

Urban park-related risks for *Giardia* spp. infection in dogs

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SUMMARY

Giardia spp. is a common gastrointestinal (GI) parasite of multiple host species, including dogs and humans, with the potential for zoonotic transmission. The risk of GI parasitism in dogs (including *Giardia* spp.) may increase with park use in urban areas. This study aimed to (1) determine whether park attendance is a risk factor for *Giardia* spp. infection in dogs and (2) characterize the behavioural and demographic risk factors for *Giardia* spp. infection in park-attending and non-park-attending dogs. From August to September 2012, a total of 1293 dog owners completed a survey and 860 corresponding dog faecal samples were collected. Dog faeces were screened for *Giardia* spp. using a direct immunofluorescence assay and associations assessed among behaviours, demographics, and *Giardia* spp. infection. Main results included off-leash and swimming frequencies within parks as significantly positively associated with *Giardia* spp. infection in dogs. Dog-owner age was negatively associated with off-leash and swimming frequencies in parks. The results suggest some recreational behaviours in parks and certain demographics are risk factors for parasitism in pet dogs.

Key words: Dog, epidemiology, *Giardia* spp., parasitism, urban park, zoonotic.

INTRODUCTION

City parks provide dogs the opportunity for exercise, socialization, and are areas where dogs urinate and defecate. Other walking routes outside of parks can provide additional venues for dogs to participate in these activities [1–3], and backyards are also areas where dogs may be permitted to urinate and defecate. The spread of gastrointestinal (GI) parasites within and among these areas is possible, given the faecal–oral

transmission route common to many GI parasites [4–6]. One factor that may influence the likelihood of transmission is undisposed dog faeces. It is possible that risk for infection may be highest in confined areas where canid faeces can accrue and also where re-exposure is possible, such as in parks and urban backyards.

Much of the research incorporating risk factors for GI parasitism in dogs has been demographic in nature, or based on geographical location, time of year, and husbandry practices [7–10]. Within the social sciences, investigations into the relationships between spatial and temporal patterns of dog-walking, dog-to-dog contact, and dog demographics have indirectly explored behaviours that could influence the

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risk of GI disease transmission in dogs [3, 11–13]. However, only a limited number of studies have investigated the extent to which parks might pose risks for infection and transmission of GI parasites in dogs [2, 7, 9, 13–21], a relevant query given that in urban settings, parks figure prominently as dog-walking destinations [22]. *Giardia* spp. is a common GI parasite infecting dogs and humans [6] that has figured into some park-related investigations. This parasite can cause gastroenteritis and transmit interspecifically [6, 23], with an infective cyst that is resilient, persists in damp soil and water [24], and can be transmitted directly via contaminated water, food, or physical contact [25].

Certain behaviours may increase the risk of *Giardia* spp. infection, such as dog owners who do not reliably pick up their dogs' faeces while attending parks [13, 21], as *Giardia* spp. cysts have been isolated from undisposed dog faeces within parks [19, 20]. Other park-related behaviours that may pose risks for infection and transmission of GI parasites, including *Giardia* spp., have been investigated, but with mixed results [2, 7, 9, 13–18]. In particular, Wang *et al.* [18] reported that dogs taken to parks in an urban region of the United States had a higher risk of infection with *Giardia* spp. and *Cryptosporidium* spp. than dogs not taken to parks. A British study performed by Westgarth *et al.* [13] investigated behaviours *within* a park that may increase transmission risk of GI parasites, and found that unleashed dogs made more frequent contact than leashed dogs, suggesting that GI disease transmission may be more likely between off-leash dogs. Procter *et al.* [14, 15] similarly investigated off-leash activity as a potential risk factor for GI infection with bacteria in dogs in Canada, but did not detect any significant association between unleashed dogs and infection with antimicrobial-resistant *Escherichia coli* and *Campylobacter* spp. Conversely, Smith *et al.* [16], reported a significant positive association between both overall GI parasitism and *Giardia* spp. infection intensity in park-attending (PA) dogs in Canada with frequency of park attendance and off-leash activity, and number of parks attended.

Park use is not the only owner-controlled behaviour of relevance to *Giardia* spp. infection in dogs. Urban-dwelling dogs whose owners never allow them to enter parks could still be exposed to *Giardia* spp. via accumulations of faeces in backyards, and they could be walked in areas besides parks that pose a risk for infection with *Giardia* spp. The risks for *Giardia* spp. infection in non-park-attending (NPA) dogs have been infrequently explored, as

Wang *et al.* [18] are the only research group to have addressed behaviours that may contribute to parasite transmission *within* the NPA subpopulation. They did not, however, directly test for associations between parasitism and these behaviours but speculated that regular contact with other dogs and thus transmission of parasites was still feasible for NPA dogs through activities like dog daycare and scheduled time with other dogs.

Similar to Wang *et al.* [18], the present study evaluates the role of park attendance as a risk factor for *Giardia* spp. infection, but with a different sampling strategy. Wang *et al.* [18] focused on dogs owned by veterinary students or veterinary clinic employees, whereas we explore the effects of park attendance on members of the general urban dog-owning population. We additionally assess the behavioural and demographic risks for *Giardia* spp. infection for *both* PA and NPA dogs. More specifically, we aimed to: (1) determine if park attendance is a risk factor for *Giardia* spp. infection in dogs; (2) determine the behavioural risk factors other than park attendance contributing to *Giardia* spp. infection in dogs; (3) profile the demographics of dogs and dog owners engaged in risk-related behaviours. We hypothesized that infection with *Giardia* spp. would be positively associated with: (a) park attendance, (b) off-leash activity and swimming in parks, (c) frequency of unleashing NPA dogs in areas outside of parks, (d) frequency of backyard use by NPA dogs, and (e) negatively associated with the frequency of removing dog waste from backyards within households owning NPA dogs.

MATERIALS AND METHODS

Study design and study areas

We used an observational, cross-sectional study design. The study recruited participants from residential communities surrounding six urban parks in Calgary, Alberta, Canada (51° 50' N, 114° 55' W). A subsample of parks used as study sites in previous research [16] was selected for the current study in order to expand on previous findings targeting similar areas. Parks included Southland (SL); River (RP), Fish Creek Provincial (FCPP), Weaselhead (WSH); Bowmont (BOW), and Nosehill (NH) parks.

Research protocol and questionnaire design

In June 2012, prior to recruiting participants, a modified survey piloting technique was conducted with colleagues and experts in survey design [26, 27]. In July 2012, 1000 dog-owning households in communities

bordering each of the six study sites were randomly selected from the City of Calgary's 2011 dog license database (for a total of 6000 forms sent) and participation request forms outlining the nature of the study and a website address and password for the online survey were mailed by The City of Calgary, Animal Services & Bylaw Division to these households. We aimed to maximize the validity of our sample to all dog owners residing in these areas, which was supported by the estimated 90% rate of dog licensure in Calgary (based on 2010 census data *vs.* licences purchased) [28]. Research involving human subjects was approved by the University of Calgary Conjoint Faculties Research Ethics Board (file no. 6498). A phone line was also provided for individuals who did not have internet access and requested an interview over the phone. A media campaign outlining the nature of the study was released shortly before the initial mail-out to raise the awareness of those individuals randomly selected to participate in the study. Reminder cards were sent to the same addresses 10 days after the initial mail-out. The survey instrument consisted of 25 questions and was arranged in the following sections: (1) screening; (2) questions about your dog; (3) outside of park: dog-owner recreational and other activities; (4) within park: recreational activities; (5) questions about you and your household; (6) request for dog faecal sample; (7) personal information. In order to conduct the questionnaire, individuals were required to answer 'yes' to screening questions requiring a yes or no answer, and live within one of the communities listed in the dropdown menu (Supplementary Table S1). At the end of the questionnaire, participants were asked if they would be willing to provide a sample of their dogs' faeces, and if so, their name and contact information was requested. In return, communication of *Giardia* spp.-positive results was assured. Upon collection of faecal samples, participants were asked in writing to repeat the questionnaire (and to ensure that the same individual completed both surveys), using a different web-link and password to establish test-retest reliability of survey items [29].

Faecal sampling protocol

A package including a labelled collection bag and instructions for sample pickup was sent via mail to individuals that participated in the online survey and indicated their willingness to provide a sample of their dogs' faeces. Owners were asked to leave the sample for pickup on their doorstep in the shade over an

indicated 2-day period. Two rounds of collection occurred during August and September 2012. The samples were stored at -80°C for 72 h to kill *Echinococcus* spp. eggs [30] and promote the safety of the researchers. This parasite has recently been found in coyotes in Calgary [31–34], and therefore this precaution was determined to be necessary. Samples were then stored at -20°C until laboratory analysis.

Laboratory analysis

Two grams of faeces were prepared for direct immunofluorescence (DFA) microscopy using a modified version of the manufacturer's instructions (Waterborne Inc., USA) for detection of *Giardia* spp. Faeces were homogenized in phosphate-buffered saline (PBS), strained through double-layered cheesecloth, and centrifuged for 5 min at 528.2 g to isolate cysts ($n = 860$). The majority of supernatant was discarded, apart from 1.5 ml used to homogenize sediment. Samples were analysed in a biocontainment level-2 facility using associated protocols. For each sample, 20 μl from 1.5 ml of homogenized sediment was transferred to a microscope slide, dried, and mounted with 20 μl of Aqua-Glo™ (20 \times) containing *Giardia* spp. fluorescein-labelled monoclonal antibodies. A 20 \times magnification was used to scan for cysts, and 40 \times to more closely investigate suspected cysts (Olympus, BX51). Positive samples were identified as those containing cysts that were within correct size, shape, and colour parameters [35], and the number of cysts per slide was quantified. Three individuals separately prepared slides for microscopy (including the lead author), and microscopy was conducted exclusively by the lead author. The lead author took measures to minimize operator effects by noting which of the operators prepared each sample after the completion of each microscopy session.

Data analysis

Reclassification of some variables was conducted to simplify statistical output and to provide more power to ordinal variables with uneven distribution across categories. For multivariate statistics, dog age was classified into five categories (in years): ≤ 1 , $>1-5$, $>5-10$, $>10-15$, >15 and breeds were classified according to a modified version of the Canadian Kennel Club Organization (CKC) breed standards [36]. We used the following breed classifications: sporting, working, terriers, toys, non-sporting, and herding. Due to the relatively low number of individuals falling into the CKC 'hounds' classification in our sample, we incorporated 'hounds'

into the CKC 'sporting' breed class. Moreover, we added an additional category of 'mixed or cross' breed dogs. To simplify reported results for descriptive analyses, breed categories were further reclassified and reported as active (sporting, working, herding breeds), less active (toys and non-sporting breeds), terriers, and cross or mixed breeds. Dog age was also further refined into classifications of >1 year (adult) or ≤1 year (juvenile). Frequency of visiting the veterinarian within the previous 6 months, park attendance, swimming frequency within parks, frequency of attending schoolyards or sports fields, and off-leash frequency within these locations were all reclassified into new dichotomous variables with yes/no values. Frequency of park attendance was classified as 0 (never); 1 time per week (rarely); 2–6 times per week (sometimes); 7–32 times per week (often). Off-leash frequency was collapsed into three categories of never or rarely (never or rarely); most of the time to some of the time (regularly); all of the time (often). Frequency of outdoor mountain trips was classified as: never (never); <1 time per month – 1 time per week (rarely); 2–6 days per week (sometimes); ≥1 times per day (often). Frequency of yard use was classified as never or rarely (never or rarely); sometimes to regularly (moderately) or always (often), and those who did not have a backyard were eliminated from analyses incorporating this variable. Frequency of cleaning yards was collapsed into similar categories: 0–3 times per week (never or rarely); 4–9 times per week (moderately); ≥10 times per week (often). Last, human age was collapsed into four groups (in years): 18–29, 30–44, 45–59, ≥60. The alpha level used for all bivariate and multivariate analyses was 0.05. Statistical analyses were conducted using SPSS version 20.0 (SPSS Inc., USA).

Population characteristics

Descriptive statistics were calculated using the entire survey database ($n = 1293$) and included proportions of dog demographics (breed class, age group, gender), and human demographics (age group, gender) attending and not attending parks. χ^2 exact tests and an independent samples t test were used to detect significant differences between population characteristics and park-attendance status [37].

Parasite prevalence and risk factors

Estimated parasite prevalence and median infection intensity values were calculated overall, and stratified for dog age and park-attendance status. Confidence

intervals were calculated using the Sterne estimator [38] and upper and lower limits calculated for infection intensities. Median infection intensity was calculated using only those samples positive for *Giardia* spp. The number of cysts per gram (cpg) was calculated by multiplying the number of cysts per microscope slide by 37.5 (i.e. 20 μ l of homogenized sediment was used per slide from 1500 μ l of homogenized sediment sourced from 2 g faeces), and values were rounded up to the nearest whole number. Pearson's χ^2 exact test was used to detect significant differences between age group, park-attendance status, and *Giardia* spp. prevalence [37].

To determine whether off-leash and swimming frequencies in parks were confounders for park attendance, we used a single binary logistic regression model [39] to compare *Giardia* spp. parasitism in NPA dogs with PA dogs that, according to their owners, were never or rarely off-leash and never swam.

Because PA and NPA subpopulations of dogs were exposed to different hazards, we conducted two separate analyses to investigate the infection status against behavioural risk factors. We used Quick, Unbiased, Efficient, Statistical trees (QUEST) [40] to determine the associations between predictor and response variables for both subpopulations. QUEST is one of several types of statistical trees; hierarchical analyses incorporating multiple predictor variables (or 'recursive partitioning') [41, 42]. To determine subdivisions, QUEST selects the most significant association between independent and dependent variables using χ^2 P values for categorical predictors and analysis of variance F test P values for continuous or ordinal predictors, within each subcategory within a classification tree [41]. Classification trees have some advantages over more traditional methods of analysis such as logistic regression. First, classification trees display the percentage of the response variable within groups of individuals, vs. regression, which analyses the average response variable probability for each predictor variable. Classification trees are increasingly being used in health science research [42–44], and can be valuable in epidemiological studies by isolating high-risk groups of individuals (e.g. those performing risk-related behaviours). These subsets of the population may then be easily identified and targeted for intervention and management [42]. For these reasons, we considered QUEST the most effective statistical method for the current epidemiological study. Further, we selected QUEST because it creates binary splits (i.e. improving the clarity of statistical output),

and lacks issues pertaining to selection bias seen with other types of classification trees [41].

For PA dogs, QUEST trees were developed to determine the association between *Giardia* spp. infection (outcome variable) and recreational park activities (predictor variables) including: off-leash, swimming, and park-attendance frequencies.

For NPA dogs, QUEST trees were developed to determine the association between *Giardia* spp. infection status (outcome variable) and recreational/other activities outside the park (predictor variables) including: frequencies of attending schools/sports fields and mountains, off-leash frequencies within these areas, how often these dogs were in the backyard, and how often dog owners cleaned up dog faeces from their yards.

Owners and dogs with behaviours posing risks for *Giardia* spp. infection were profiled using QUEST trees to determine the relationships between each risk-related behaviour (outcome variable) and demographics (predictor variables: dog gender, dog age, breed classification, neuter or spay status, number of dogs in the household, whether or not the dog had visited the veterinarian in the previous 6 months, human age, human gender, and whether or not a child aged ≤ 5 years resided in the household). These profiles incorporating behavioural outcome variables were created using data from all survey participants (i.e. a greater number than for the subsample of participants providing a sample of their dogs' faeces for calculation of *Giardia* spp. prevalence and the QUEST using *Giardia* spp. presence or absence as an outcome variable), in order to maximize the power of the analysis.

Data quality control

Test-retest reliability analysis. Agreement between the original and follow-up surveys was determined using Cohen's kappa statistic [45–47]. Agreement between dog gender, human gender, and park-attendance status variables were determined for the entire database. Agreement between off-leash and swimming frequencies was determined for PA dogs, and frequencies of attending schoolyards and allowing dogs in the backyard was determined for NPA dogs. The following kappa scale was used: ≤ 0 = poor; 0.01–0.20 = slight; 0.21–0.40 = fair; 0.41–0.6 = moderate; 0.61–0.80 = substantial; 0.81–1.0 = almost perfect [45].

Evaluation of a potential operator bias. We aimed to assess whether or not there was an operator bias in the individuals who prepared the slides for microscopy

(between the lead author/senior operator and the two research assistants/junior operators), and whether or not this would affect the distributions of *Giardia* spp. positives and negatives in PA vs. NPA dog samples. We used a χ^2 exact test [37] to look for significant differences between: (a) *Giardia* spp. presence or absence vs. operator (i.e. the senior operator compared with the junior operators grouped together); (b) park-attendance status vs. operator. Last, we investigated whether off-leash and swimming frequencies in parks were confounders for park attendance using only the senior operator's data, i.e. to ensure the result calculated with all data was not affected by an operator bias that might have caused a lower estimate of prevalence in PA dogs. We did this by performing a single binary logistic regression [39] to compare *Giardia* spp. parasitism in NPA dogs with PA dogs that were never or rarely off-leash and never swam using only the senior operator's data.

RESULTS

A total of 1283 participants completed the survey online and ten over the phone ($n = 1293$, 21.6% response rate). Of these, 1082 were willing to provide a corresponding faecal sample, and 860 of these were collected from residences. The difference between the number of dog faecal samples collected and the number willing to provide a sample (difference of $n = 211$) was mainly due to individuals who had indicated their willingness to provide a dog faecal sample but did not leave the sample out for collection. Also, partially contributing to this difference was the method by which samples were collected: some participants indicated their willingness to provide a faecal sample from their dog after the complex logistics of the last collection round had been finalized. As a result, they were not included in the list of residences targeted for dog faecal sample collection.

Data analysis

Population characteristics

The majority (38%) of dogs were cross or mixed breed relative to other breed categories and were adults (98.7%), with juveniles only representing 1.3% of the samples (Table 1). Consequently, our findings should be considered representative of adult dogs only. Most of the dogs were walked in city parks (PA, 79.4%). No difference in age structure was detected

Table 1. *Proportion of dogs within categories of age, breed, gender, and park-attendance status*

Park-attendance status	Breed category (<i>n</i> = 1251)								Overall (<i>n</i> = 1160)
	Age (<i>n</i> = 1256)						Gender (<i>n</i> = 1251)		
	Juveniles (%)	Adults (%)	Active (%)	Less active (%)	Cross or mixed breed (%)	Terriers (%)	Male (%)	Female (%)	
Park-attending	1·3 (<i>n</i> = 919)	98·7 (<i>n</i> = 919)	38·1 (<i>n</i> = 916)	15·3 (<i>n</i> = 916)	37·2 (<i>n</i> = 916)	9·4 (<i>n</i> = 916)	51·6 (<i>n</i> = 914)	48·4 (<i>n</i> = 914)	79·4
Non-park-attending	1·7 (<i>n</i> = 239)	98·3 (<i>n</i> = 239)	24·9 (<i>n</i> = 237)	24·5 (<i>n</i> = 237)	41·8 (<i>n</i> = 237)	8·9 (<i>n</i> = 237)	52·5 (<i>n</i> = 238)	47·5 (<i>n</i> = 238)	20·6
Overall	1·3	98·7	34·8	17·9	38·0	9·3	50·8	49·2	

Table 2. *Proportion of dog owners within categories of age, gender, and park-attendance status*

Park-attendance status	Age, years (n = 1227)				Gender (n = 1233)		Overall (n = 1160)
	18–29 (%)	30–44 (%)	45–59 (%)	≥60 (%)	Male (%)	Female (%)	
Park-attending	8.1 (n = 909)	27.2 (n = 909)	48.8 (n = 909)	15.8 (n = 909)	23.1 (n = 915)	76.9 (n = 915)	79.4
Non-park-attending	9.4 (n = 235)	20.0 (n = 235)	48.9 (n = 235)	21.7 (n = 235)	23.0 (n = 235)	77.0 (n = 235)	20.6
Overall	8.0	24.6	49.3	18.1	23.2	76.8	

between PA and NPA dogs (98.7%, 98.3% adults, respectively; $\chi^2 = 0.188$, D.F. = 1, $P_{\text{exact}} = 0.755$), although there was a significant difference in distributions of PA and NPA breed classifications [active breeds were more highly represented in PA dogs (38.1%) than in NPA dogs (24.9%); $\chi^2 = 19.6$, D.F. = 3, $P_{\text{exact}} < 0.001$]. Sex ratio was close to 1 overall, with no difference between PA and NPA dogs (Table 1; $\chi^2 = 0.059$, D.F. = 1, $P_{\text{exact}} = 0.827$).

Approximately half (49.3%) of dog owners were aged between 45 and 59 years and the majority of dog owners were female (76.8%, Table 2). PA dog owners were significantly younger than NPA dog owners, overall (PA mean = 48.2 years, NPA mean = 50.3 years, t statistic = 2.2, $P = 0.028$). There was no significant difference between proportions of females within the PA and NPA groups (76.9%, 77.0%, respectively; $\chi^2 = 0.001$, D.F. = 1, $P_{\text{exact}} = 1.000$) (Table 2).

Parasite prevalence and risk factors

The overall prevalence of dogs infected with *Giardia* spp. was 7.4% ($n = 64/860$) and overall median infection intensity was 10 313 cpg (Table 3).

Giardia spp. infection occurred more often in juveniles than in adult dogs (41.7% vs. 7.0%, $\chi^2 = 20.663$, D.F. = 1, $P_{\text{exact}} = 0.001$). Overall prevalence of *Giardia* spp. in PA dogs (8.9%) was higher than in NPA dogs (2.5%) ($\chi^2 = 7.185$, D.F. = 1, $P_{\text{exact}} = 0.007$), and therefore confirmed park attendance as a risk factor for parasitism. PA adult dogs were parasitized with *Giardia* spp. less often than PA juveniles (8.3% vs. 45.5%; $\chi^2 = 18.452$, D.F. = 1, $P_{\text{exact}} = 0.001$). PA adult dogs were parasitized with *Giardia* spp. more often than NPA adults (8.3% vs. 2.6%; $\chi^2 = 6.148$, D.F. = 1, $P_{\text{exact}} = 0.014$). No comparison was possible for NPA juvenile dogs, as this subsample consisted of a single case (Table 3).

Although we detected a significant positive association between *Giardia* spp. infection status and park attendance, we did not detect a significant difference in *Giardia* spp. infection status between NPA (4/157 = 2.5%) and PA dogs that were walked on-leash, and did not swim (2/102 = 2.0%) (Wald $\chi^2 = 0.094$, $B = 0.268$, D.F. = 1, $P = 0.760$, LL = -2.917, LL ratio $\chi^2 = 0.096$).

Within the PA dog subset, the QUEST analysis highlighted that *Giardia* spp. (Fig. 1, 8.9%, $n = 58/653$, level 1) was more likely to infect dogs often

Table 3. Prevalence of *Giardia* spp. in dogs stratified by park-attendance status and dogs' age

Age	Park-attending (n = 653)		Non-park-attending (n = 157)		Overall (n = 860)	
	%	cpg	%	cpg	%	cpg
Juveniles	45.5 (10.0–73.5)* (n = 11)	16 875† (1125–41 250)‡ (n = 11)	0 (n = 1)§	(n = 1)	41.7 (18.1–70.6) (n = 12)	16 875 (1125–41 250) (n = 12)
Adults	8.3 (6.3–10.7) (n = 641)	7500 (38–157 500) (n = 641)	2.6 (0.9–6.2) (n = 156)	35 625 (20 625–78 750) (n = 156)	7.0 (5.4–8.9) (n = 847)	8438 (38–157 500) (n = 847)
Overall	8.9 (6.9–11.3)	7969 (38–157 500)	2.5 (0.9–6.6)	35 625 (20 625–78 750)	7.4 (5.9–9.4)	10 313 (38–157 500)

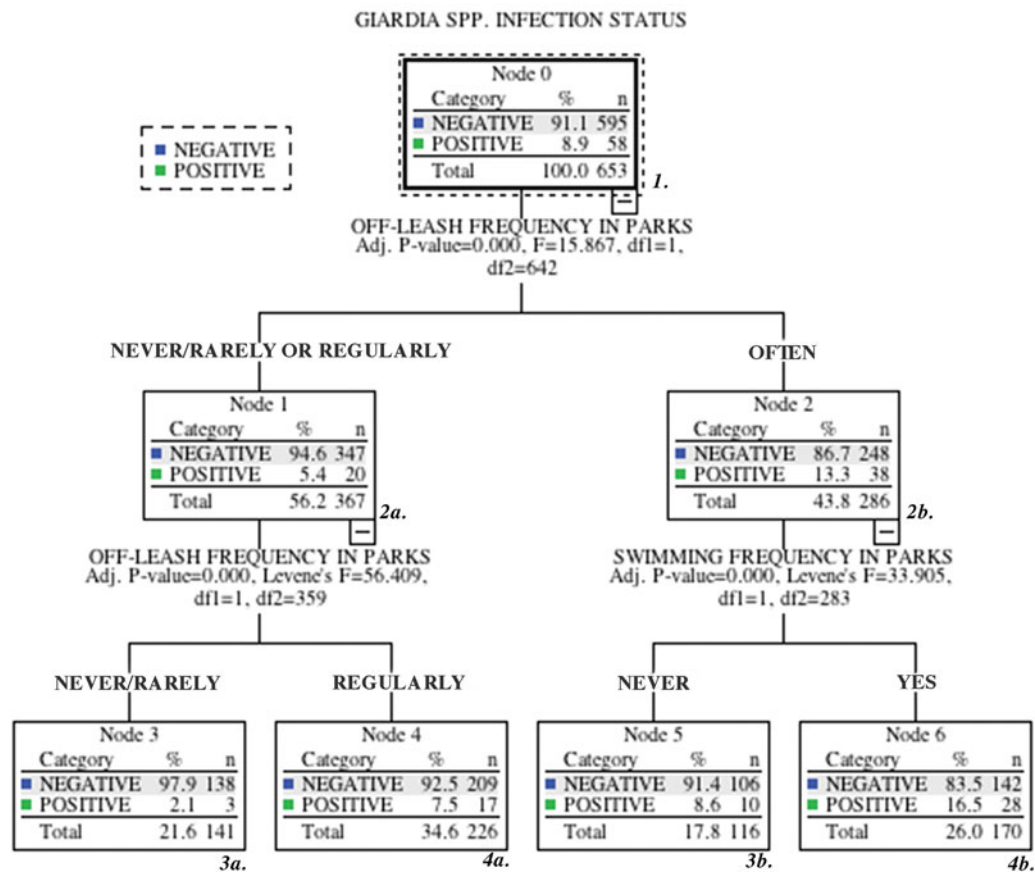
cpg, Cysts per gram.

* 95% confidence intervals.

† Median intensity values rounded up to the nearest whole number.

‡ Infection intensity intervals (upper and lower limits of cpg).

§ Cannot compute due to low sample size.

**Fig. 1.** QUEST decision tree representing significant associations between *Giardia* spp. infection status and park visitation frequency, off-leash frequency, and swimming frequency in park-attending dogs.

permitted off-leash (positive for *Giardia* spp.: 13.3%, $n = 38/286$, level 2b) vs. dogs regularly, or never/rarely off-leash (positive *Giardia* spp. status: 5.4%, $n = 20/367$, level 2a). The majority of dogs often unleashed

were also permitted to swim (59.4%, $n = 170/286$, level 4b), and dogs that swam were more likely to be infected (positive for *Giardia* spp.: 16.5%, $n = 28/170$, level 4b) than dogs that did not swim (positive for

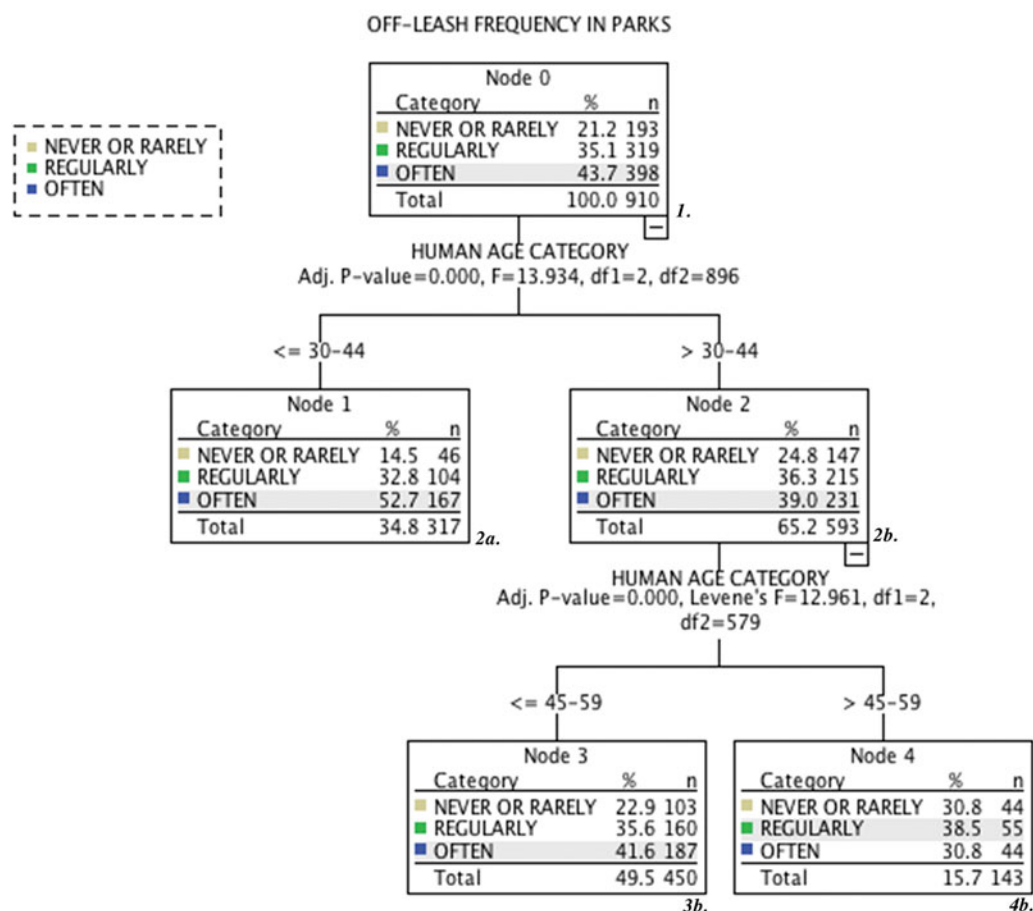


Fig. 2. QUEST decision tree representing significant associations between off-leash frequency and human and dog demographics in park-attending dogs.

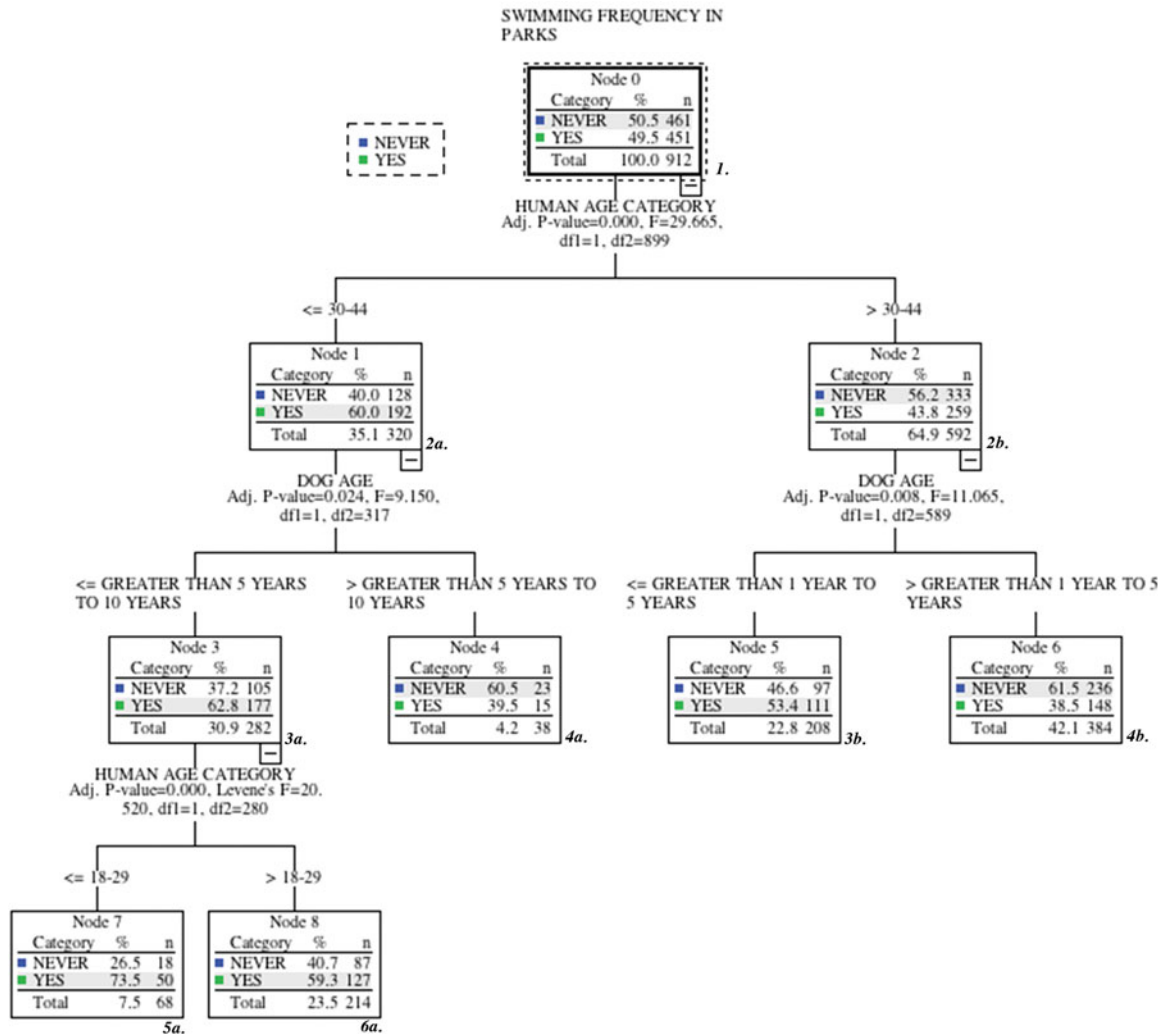
Giardia spp.: 8.6%, $n = 10/116$, level 3b). Dogs that were regularly or never/rarely off-leash were grouped together to form the second branch of the tree (56.2%, $n = 367/653$, level 2a), and the majority of them were regularly off-leash (61.6%, $n = 226/367$, level 4a), vs. never/rarely off-leash (38.4%, $n = 141/367$, level 3a). The latter group was significantly less likely to be infected (positive for *Giardia* spp.: 2.1%, $n = 3/141$, level 3a) than the former group (Fig. 1; positive for *Giardia* spp.: 7.5%, $n = 17/226$, level 4a).

The majority of people allowed their dogs off-leash regularly or often (Fig. 2; 78.8%, $n = 717/910$, level 1), and off-leash frequency was strongly associated with owners' age. The majority of responding owners were aged >44 years (65.2%, $n = 593/910$, level 2b) and allowed their dogs off-leash less frequently (often off-leash: 39%, $n = 231/593$, level 2b) than individuals who were aged ≤44 years (often off-leash: 52.7%, $n = 167/317$, level 2a). The older age group was further refined into those aged >59 years (24.1%, $n = 143/593$, level 4b) and those aged ≤59 years (75.9%, $n = 450/593$, level 3b).

Once again, the older individuals were less likely to allow their dogs off-leash (often off-leash: 30.8%, $n = 44/143$, level 4b) than younger individuals (Fig. 2; often off-leash: 41.6%, $n = 187/450$, level 3b).

Approximately half of participants reportedly allowed their dogs to swim in parks (Fig. 3; 49.5%, $n = 451/912$, level 1). Swimming was also strongly determined by owners' age. Individuals aged ≤44 years were more likely to allow their dogs to swim (never swim: 40.0%, $n = 128/320$, level 2a) than older individuals. Within the younger group, the people less likely to allow their dogs to swim were those who owned dogs aged >10 years (never swim: 60.5%, $n = 23/38$, level 4a) and people aged >29 years who owned dogs aged ≤10 years (Fig. 3; never swim: 40.7%, $n = 87/214$, level 6a).

Within the NPA dog subpopulation, *Giardia* spp. was present in 2.5% of samples (Fig. 4; 2.5%, $n = 4/157$, level 1) and was significantly more likely to infect dogs with owners who never/rarely cleaned dog litter from their backyards (positive for *Giardia* spp.:



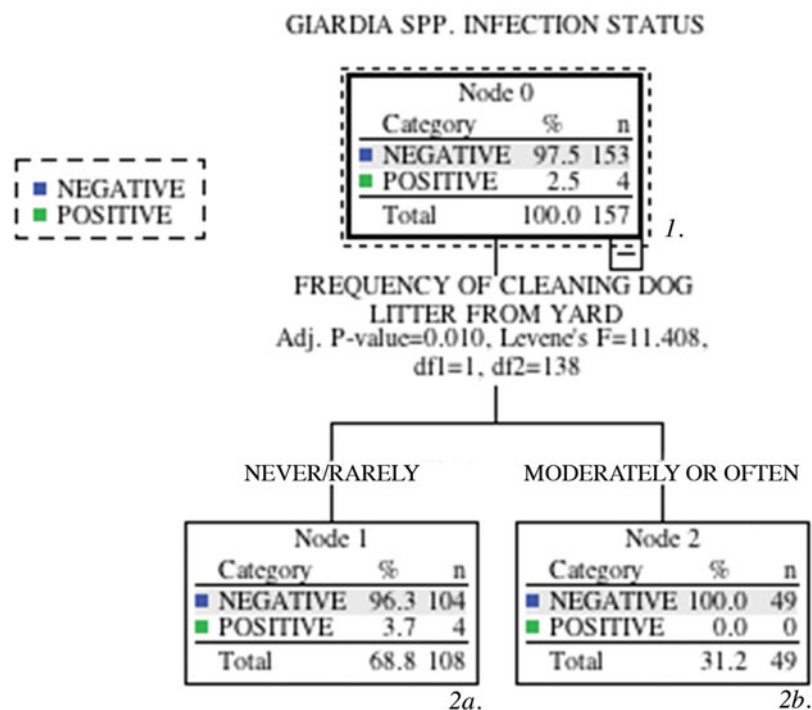


Fig. 4. QUEST decision tree representing significant associations between *Giardia* spp. infection status and frequencies of attending schools/sports fields and mountains, off-leash frequencies within these areas, and frequencies of dogs being in the backyard and of their owners cleaning up dog faeces from backyards in non-park-attending dogs.

Table 4. Intra-rater statistics measuring agreement between surveys using select variables

Variable	n	Kappa	P value
Dog gender	477	0.870	<0.001
Human gender	474	0.779	<0.001
Park-attendance status	439	0.701	<0.001
Off-leash frequency	329	0.648	<0.001
Swimming frequency	330	0.691	<0.001
Frequency of walking in schools or sports fields	74	0.720	<0.001
Frequency of dog in backyard	74	0.391	0.001

operators prepared a significantly higher proportion of PA dog samples relative to the senior operator (425/653 = 65% vs. 228/653 = 35%, respectively; $\chi^2 = 31.290$, D.F. = 1, $P_{\text{exact}} < 0.001$, $n = 810$). This might have generated a bias toward having higher overall sensitivity for the NPA group, which further confirms the risk analysis results showing a relationship between park attendance and risk. Similar to the results conducted using data from all operators, there was no significant difference in *Giardia* spp. infection status between NPA and PA dogs that were walked on-leash and did not swim (Wald $\chi^2 = 0.067$, $B = -0.321$, D.F. = 1, $P = 0.796$, LL = -2.281 , LL ratio $\chi^2 = 0.065$).

DISCUSSION

The hypothesis predicting park attendance as a risk factor for *Giardia* spp. infection was supported, but highlighted certain behaviours while attending parks, such as off-leash activity and swimming, as risks for parasitism in adult dogs. Our work also illustrates that these behaviours were most frequently conducted by relatively younger owners, and associated with dogs within certain age groups.

Although we found a strong association between infection with *Giardia* spp. and park attendance, our results suggest that off-leash activity and swimming within parks have a stronger influence on infection risk than the act of park attendance alone, as we did not find a significant difference between *Giardia* spp. infection in PA dogs that were kept on-leash, and NPA dogs. This is probably because off-leash dogs are more exposed to environmental contamination from sources like undisposed dog faeces [13, 19–21] than on-leash PA, and NPA dogs. Although Wang *et al.* [18] did not consider behaviours within parks as potential confounders for the association they found between park attendance and infection with *Giardia* spp. in dogs, our findings are supported by their research. In their investigation of dog-to-dog

contact in NPA dogs, they reported dog daycare, scheduled meetings with other dogs, and grooming appointments to be the most common. They speculated that because dog-to-dog contact appeared to be maintained outside of parks, the higher prevalence of *Giardia* spp. in PA dogs was primarily influenced by environmental contamination within parks from PA dogs.

In addition to the risk off-leash activity posed for *Giardia* spp. infection within the PA dog subpopulation, the combination of recreational behaviours (i.e. off-leash and swimming activities) within parks exerted an additive effect on infection frequency. This result could be interpreted to suggest swimming frequency confounded off-leash frequency, but QUEST trees are hierarchical, and therefore if swimming more strongly affected the rate of *Giardia* spp. infection than the frequency of off-leash activity, we would have expected the former predictor variable to enter the tree before the latter. Rather, the results suggest that while off-leash frequency was a risk factor for *Giardia* spp. infection, dogs that were often off-leash and swam were at a higher risk for infection than dogs that were often off-leash but did not swim, suggesting that swimming while off-leash compounds the risk for infection – a logical finding considering the prominent waterborne-route of infection often associated with *Giardia* spp. [24].

In general, the majority (78.8%) of participants unleashed their dogs regularly or often. Swimming was only permitted by approximately half of dog owners; this is a logical finding because the ability for a dog to swim is limited to parks with swimming areas. Similar to our findings, Westgarth *et al.* [13] reported a high frequency of unleashing dogs in parks, occurring approximately 66% of the time. Degeling & Rock [12] performed a qualitative study investigating certain dynamics of human and dog physical activity, and also reported that the majority of people allowed their dogs off-leash, at least sometimes. Although this latter investigation incorporated a small sample size, it is of notable relevance because it was performed in the same city as the current study (Calgary, Alberta). The City of Calgary appears to have more off-leash space than many cities in North America [48], making it an excellent model for studying risks and benefits of off-leash behaviour. The high frequency of unleashing dogs in parks underscores the potential for parasite transmission in a high proportion of PA dogs.

Human age was a common factor affecting swimming and off-leash frequencies. Although a

considerable proportion of PA dog owners were middle aged or older (i.e. >44 years), they were less likely to allow their dogs to engage in risk-related activities. The demographic profile of swimming frequency showed that the majority of individuals aged ≤ 44 years owned dogs aged ≤ 10 years, which may contribute to the elevated swimming frequency of dogs owned by people in these younger age groups: younger dogs are likely to engage in physical activity more frequently than older dogs. Studies performed by Degeling & Rock [12] and Westgarth *et al.* [3] investigated physical activity in dogs as a component of their research, and reported some dog owners provided less exercise to aged dogs. Another factor that may contribute to the negative association between human age and activity level in PA dogs is the potential for higher vigilance in older dog owners. Certain fears people have about unleashing their dogs have been reported in the literature. The fear of unleashing due to other, potentially aggressive dogs and breeds is one example. Some owners have also reported leashing dogs in order to minimize any effects their unleashed dogs might have on others [12]. Although these precautions have not been directly linked to human age, Davey [49] reported a heightened sense of fear towards dogs in individuals aged >45 years relative to those he considered middle aged, suggesting a potential for these opinions to form with age.

Regarding the results within the NPA dog population, we did not detect an association between *Giardia* spp. infection and off-leash activities in areas outside of parks, or with the amount of time dogs spent in the backyard, but did detect a negative association between *Giardia* spp. infection and frequency of cleaning up dog faeces from the backyard. However, the low number of NPA dogs positive for *Giardia* spp. (4/157) reduced the statistical power within this subpopulation and therefore precludes confirmation of these results.

The overall prevalence of *Giardia* spp. in PA dogs is less than reported within a previous year and similar geographical area [16]. Although sample collection design differed between the past and present studies, there may be a minor underestimate in overall prevalence in the current study due to operator bias, presuming the senior operator is more adept at preparing samples for microscopy. Smith *et al.* [16] reported a 19% *Giardia* spp. prevalence in adult, PA dogs with all samples prepared by the same senior operator from the current study. This prevalence is slightly higher (19.6%) when including only dogs

with an elevated frequency of park use (i.e. at least once a week). Within the current study, we report an 8.3% prevalence of *Giardia* spp. in adult PA dogs that visit the park at least once per week. However, when considering only those dog samples prepared by the senior operator, the prevalence increases to 13.7%. Whether or not an operator bias in the current study affected overall prevalence, temporal *Giardia* spp. prevalence variation is not unusual [50], and therefore natural fluctuation may account for some of the difference in *Giardia* spp. prevalence between the past and present studies. Additionally, the operator bias does not affect the implications of our results for either dog or human health, as the senior operator prepared more NPA and fewer PA dog samples than the other operators, thus the significantly lower overall prevalence of *Giardia* spp. in the NPA relative to PA dog subpopulations remains supported. Moreover, upon re-analysing some of the statistics using only the senior operator's data, including both the χ^2 exact test [37] used to determine off-leash frequency as a potential confounder, as well as the QUEST [40] with *Giardia* spp. presence or absence as the dependent variable (data not shown), the results remained unchanged. Last, the senior operator was the only person to conduct microscopy, eliminating any further effects of operator bias. Our investigation into operator bias strengthens our findings, and we encourage consideration of a similar type of analysis in future research, as a critical component in interpreting results.

Despite the risks certain recreational activities within parks can pose for infection with *Giardia* spp. in adult dogs, parks also provide areas of social and physical activity beneficial for dogs, dog owners, and non-dog owners [13, 51, 52]. We recommend the continued use of parks for on-leash and off-leash dogs and their human companions, but also recommend that dog owners exercise responsibility in maintaining healthy parks and dogs by minimizing environmental contamination, e.g. ensuring the proper disposal of dog faeces. Further, city-led enforcement for the proper disposal of faeces, and educational initiatives regarding responsible park use and geared towards veterinarians about the regional status and risk factors for *Giardia* spp. infection is recommended, particularly targeting younger PA dog owners, as well as those who own young dogs. Approximately 33% and 8.5% of NPA dog owners surveyed for this study reported that they did not attend parks primarily because of the presence of off-leash dogs and undisposed dog faeces,

respectively (data not shown). Providing designated fenced areas for off-leash dogs that are conveniently located within heavily used parks may help appease offended individuals and encourage park use for both dog owners and non-dog owners. Also recommended is public involvement in park management. Understanding the needs of citizens first hand may improve the likelihood of success. Enjoying the benefits of parks with a reduced concern regarding the potential negative effects of park use should be the objective for park managers, public health, and dog owners.

There are some limitations to this study. First, because both PA/on-leash and NPA subpopulations were associated positively with human age, it is possible that in addition to the reduced frequency of unleashing their dogs in parks, these older age groups walked for shorter periods of time than younger dog owners, overall. If so, this latter behaviour could also potentially contribute to reduced exposure of these dogs to infection sources and therefore reduced risk of parasitism for these dogs. On the other hand, younger dog owners may have less time than older dog owners to walk with their dogs, and therefore the reverse could be true. Either way, we did not measure how long dogs were walked for, and therefore cannot confirm whether or not this affected the rate of *Giardia* spp. infection. Also, only about 10% of the sample was in a senior age group (>65 years), i.e. retirees potentially with more time or those that may have a higher potential for restricted mobility. So although the way in which older relative to younger age groups walked their dogs tended to differ in this study (i.e. park attendance and frequency of unleashing dogs), we do not expect considerable variation in walking duration among these dog owners. Another potentially limiting factor of this study is the incomplete investigation of NPA dogs. Many activities that could potentially contribute to *Giardia* spp. infection in NPA dogs were not addressed and the sample size was small, therefore our results pertaining to this subpopulation are less conclusive than the more thoroughly investigated PA population. Further, we did not directly measure the amount of environmental contamination PA or NPA populations were exposed to, so can only speculate the degree to which contamination affected *Giardia* spp. infection in these subpopulations. Last, selection bias is possible due to the nature of online data collection; although we conducted a small proportion of interviews over the phone, the majority of surveys were completed online. As a result, we may have marginalized certain

demographics of dog owners, such as the elderly and disabled, people with lower levels of education and literacy, and individuals with English as their non-dominant language.

CONCLUSION

Park attendance poses a risk for *Giardia* spp. infection in dogs that are permitted off-leash and to swim. Dog owners who were middle-aged or older were less likely to allow their dogs to participate in risk-related activities in parks. Park attendance is still encouraged for the health benefits it provides for humans and dogs; however, adjustments to current practices within parks are recommended. These measures include systematic and prompt removal of dog faeces, education initiatives targeting dog owners with dogs at a higher risk of infection with *Giardia* spp., and engaging the public in the management process.

SUPPLEMENTARY MATERIAL

For supplementary material accompanying this paper visit <http://dx.doi.org/10.1017/S0950268815000400>.

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DECLARATION OF INTEREST

None.

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