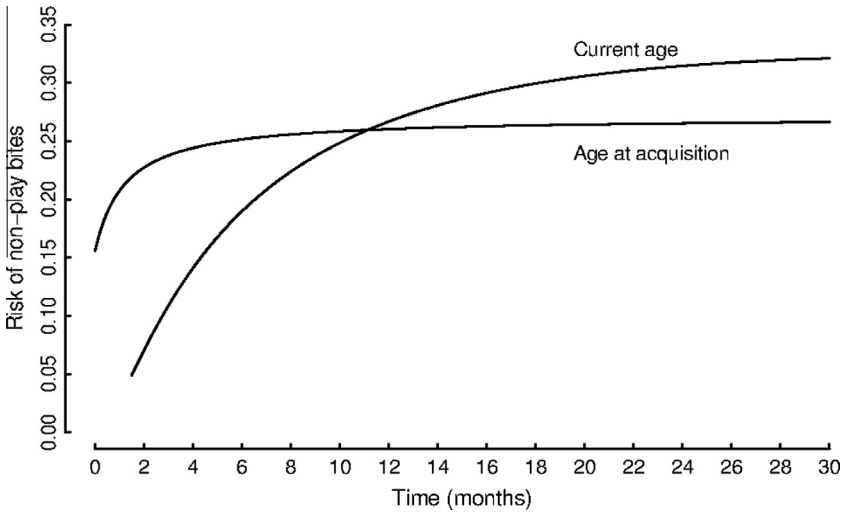

Fig. 3. Plot comparing the effects of age at acquisition and current age on the risks of non-play bites.

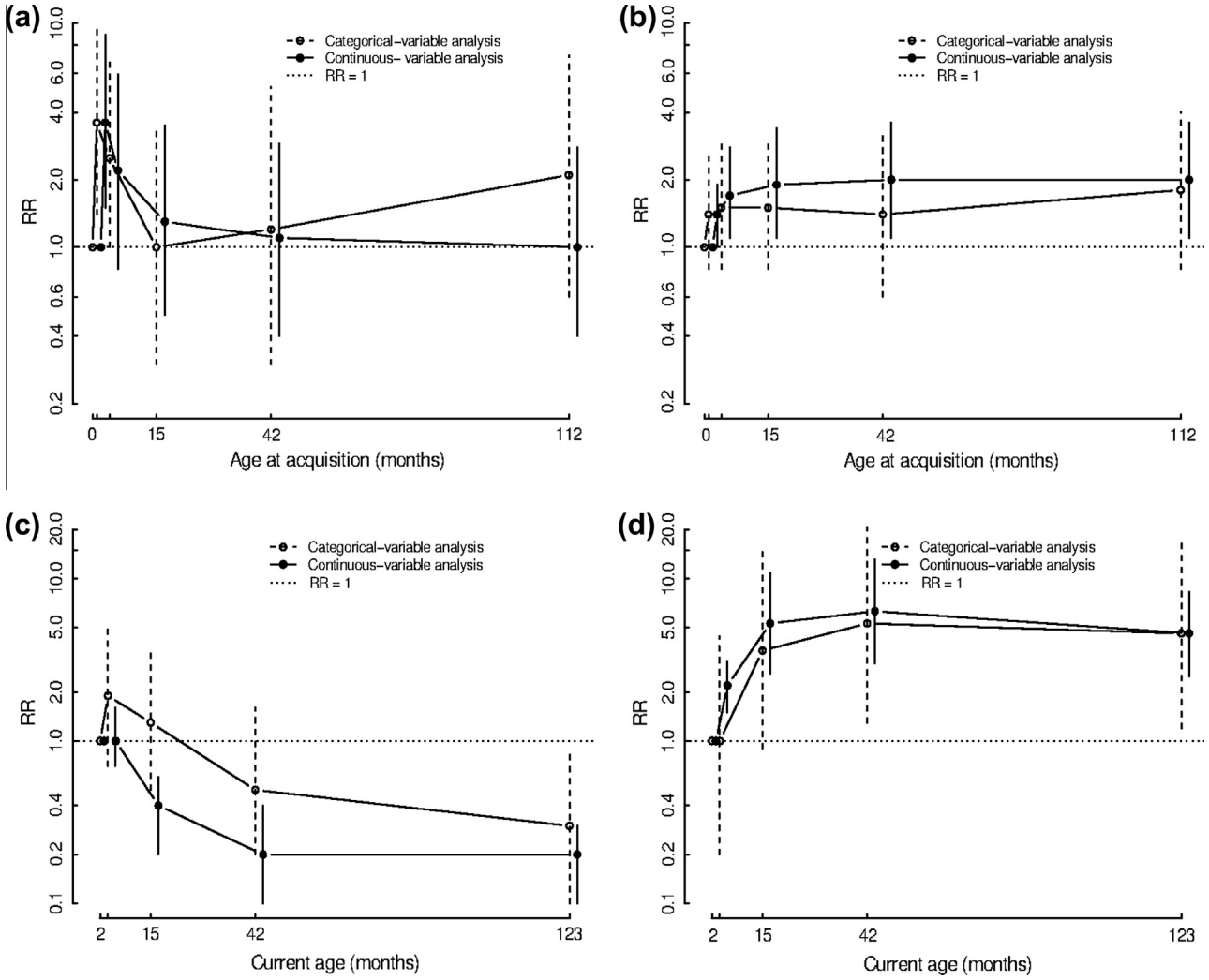

Fig. 4. Plots of estimated relative risks (RR) and 95% confidence intervals from categorical- and continuous variable analyses for (a) age at acquisition–bites during play; (b) age at acquisition–non-play bites; (c) current age–bites during play; and (d) current age–non-play bites associations. RR estimates for the continuous variable analysis are calculated at the midpoints of categories used for the categorical variable analyses. Straight lines used to connect point estimates from continuous variable analyses are used for comparison purposes only. In reality lines connecting these point estimates are not straight.

(Tables 4 and 5, Fig. 2b), which suggest that the relationship between age and risk of dog bites varies with the dog's developmental stage.

The rapid increase in non-play bite risk observed in the first year of the dog's life corresponds to the period of most rapid sensory, motor and social development (Estep, 1996). Further increases in non-play bite risk up to approximately 3 years of age, with little change for 2–6 year old dogs (Fig. 1c), are consistent with the appearance, within the first 3 years of age, of various types of canine aggression towards humans, as noted by others (Borchelt and Voith, 1996b; Luescher and Reisner, 2008).

Comparisons between the effects of age at acquisition and age at the time of biting suggest that effects of re-homing are more important than correlates of age in determining non-play bites for younger dogs. However, as the dog matures, correlates of age become more determinant in whether a dog reacts by biting in a given circumstance (Fig. 3).

The high positive correlation between duration of ownership and age for both play and non-play bites explains the similarity in their relationships to dog bite risk and supports a belief that both are proxies for similar developmental processes. If so, both duration of ownership and current age should be associated with each type of bite through similar mechanisms, even if these mechanisms differ between non-play bites and bites occurring during play. These results also suggest that changes in non-play bite risk with increasing duration of ownership are greatest during the first year (SF) to 1.5 years (KGN) of ownership. As no city-related differences in RRs were detected for current age, the observed city-related differences for duration of ownership might point to underlying qualitative differences in norms for human–canine interactions between the two countries.

It is possible that there was some misclassification of the age–time exposures recorded. As most dogs were unregistered, documented dates of birth and acquisition were not available and owner recall remained the only practical source of age–time information. Thus, estimated values of age–time variables based on information provided by owners are not likely to be exact. While this misclassification of the exposures of interest could cause inaccurate RR estimates, consistency between the results from the categorical and continuous variable data analyses (Fig. 4a–d) inspire some confidence that the results obtained in this study are not artefacts of the estimated values of the exposures of interest. Nevertheless, greater importance should be attached to the overall relationships that the results describe, as opposed to the precise numeric values of RR estimates. Additionally, the low prevalence of dogs born in their current home in SF (<1%) suggests that comparisons involving dogs born at home were heavily influenced by KGN data (28%) and that the conclusions apply primarily to dogs from KGN. Nevertheless, these results might still be relevant to other US localities, as one study based on US national estimates reported that 26.5% of newly acquired dogs were born in the respondent's home (New et al., 2004). Finally, breed-related differences are also likely to exist between groups of dogs, but this was not investigated as it would require much larger breed-specific sample sizes.

Conclusions

This study suggests that the associations of dog age at acquisition, current age and duration of ownership with the risk of bites occurring during and outside of play differ from each other; that these associations vary during the lifetime of the dog in an age-dependent manner; that the association between these age–time variables and dog bites is strongest in the first year of the dog's life, and that the dogs most likely to bite while being played with are younger than those most likely to bite outside of play. Using fractional polynomials to model these age-time characteristics as continuous variables has been a valuable step in providing an insight into how their relationships with dog bites change over the lifetime of a dog. Pending confirmation of these findings, it is to be hoped that veterinarians can use this information to help owners develop realistic expectations regarding changes in their dogs' behavior over time. This is important, as incongruencies between dog–owner expectations and canine aggressive behavior sometimes culminate in relinquishment and/or euthanasia.

Conflict of interest statement

None of the authors of this paper has a financial or personal relationship with other people or organizations that could inappropriately influence or bias the content of the paper.

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