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If they could choose: How would dogs spend their days? Activity patterns in four populations of domestic dogs

Silja Griss[a], Stefanie Riemer[b], Charlotte Warembourg[a], Filipe Maximiano Sousa[a], Ewaldus Wera[c], Monica Berger-Gonzalez[d,e], Danilo Alvarez[d], Petrus Malo Bulu[c], Alexis López Hernández[d], Pablo Roquel[d], Salome Dürr[a,*]

[a] Veterinary Public Health Institute, Vetsuisse Faculty, University of Bern, Schwarzenburgstrasse 161, Bern 3097, Liebefeld, Switzerland
[b] Companion Animal Behaviour Group, Division of Animal Welfare, Vetsuisse Faculty, University of Bern, Bern, Switzerland
[c] Kupang State Agricultural Polytechnic (Politeknik Pertanian Negeri Kupang), West Timor, Indonesia
[d] Universidad del Valle, Guatemala City, Guatemala
[e] Swiss Tropical and Public Health Institute, University of Basel, Basel, Switzerland

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ABSTRACT

Although free-roaming domestic dogs (FRDD) constitute the majority of the dog population worldwide, many aspects of their ecology across habitats are little known. Activity budgets by these dogs may also inform management decisions for domestic dogs in human hands. Here we collected data on the activity patterns of owned FRDD from Guatemala (n = 58) and Indonesia (n = 37), and of farm dogs (n = 11) and family dogs (n = 20) in Switzerland. The FRDD from the two countries and the Swiss farm dogs shared the similarity that although they had owners, they spent most or all of the day outside without confinement. Conversely, activity in family dogs is largely controlled by their owners. This cross-continental study thus allowed us to tease apart environmental effects on dogs' activity from effects due to different levels of control by humans. Dogs were collared with FitBark activity trackers, which measure 3D acceleration, for 2.4–7 days. Activity for each dog was defined as the sum of BarkPoints (a continuous activity metric recorded by the FitBark tracker), calculated for each hour in the 24-hour cycle. The proportion of time resting, in 'moderate' and 'high' activity (defined by fixed thresholds of BarkPoints) over 24 h was calculated for each dog. The activity patterns of all dogs that (partly) roam freely, i.e. owned FRDD in Guatemala and Indonesia and Swiss farm dogs, showed two peaks over 24 h during 5:00–7:00 h and, less pronounced, 16:00–19:00 h. Such a bimodal activity pattern, which is also observed in other canine species, could only be detected in 45% of the family dogs. Their activity is more dependent on the owners' daily routines and predominantly showed one high mid-day peak that often changes from day to day. Swiss dogs spent significantly more time resting and less time with 'moderate' activity than the owned FRDD. However, family dogs were significantly more often highly active than all other dog groups and compensated with longer resting periods. Activity decreased significantly with age, neutering and increased body condition score, whereas sex did not have any significant influence on activity. Within this study, similarities, but also differences of the activity pattern between owned FRDD and pet dogs could be revealed. Although overall activity levels of the pet dog sample fall in the range of those observed in the less controlled FRDD, it would be of interest to investigate the potential benefit of a more structured daily schedule on pet dogs in future studies.

1. Introduction

The dog (*Canis familiaris*) was the first species to be domesticated around 15–30,000 years ago (Freedman et al., 2014; Irving-Pease et al., 2018; Skoglund et al., 2015). Today, the global domestic dog population contains an estimated 900 million individuals and represents the most abundant species of carnivores (Gompper, 2013). Only 15–25% of them are pet dogs (Gompper, 2013; Hughes and Macdonald, 2013), kept for reasons such as companionship, assistance to handicapped people, military or police work, breeding or sports. For their entire life, they are managed under direct supervision of humans, making them dependent on their owners' keeping practices. The majority of domestic dogs

* Corresponding author.
E-mail address: salome.duerr@vetsuisse.unibe.ch (S. Dürr).

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worldwide belong to the group of stray dogs (Gompper, 2013). They are predominantly found in Africa, Asia and Latin America. Stray dogs are commonly divided into three categories, based on their level of dependency from humans (World Organisation for Animal Health, O.I.E, 2009a, 2009b). The first category comprises feral dogs that do not depend on humans for feeding or breeding. The second category includes dogs that do not have a dedicated owner but rely on local communities for feeding. They may be referred to as neighborhood or village dogs (Flores-Ibarra and Estrella-Valenzuela, 2004; Ortolani et al., 2009). The third category consists of owned dogs that are allowed to roam without restriction or supervision. Dogs from the last two categories are also called free-roaming domestic dogs (FRDD) (Bombara et al., 2017; Dürr et al., 2017; Warembourg et al., 2020). Owned dogs generally account for the majority of the FRDD population in Africa, Asia and Latin America, with the proportion of ownerless dogs ranging from 0% to 20% (Dürr et al., 2009; Gsell et al., 2012; Matter et al., 2000; Muthiani et al., 2015; Touihri et al., 2011; Warembourg et al., 2020). However, studies performed in India and Bangladesh indicated that a larger fraction of the population was constituted of ownerless individuals with 61.5% and 40%, respectively (Hossain et al., 2013; Sudarshan et al., 2001).

Regardless of the geographical location, owned FRDD populations share some common features. Males often account for the largest part of the population (Czupryna et al., 2016; Mauti et al., 2017; Morters et al., 2014a; Pulczer et al., 2013; Van Kesteren et al., 2013), neutered animals are rare, unless sterilization campaigns have recently been undertaken (Hiby et al., 2011; Kitala et al., 2001; Morters et al., 2014b; Wera et al., 2015), turnover is high due to low reproduction control and high mortality rates (Acosta-Jamett et al., 2010; Conan et al., 2015), and life expectancy is often low (Mauti et al., 2017). Owners tend to keep FRDD for various purposes, such as guarding, herding, hunting, companionship, selling or meat consumption (Warembourg et al., 2021). However, the most prevalent reason for keeping dogs is guarding the house and livestock (Bouli et al., 2020; Van Kesteren et al., 2013; Warembourg et al., 2021).

Little is known about the daily activity patterns of FRDD, i.e. dogs that can make everyday life decisions on their own, without much human influences. One of the first documentations of daily behaviour pattern of urban dogs dates back to 1975 (Beck, 1975). Beck studied the ecology of FRDD in the city of Baltimore (USA) and observed a tendency for two main activity peaks during the day; the first peak in the morning around 5:00–8:00 h, and the second peak in the evening between 19:00–22:00 h. Those two periods were especially notable during the summer months. He pointed out that the observed absence of activity at midday during summer might be interpreted as heat avoidance (Beck, 1975). A study investigating FRDD in an urban environment in India revealed that dogs concentrated their activity on times of higher activity of humans in the streets (Majumder et al., 2014). Thus, the dogs were active primarily between 6:30–10:30 h and again between 16:30–19:30 h, and spent the middle of the day mostly resting (Majumder et al., 2014). Such a bimodal activity distribution was also observed in wild canids, such as wolves (*Canis lupus*) and red fox (*Vulpes vulpes*), in different environments, suggesting that the linkage with human activity cannot be the only reason for this pattern (Boitani and Cuicci, 1995; Kusak et al., 2005; Theuerkauf et al., 2003; Zingaro and Boitani, 2018). A similar study on dingoes, however, contradicts a regular, two-peak activity pattern in canids (McNeill et al., 2016). They found that the majority of the 37 tracked dingoes were primarily nocturnal, suggesting that this related to the time period of low human activity and abundance of their prey (McNeill et al., 2016).

In Western societies, domestic dogs are mostly kept as pet dogs and their activity is almost fully controlled by humans. Thus, they are much less able to shape their activity patterns according to their own needs. It is currently unknown how the activity of owned FRDD, which are largely independent from humans, compares with activity in pet dogs that are under high level of human control.

Nowadays, technology is available to provide detailed measures of animals' activity for a full 24-hour cycle in an objective manner. For example, FitBark activity trackers (https://www.FitBark.com) have been used in several studies investigating effects of breed, weight, age or sex on activity patterns in pet dogs (Di Cerbo et al., 2017; Patel et al., 2017; Zamansky et al., 2019). The advantage of using tracking technology for this purpose is that activity is recorded over 24 h, providing a more objective and unbiased measurement than point sampling, and that a potential disturbance by the human observers can be ruled out. A recent study demonstrated that FitBark measurements are highly correlated with observations of dogs' off-leash physical activities (Colpoys and DeCock, 2021). Thus, activity tracking is a useful tool to complement observational studies (Bhattacharjee and Bhadra, 2020; Majumder et al., 2014) of the activities of free-roaming dogs.

The aim of the current study was to compare activity patterns of pet dogs (which are fully dependent on humans) with those of FRDD (owned, but much less controlled by humans) in four domestic dog populations on three different continents. Using FitBark activity trackers, we investigated the activity patterns over a 24-hour cycle of owned FRDD from Indonesia and Guatemala, as well as of family pet dogs in Switzerland and of yard dogs living on Swiss farms (hereafter referred to as farm dogs). Farm dogs in Switzerland are allowed to roam freely at least part of their time, and sometimes they are not confined at all, similarly to the owned FRDD in Indonesia and Guatemala. Family dogs in Switzerland are kept indoors in houses or flats and can only leave the house when the owner takes them for a walk. Some family dogs have a small garden available for their use.

Studying dogs with little human intervention from three continents allowed us to assess how the environment affects species-specific activity patterns, while the comparison with pet dogs enabled us to assess to which extent pets have patterns of activity that resemble those of their free-roaming counterparts. This may be of particular interest regarding ideal management schedules for pet and working dogs.

2. Materials and methods

2.1. Study population

A total of 126 dogs from three countries were included in the study. They are divided into four groups: 58 owned FRDD from Guatemala, 37 owned FRDD from Indonesia, 20 family dogs from Switzerland, and 11 farm dogs from Switzerland. Fieldwork related to the FRDD was conducted in the frame of a larger research project on FRDD ecology in Guatemala and Indonesia (Warembourg et al., 2021, 2020).

Ethical approval was obtained in each country. In Guatemala, it was granted by the Universidad del Valle de Guatemala International Animal Care and Use Committee (Protocol No. I-2018(3)) and by Ethics Review Board (ERB) of the Committee for Research on Human Subjects of the Center for Health Studies in UVG (Protocol No. 175-04-2018); in Indonesia, ethical clearance was granted by the Animal Ethics Commission of the Faculty of Veterinary Medicine, Nusa Cendana University (Protocol KEH/FKH/NPEH/2019/009); and in Switzerland, the study was approved by the authorities for animal experimentation in the cantons of study execution (Bern, Basel-Stadt and Basel-Land, Licence number BE115/17). In addition, all the dog owners were informed about the goals and conditions of the study and they gave an informed consent a priori to the experimentation.

2.2. FitBark trackers: devices used for measuring activity

Dogs' activity patterns were measured with FitBark trackers (https://www.FitBark.com). FitBark trackers are small (3.5 ×2 cm/ 17 g) and waterproof devices, easily attachable to a dog collar (Supplementary Fig. S1). The tracker includes a 3D accelerometer that continuously generates multiple readings per second that are then cumulated over a one-minute period. These so-called "BarkPoints" represent a proxy measure for the physical activity of the observed dog. The number of

BarkPoints were recently shown to correlate highly with the observed step count of off-leash dogs (Colpoys and DeCock, 2021), and we therefore consider this device as suitable for our study.

Each tracker is associated with the FitBark mobile application (FitBark-App), accessible for iOS and Android systems. To fetch the activity data, trackers are connected via Bluetooth to the FitBark-App. The data are then transferred to the FitBark server to download the BarkPoints per minute, hour or day in csv format.

2.3. Data collection

2.3.1. FRDD in Guatemala and Indonesia

In Guatemala, the study sites included two villages (La Romana and Sabaneta) and one town (Poptún), all in Petén district, which is located in the northern part of the country. In each study site, an area of 1 km^2 was defined, in which 19 (in La Romana and Poptún each) and 20 (in Sabaneta) FRDD with owners were randomly selected and equipped with FitBark trackers, attached to dog collars. The dogs were collared between May to June 2018. Out of the 58 dogs, 47 datasets (17 from Sabaneta, 14 from La Romana and 16 from Poptún) were suitable for further data analysis. Trackers on ten dogs did not work properly and one dog died during the observation period for a reason unrelated to the study. At the time of collaring, an interview was conducted with the dog owners. Information on age, sex, neuter status, breed and role of the dog was collected. For each dog, a body condition score (BCS) was defined by the researcher team, ranging from 1 (very thin) to 5 (obese), with 3 referring to an ideal condition, according to The American Animal Hospital Association (2010). The FRDD wore the FitBark tracker for 2.4–4.9 days (mean = 3.5), depending on the opportunity to take it off.

The same procedure was applied for the data collection in Indonesia. Thirty-seven randomly selected owned FRDD from three villages (Habi, Hepang and Pogon) on a southeast island of Indonesia (Flores Island, Nusa Tenggara Timur) were equipped with FitBark trackers between July and September 2018. For 10 dogs, no data could be collected due to technical issues with the FitBark trackers, resulting in 27 datasets (12 from Habi, 13 from Hepang and two from Pogon). The duration of collaring in Indonesia ranged from 2.8 to 5.0 days (mean = 4.1).

2.3.2. Family and farm dogs in Switzerland

The family dogs in Switzerland represented a convenience sample recruited via veterinary practices within the cantons Basel-Land and Basel-Stadt. Dog owners who agreed to participate were selected according to the inclusion criteria mentioned below. For the recruitment of the farm dogs, farmers who were clients at the ruminant hospital of the Vetsuisse Faculty in Bern and owned a dog were contacted and invited to participate in the study. In addition, some farmers in the region of Basel were selected by convenience. We aimed at matching the study population of Switzerland with the one of the FRDD. Therefore, we excluded dogs younger than four months and older than ten years of age, as well as very small (<30 cm shoulder height) and very large (>65 cm shoulder height) breeds. Only dogs with no acute illness or injury were included in the sample. The selected dogs were collared with the trackers either in May or August 2019. In both collection periods, all dogs were collared on the same weekend, and the collars were retrieved seven days later, ensuring data collection over a full week.

In May 2019, 11 family dogs were collared, of which one tracker did not work. The dog with the broken tracker was re-collared in August 2019, in addition to nine other family dogs, leading to a study sample of 20 family dogs. Eight farm dogs were collared in May 2019, however, four of the trackers did not work correctly. These dogs were re-collared in August together with three additional dogs, leading to a total study sample of 11 farm dogs.

On the day of collaring, every dog was visited at its home. The BCS was defined for each family and farm dog and all owners completed a questionnaire to collect information on the sex, neuter status, age, breed, size, weight, function and health of their dogs. Family dog owners were asked to complete a sheet when they take their dogs for a walk.

2.4. Data analyses

2.4.1. Definition of activity metrics

After data collection, data from the trackers were downloaded from the FitBark server to retrieve the number of BarkPoints per minute and hour for each dog. The number of BarkPoints per minute was used to categorize them into three activity levels: resting, 'moderate' activity (walking) and 'high' activity (running or playing), according to FitBark's confidential threshold. The mean hourly level of activity within the 24-hour cycle was calculated for each of the 105 dogs by taking the mean number of BarkPoints for each hour of the day (00:00 – 24:00) across all sampled days. This approach was chosen in order to standardize the influence of individual dogs, as dogs wore the tracker for varying number of days due to practical constraints in the field. The sum of these 24 hourly BarkPoint values were defined as outcome metrics to compare study populations and individual dogs. Based on the number of BarkPoints per minute, the percentage of each activity level (resting, 'moderate' activity and 'high' activity) was calculated for each dog.

Statistical analyses were performed in R (https://cran.r-project.org).

2.4.2. Identifying factors influencing activity

The influence of different factors on the activity of the dogs was assessed by linear regression analyses, using the sum of the hourly mean BarkPoints of each dog as dependent variables. Additionally, the percentages of minutes spent in each of the three different activity levels (resting, 'moderate' activity, 'high' activity) were used as dependent variables. Normality of all of the five dependent variables was assessed with Shapiro-Wilk tests and graphical exploration using the function of *qqnorm()*. The variable resting was log transformed to achieve normality, whereas for all other variables a normal distribution could not be rejected. First, univariable linear regression analyses (function *lm()* of the package *stats*) were conducted to investigate the effect of the independent variables age, sex, BCS and study population (Swiss family dog, Swiss farm dog, FRDD Guatemala, FRDD Indonesia) on the four activity outcomes. The effect of the independent variables neuter status and the month (May versus August) was additionally tested for the Swiss dogs separately. Furthermore, the effect of the independent variable home range size of the individual dogs, calculated as described in Warembourg et al. (2021), on the activity metrics for the FRDD populations in Indonesia and Guatemala was analysed, as data to calculate home range size for the Swiss dogs were not gathered. In a second step, independent variables with p-values < 0.2 in the univariable analyses were included in multivariable regression models (function *lm()*) with the same dependent variables as in the univariable models. A stepwise backwards approach was applied and the model with the lowest AIC was selected as final model. Associations between age and BCS (Spearman rank correlation test *cor.test(method="spearman")*) and between age and neutering (Wilcoxon rank sum test, *wilcox.test()*) were explored.

For the family dogs, we investigated whether activity levels were larger during the hours when the owner stated to have (1) or have not (0) taken the dogs for a walk. We applied a Wilcoxon rank sum test comparing the hourly activity levels of those hours when the dogs was walked with those when the dogs were not walked.

2.4.3. Activity patterns over the 24-hour period

A mixed effect linear regression model (function *lmer()* of the package *stats()*) was applied for each study population separately. In the model, the absolute number of hourly BarkPoints (log transformed to achieve a normal distribution) was used as dependent variable, the 24 h as independent categorical variable, and the dog as random effect. The Tukey Honest Significant Differences (HSD) test (function *TukeyHSD()*) was used as post-hoc test to investigate differences in activity between each pair of hours adjusted for multiple comparisons.

3. Results

3.1. Study population

Males and females were distributed equally within each study population, with the exception of Guatemala, where more male dogs were collared (Table 1). The majority of dogs in Switzerland were neutered, whereas this was the case for only one FRDD of Guatemala and two dogs in Indonesia. Age and BCS were higher in Swiss dogs than FRDD, while both variables were lowest in the Indonesian dogs. Most FRDD were kept as guard dogs, but some also as pet and hunting dogs. All FRDD are kept at least part of their time free-roaming in similar conditions, including those kept for the main purpose of sale or meat source. All family dogs were partially off leash during walks.

3.2. Study population and other factors influencing dogs' activity

Based on the univariable regression analyses, most variables were found to be significantly associated with at least one of outcome variables ($p < 0.05$, Table S1). The variable study population met the criterion for further inclusion in the multivariable model ($p < 0.2$) for all four investigated outcome variables (percentage of time spent resting, with 'moderate' activity and with 'high' activity, and the sum of the BarkPoints over 24 h (Table S1). The same was true for age; younger dogs were more active than older dogs. Sex was only related to 'moderate' activity in the univariable analyses, with males spending more time in 'moderate' activity than females. The higher the BCS, the lower was the activity, with p-values < 0.2 for all outcome variables, except for the time spent in 'moderate' activity. An effect of neuter status within the Swiss dog populations (family and farm dogs) with a p-value < 0.2 was detected for the outcome variable time spent in 'high' activity (Table S2). The variable season (collected during May or August) in the Swiss study populations revealed p-values < 0.2 for the outcome variables resting time and 'moderate' activity. For 48 of the 74 FRDD in Guatemala and Indonesia, the home range size was available, and an association with a p-value < 0.2 was revealed for the outcome variable 'moderate' activity and resting (Table S3).

The best fitting multivariable regression models revealed that Swiss family dogs and FRDD in Indonesia had a significantly higher sum of BarkPoints compared to the FRDD in Guatemala (Table 2, Fig. 1). Swiss family dogs and farm dogs spent similar times resting (14.1 and 13.4 h, respectively). These two populations spent significantly more time with resting compared to FRDD in Indonesia and Guatemala (10.8 and 11.3 h, respectively; Table 2, Fig. 1). FRDD in Indonesia and Guatemala spent significantly more time in 'moderate' activity (11.2 and 11.3 h, respectively) compared to Swiss dogs, while the comparison of Swiss family with farm dogs revealed that farm dogs were more often in 'moderate' activity (9.2 h) than family dogs (7.8 h). Investigating the 'high' activity level, Swiss family dogs were found to be the study population that spent most time with (2.2 h), significantly more than farm dogs (1.4 h), FRDD in Indonesia (2.0 h) and Guatemala (1.4 h). The best fitting model also include age as co-variate for all four outcomes, and the BCS for two outcomes (Table 2). The correlation between BCS and age was found to be low, but significantly different from no correlation (Spearman Rank correlation test, rho = 0.28, p-value = 0.0035; the younger the dogs, the lower the BCS). While the effect of BCS was never significant in the multivariable models when correcting for age, age was found to significantly influence all outcomes except for time spent in 'moderate' activity (Table 2). The younger the dogs, the more active they were.

In the multivariable models of the Swiss dog population, where neuter status and season (May versus August) were investigated in addition to the predictors in the full dataset, neutering was found to be associated with a significantly lower time the dogs spent in 'high' activity (Table 3). Neutering was significantly associated with age (Wilcoxon rank sum test W=46.5, p-values = 0.009), with older dogs being more likely to be neutered. In August, the dogs were found to spend less time resting and more time in 'moderate' activity compared to those sampled in May. Unlike in the full dataset, in the Swiss dogs, the BCS significantly influenced the time dogs spent in 'high' activity, with dogs of higher BCS showing less activity. A low to moderate correlation between age and BCS was revealed in the Swiss dataset (Spearman's rank correlation rho= 0.364, p-value = 0.044). Differences between farm and family dogs remain the same as detected in the full dataset (Table 2).

Amongst the FRDD in Guatemala and Indonesia, for which the influence of the home range size on the activity was explored, this parameter (in ha) was only found to significantly influence the time dogs spent with 'moderate' activity (coefficient = −0.20, SE = 0.09, p = 0.032), but neither the time the dogs spent resting (coefficient = 0.003, SE = 0.002, p = 0.139), nor with 'high' activity (coefficient = 0.04, SE = 0.05, p = 0.438), nor the home range size was associated with the total number of daily BarkPoints (coefficient = 26.54, SE = 59.24, p = 0.656).

3.3. Activity patterns over the 24-hour period

In the study population of FRDD in Guatemala, a noticeable activity peak was observed in the morning hours (Fig. 2, level of significance shown in supplementary Fig. S2). Most dogs started to be active between 4:00 and 5:00 h, with a significant increase in activity detected by the mixed effect regression model ($p < 0.01$) in these hours. The activity peaked at 7:00 h. Thereafter, dogs' activity decreased again and remained low (but still higher compared to the night's activity) until late afternoon. It increased again around 17:00 h and reached a second peak between 18:00 and 19:00 h. The activity decreased significantly between 19:00 and 22:00 h, reaching the lowest activity at 22:00 h. Two dogs showed considerable activity during the night. Those individuals were still active during the day.

The FRDD of Indonesia showed a clear morning and late afternoon activity peak (Fig. 2, supplementary Fig. S2). According to the mixed effect model results, activity increased significantly ($p < 0.01$) between 4:00 and 5:00 h with a peak at 6:00 h. In most dogs, activity was low between 9:00 and 12:00 h, which was comparable (thus not significantly different) with the activity during the night. After noon, the activity increased again and hit a second peak at 17:00 h, with a rapid significant decrease between 17:00 and 19:00 h. Some individuals showed modest

Table 1
Structure of the study population of owned free-roaming domestic dogs (FRDD) from Guatemala and Indonesia, Swiss family dogs and Swiss farm dogs in a study to investigate activity patterns. Data was collected in 2018 and 2019.

	FRDD Guatemala	FRDD Indonesia	Swiss Family dogs	Swiss Farm dogs
Total numbers of dogs	47	27	20	11
Male intact	32 (97%)	12 (86%)	2 (20%)	2 (40%)
Male neutered	1 (3%)	2 (14%)	8 (80%)	3 (60%)
Female intact	14 (100%)	13 (100%)	4 (40%)	2 (33%)
Female neutered	0	0	6 (60%)	4 (67%)
Mean (range) of age in months	29 (4–120)	15.1 (4–60)	52.7 (6–104)	59.4 (17–125)
Mean (range) of BCS[a]	2.66 (2–4)	2.27 (1–4)	2.9 (2.5–4)	3.18 (2.5–4)
Keeping reason[b]	44	26	0	11
Guard dog	14	6	20	11
Pet dog	10	0	0	0
Hunting	1	0	0	0
Shepherd	0	5	0	0
Meat source	0	1	0	0
For sale	0	0	2	0
Sports	0	0	1	0
Social dog				

[a] ranging from 1 to 5 (1 =very thin; 3 = ideal condition; 5 =obese)
[b] multiple answers possible

Table 2
Results from the best fitting multivariable regression models assessing the influence of dog-related factors and population (FRDD dogs in Guatemala and Indonesia, Swiss farm and Swiss family dogs) on the four outcomes (sum of BarkPoints over 24 h and percentage of time dogs spent resting, 'moderate' and 'high' activity). The study population variable was tested and presented separately for each variable level as reference.

	Sum of daily BarkPoints			*Resting (log)*			*Moderate Activity*			*High Activity*		
Variable	Coeff	S.E.	P-value	Coeff	S.E.	P-value	Coeff	S.E	P-value	Coeff	S.E.	P-value
Age	-35.6	13.4	**0.009**	0.001	0.0005	**0.011**	-0.04	0.02	0.102	-0.03	0.01	**0.007**
BCS	-642	532	0.231							-0.49	0.49	0.312
Study population – reference family dogs												
Farm	-1972	1243	0.116	-0.05	0.05	0.249	6.06	2.08	**0.004**	-2.84	1.13	**0.014**
Guatemala	-2465	938	**0.01**	-0.2	0.04	**< 0.001**	13.87	1.57	**< 0.001**	-3.95	0.85	**< 0.001**
Indonesia	-214	1137	0.851	-0.22	0.04	**< 0.001**	12.91	1.83	**< 0.001**	-2.18	1.04	**0.040**
Study population – reference farm dogs												
Guatemala	-493	1198	0.68	-0.14	0.05	**0.004**	7.81	2	**< 0.001**	-1.11	1.10	0.312
Indonesia	1757	1392	0.21	-0.16	0.05	**0.003**	6.86	2.21	**0.003**	0.66	1.27	0.604
Study population – reference Guatemala												
Indonesia	2251	845	**0.009**	-0.02	0.03	0.46	-0.96	1.37	0.49	1.77	0.88	**0.024**

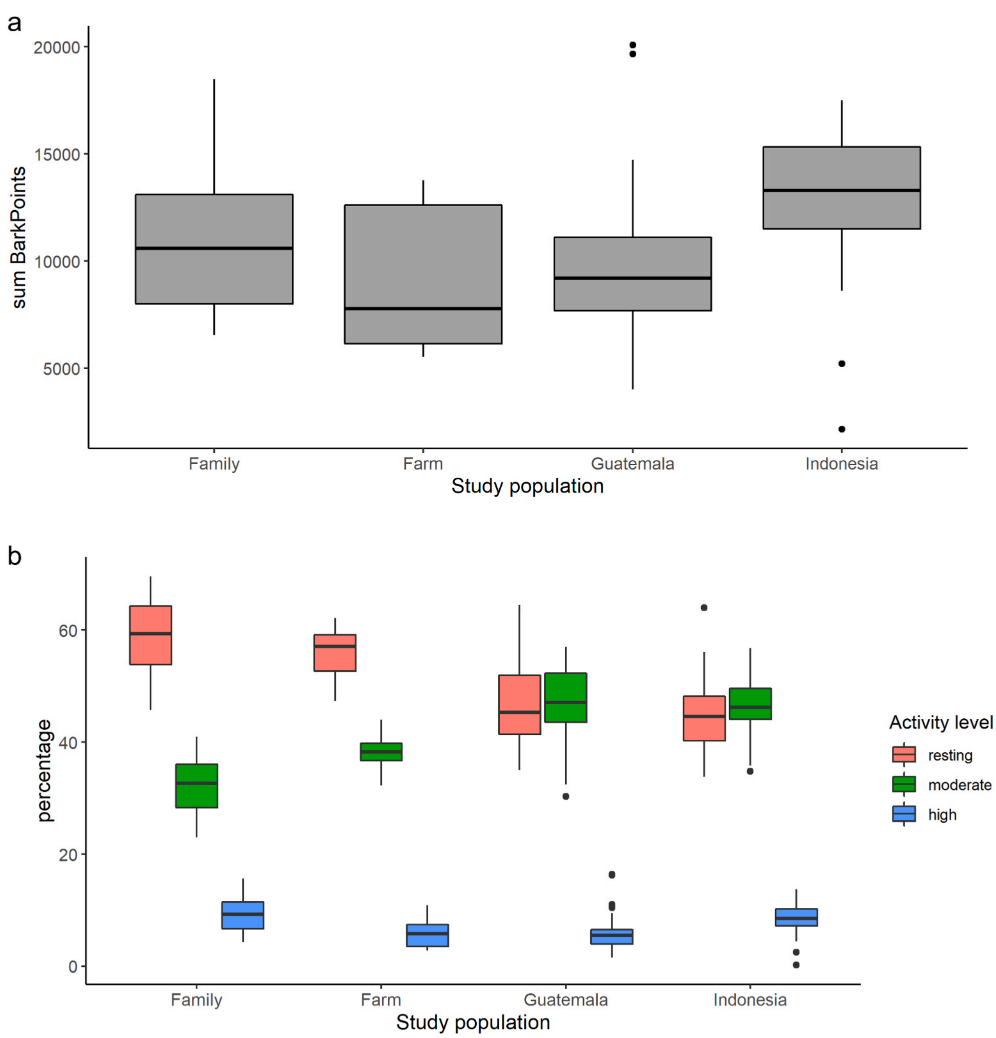

Fig. 1. (a) The sum of hourly BarkPoints over a 24 h period, and (b) the percentage of time individual dogs spent with resting, 'moderate' activity and 'high' activity compared between the four study populations.

activity at night. One dog did not show any activity between 6:00 h and 16:00 h.

Five pairs of FRDD living in the same household could be observed, three pairs in Guatemala and two in Indonesia (Fig. 3, Supplementary Fig. S3). All dogs were males and less than three years of age, with the exception of one 6-year-old female dog. The activity patterns for both dogs in each pair were found to be very similar.

The study population of family dogs did not show a bimodal activity pattern as observed in the other study populations (Fig. 2, Supplementary Fig. S2). Overall, Swiss family dogs had in common that the activity started between 5:00 and 7:00 h, with a significant increase between 5:00–6:00 h and 6:00–7:00 h, as revealed by the mixed effect model. The median activity stayed overall high and decreased again significantly between 19:00–23:00 h. None of the dogs showed activity during the

Table 3
Results from the best fitting multivariable regression models investigating the influence of neutering and months of collaring (May vs. August) season on percentage of time spent resting, with 'moderate' and 'high' activity in Swiss farm and family dogs.

	Resting (log)			*Moderate Activity*			*High Activity*		
Variable	Coeff	S.E.	P-value	Coeff	S.E	P-value	Coeff	S.E.	P-value
BCS							-3.34	-2.39	**0.024**
Study population – reference family dogs									
Farm	-0.04	0.04	0.272	5.18	1.51	**0.002**	-2.3	-2.08	**0.015**
Neutering – reference no neutering									
Yes							-2.87	1.11	**0.015**
Season – reference August									
May	0.08	0.04	**0.032**	-4.6	1.45	**0.004**			

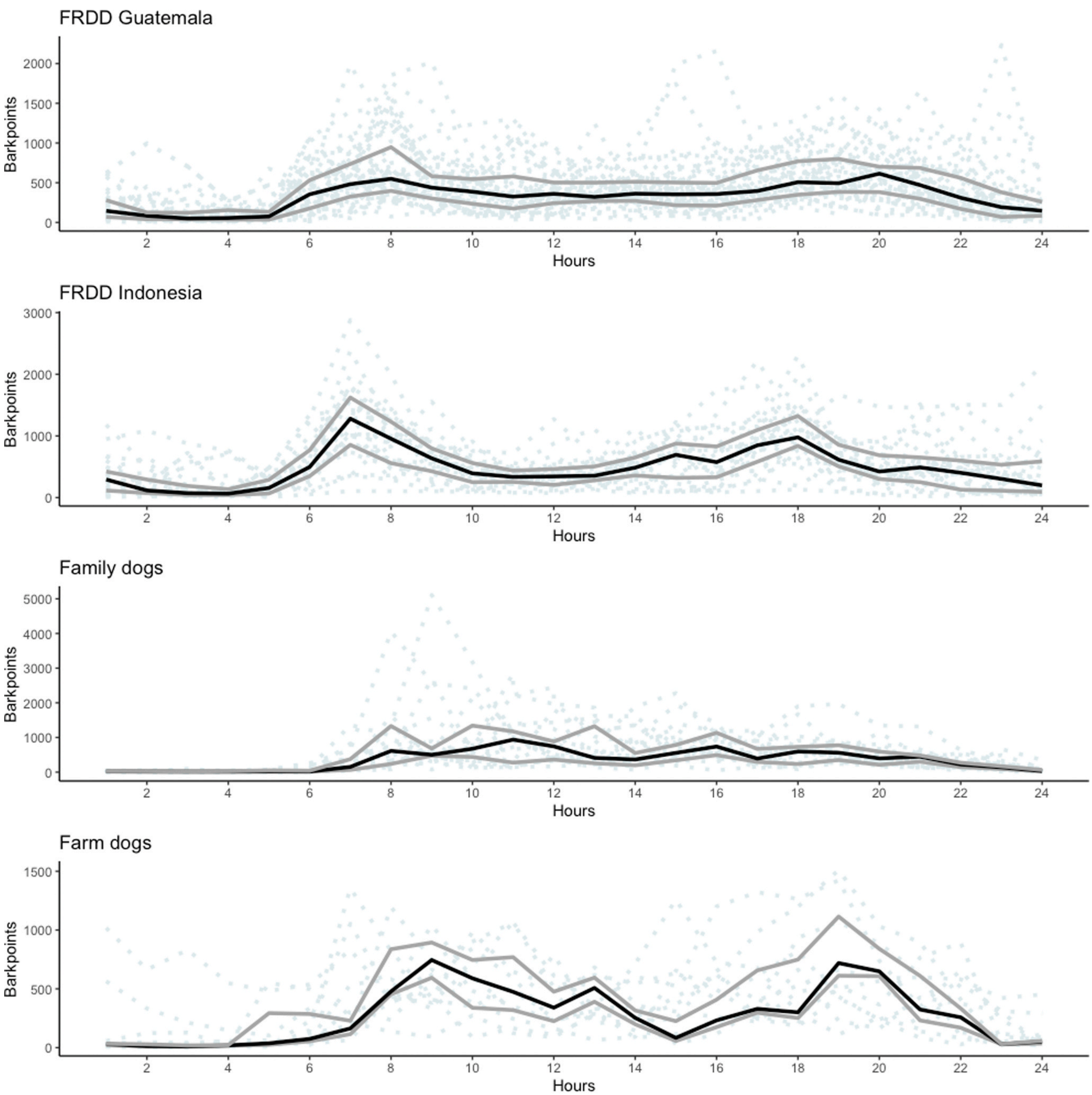

Fig. 2. Activity pattern of a) free-roaming domestic dogs in Guatemala, b) free-roaming domestic dogs in Indonesia, c) family dogs in Switzerland and d) farm dogs in Switzerland over the 24 h cycle. The blank line indicates the median, the grey lines the 25 and 75 percentile values over all dogs. The individual dogs' activities are presented as dotted lines.

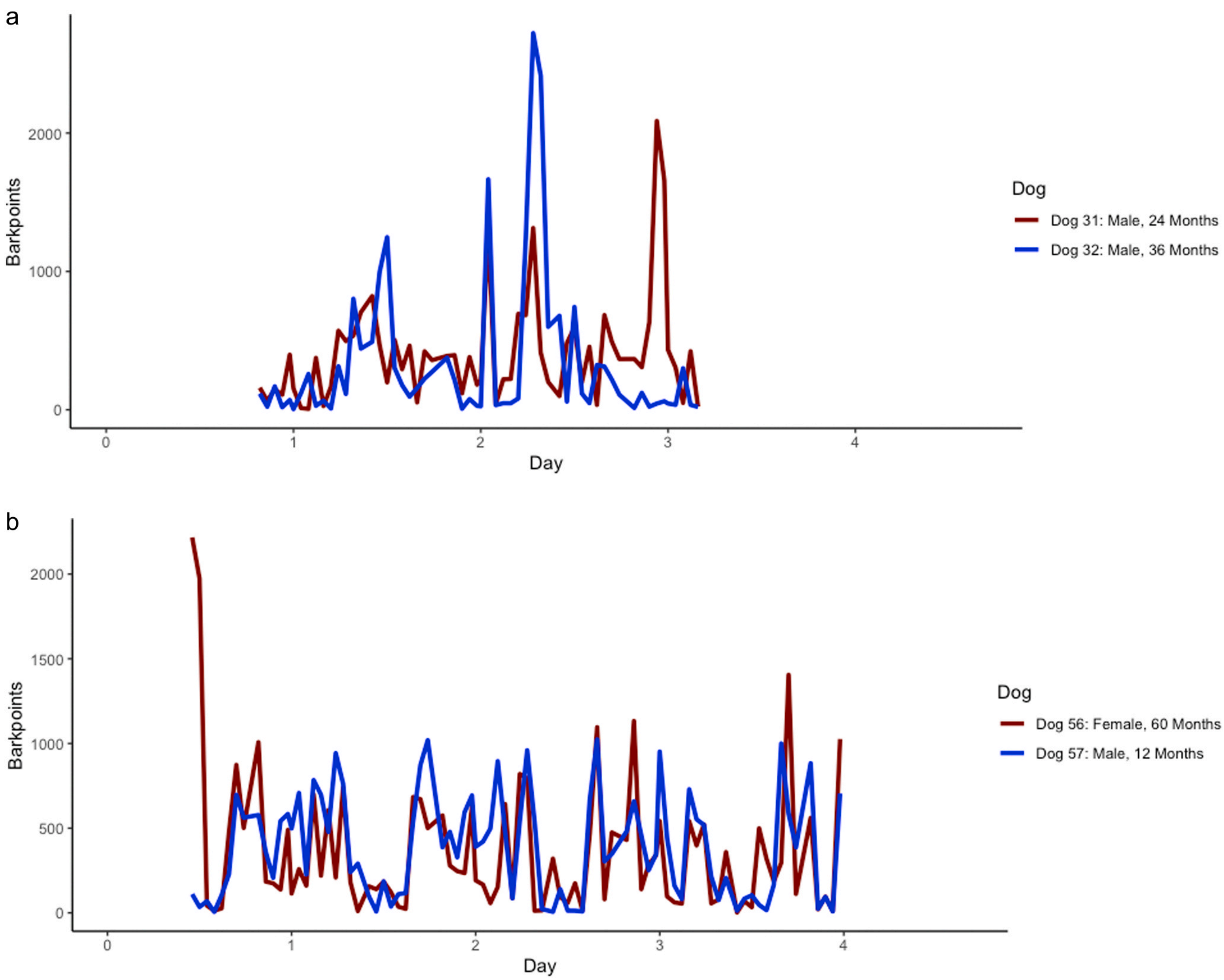

Fig. 3. Activity pattern of free-roaming domestic dogs in the same households over several days of data collection, a) one example pair in Indonesia and b) one example pair in Guatemala; another three pairs of free-roaming domestic dogs living in the same households are presented in Supplementary Fig. S3.

night. For nine (45%) of the 20 family dogs, one activity peak was observed, while for another nine dogs, two peaks were observed. For the remaining two (10%) dogs, the number of peaks change from day to day. By investigating daily data over the course of a week, nine family dogs showed a repetitive pattern with activity peaks at the same time point every day (example dog Fig. 4a), whereas 11 (55%) dogs were found to be active at different times each day (example dog Fig. 4b). For nine dogs, the activity peaks were found to be shifted towards later hours in the mornings during the weekend (Fig. 4a). The activity pattern of the family dogs highly correlated with the records of the owners when they took their dogs for a walk ($p < 0.001$) (Supplementary Fig. S4).

Similar to the FRDD in Guatemala and Indonesia, the study population of Swiss farm dogs showed two activity peaks in the morning between 6:00 and 10:00 h, with the highest activity at 9:00 h, and in late afternoon between 16:00 and 20:00 h, with the highest activity at 17:00 h (Fig. 2). The mixed model analysis revealed a significant change in activity between 4:00–5:00 h and 5:00–6:00 h and again between 21:00 and 22:00 h (supplementary Fig. S2). During the day, no significant change in activity was detected, which was significantly higher compared to night times. Two of the 11 (18%) dogs showed activity at night.

4. Discussion

The activity pattern and activity level of 74 FRDD (47 from Guatemala and 27 from Indonesia) were explored and compared with those of 20 Swiss family dogs and 11 Swiss farm dogs. The activity patterns of all dogs that had at least partly free choice on distributing their activity – i.e. the FRDD in Guatemala and Indonesia and the Swiss farm dogs – showed two activity peaks over 24 h, one in the early morning hours and one in the late afternoon. This consistent finding across continents indicates that bimodal patterns of activity seems to be the preferred pattern in *Canis familiaris*, regardless of environmental circumstances. Such a bimodal pattern was found not only in other studies on FRDD (Beck, 1975; Majumder et al., 2014), but also in other canine species such as wolves or red foxes (Boitani and Cuicci, 1995; Kusak et al., 2005; Theuerkauf et al., 2003; Zingaro and Boitani, 2018). A study on wolves indicated a bimodal pattern, with showed repetitive daily activity levels for about a month, before changes in weather and breeding cycles modified their behaviour, although still maintaining a bimodal pattern (Theuerkauf et al., 2003; Zingaro and Boitani, 2018). Unfortunately, our data did not allow to investigate the repetitiveness of individual activity patterns of FRDD over more than a few days; however, already in the given limited dataset, the two peaks were consistently observed over several days. A study in Northern Australia, investigated how far FRDD in Aboriginal communities travelled away

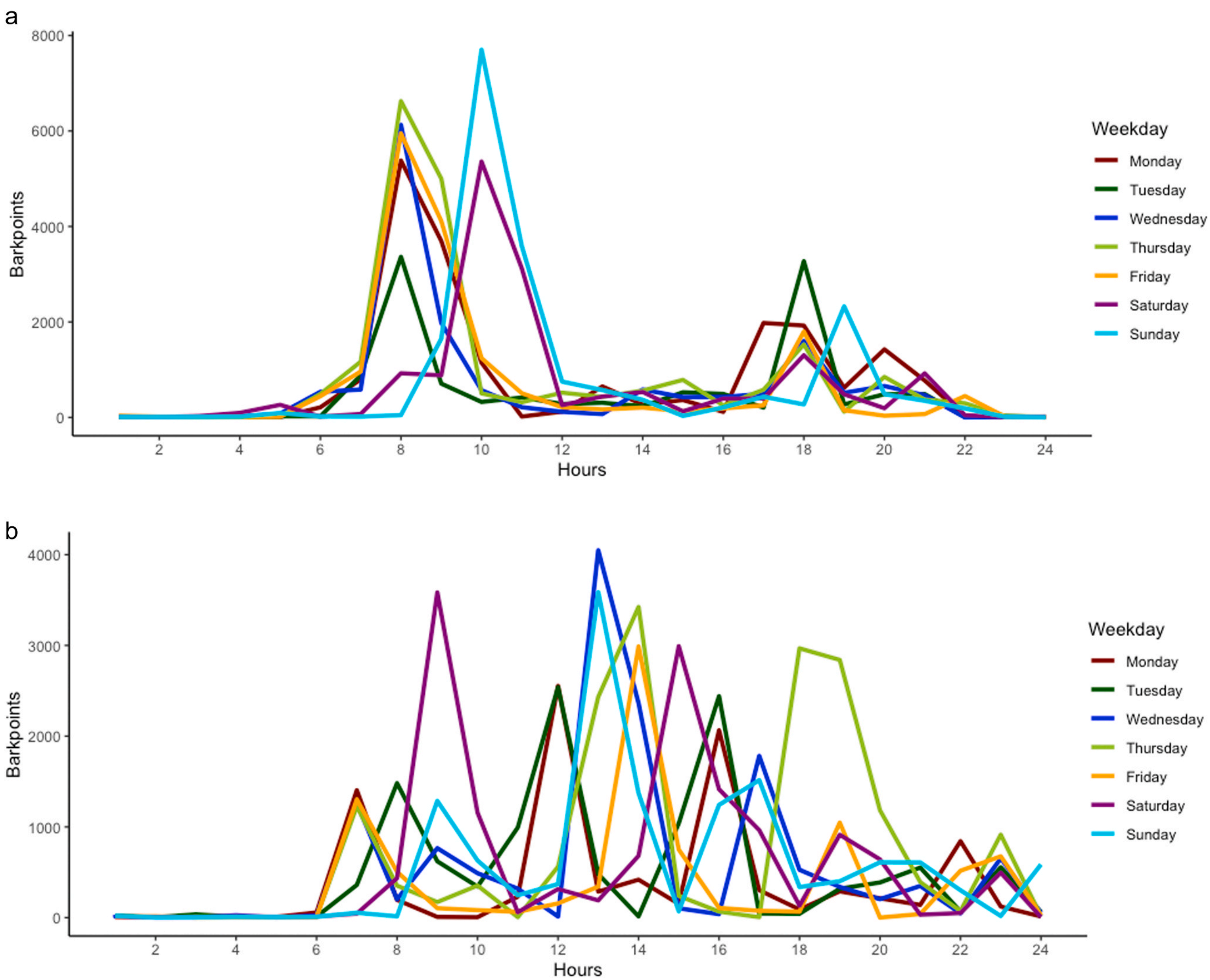

Fig. 4. Examples of a Swiss family dog with a) a regular activity pattern and b) an irregular activity pattern over the course of a week.

from their homes (Maher et al., 2019). In one of their study regions, the authors identified morning and evening activity peaks, whereas in the other region a clear peak was only observed in the evening. This corresponds to the findings of a study performed in India, were FRDD were more active during peak times of humans' activity, especially in the evening hours, and less pronounced during early morning (Banerjee and Bhadra, 2019). In our dataset, we detected almost equal activity patterns in individual dogs that are kept in the same household (five pairs), independent of their age or sex. This may suggest the influence of the owner also on FRDD activity, or that dogs in the same household are socially bonded and act together for reasons other than the owner's activity.

Activity patterns were more variable in family dogs, which are largely dependent on the owners' activity. This is in line with the results of a study on the distribution of activity and rest in five dogs in Italy, which showed that owners' routine and lifestyle influences the activity pattern of pet dogs (Piccione et al., 2014). Nonetheless, for nine (45%) of the 20 family dogs in our study, two activity peaks per day occurred at similar times as the peaks in the FRDD populations. An averaged bimodal activity pattern was also found in a study in North Carolina, US, investigating the activity pattern of 42 pet dogs (Woods et al., 2020). None of the family dogs in our sample showed activity during the night, which is in contrast with the FRDD and farm dog populations. Interestingly, we observed that the overall range of the activity pattern of the family dogs was found to be in the range of those of the three other populations (Fig. 1a), with significantly higher activities compared to the dogs in Guatemala only. This indicates that the owner-driven activities of the family dogs seem to be adapted to the dogs' needs.

On the other hand, the distribution between the three levels of activity differs between the populations. The Swiss family and farm dogs in our study spent more time resting compared to the FRDD. This may be due to the higher level of confinement of most of the Swiss dogs compared to the FRDD study populations, particularly during the night; but may be also caused by other reasons. A study investigating the electrophysiology of domestic dogs' sleep indicated that dogs showed a deeper sleep at night after days of high activity, and when they were resting in their own homes as opposed to not at home (Bunford et al., 2018). In line with this, in our study, FRDD rested significantly less than Swiss dogs. Family dogs showed higher levels of 'high' activity and at the same time rest more, particularly during the night, compared to the dogs of the other study populations. In addition, the clear definition of a dog's home, which is the case in the Swiss family and farm dog populations, may lead to the higher proportion of time spent resting compared to FRDD. Although FRDD in our study still have a defined owner, disturbance in these sites during night may be substantially greater compared to the Swiss dogs homes.

Accordingly, a study on FRDD in various urban areas in Australia found that the proportion of sleep during the night was highest in dogs sleeping indoors, followed by dogs sleeping in an outdoor fenced area, and lowest in dogs that spent the night in an outdoor unfenced area

(Adams and Johnson, 1993). FRDD typically sleep in unfenced outdoor locations in the owners' yards, suggesting that their sleep is less efficient, which was detected by the shorter time spent resting.

In the full dataset, younger dogs were found to be more active than older dogs, confirming previous findings from experimental and observational studies (Siwak et al., 2003; Woods et al., 2020; Zanghi et al., 2013). The BCS was only significantly associated with activity (sum of BarkPoints) in the univariable model. In the multivariable model after adjusting for age, BCS was no longer significant. In the Swiss dog population dataset, although a moderate correlation of these two variables was detected, the best fitting multivariable model only included the effect of BCS on the time spent in 'high' activity. Similarly, the analysis of the Swiss dog population demonstrated that neutering was associated with significantly lower activity. Neutering was also correlated with age, which might explain why neutered dogs seem to be less active. However, the data were better explained by the models including neutering compared to those including age as fixed effect variable, suggesting an influence of neutering beyond the effect of age. A larger home range size in FRDD was only found to be significantly associated with less time the dog spent in 'moderate' activity, but not overall activity (sum of BarkPoints). This implies that dogs with smaller home ranges are still equally active overall as those with larger home ranges.

In our study, we only observed each dog for a single period of time. This limited us from investigating effects of seasonal activities such as mating, denning or lactating, as well as weather and temperature on the activity level of an individual dog. Seasonal mating is debated in FRDD with contradictory findings in studies in several countries (Fielding et al., 2021). Therefore, a repeated measures study with data collection at different seasons using activity trackers would provide insights into individual changes in activity patterns over the year. In a study in Newark, New Jersey (USA), researchers observed higher activity of FRDD when the weather was cloudy (and thus less hot) during summer times (Daniels, 1983). They also found that rain, even if heavy, had only little effect on the activity of the dogs. To reduce potential bias introduced by the weather, we selected sampling weeks in Switzerland with comparable temperature to the one measured during the study period in Indonesia and Guatemala (supplementary Fig. S5). While the temperatures of the four study populations were comparable (25–30 °C), with the exception of the lower temperature in the May sampling in Switzerland (15–20 °C), the humidity in Guatemala (68–85%) was higher than in the other populations (range 50–78%). The high humidity and temperature in Guatemala, where sampling was performed during the rainy season, might be a cause for the relatively low activity level of the dogs in this study population. The month of collaring (May versus August) was indeed found to be influential within the Swiss dog population after adjusting for other factors, with longer resting times in May and more 'moderate' activity in August. This may be due to a direct influence of the season on dogs' behaviour, or indirectly via the owners' activity, at least for the family dogs. Factors that may have influenced the activity of the owners differently between the two study periods are the partly rainy weather in May (which may have caused less activity) or the holiday period in August, with people having more time to walk their dogs.

Another limitation of our study is the non-random sampling of Swiss family and farm dogs that may have led to a biased sample. The voluntary participation of healthy dogs selected at veterinary practices is likely to result in a sample with an overrepresentation of conscientious dog owners. Nonetheless, we attempted to reduce selection bias by refraining from advertising the study on social media, but inviting a random selection of owners personally. According to studies performed by the FitBark developer in 2015, Swiss dogs have the highest activity compared to other companion dogs worldwide (https://public.tableau.com/profile/fitbark#!/vizhome/shared/4N6FC4F3M). In this study, the average daily activity of Swiss dogs was calculated at 9634 BarkPoints, whereas in our study population this was even higher (mean = 10,287 BarkPoints for the entire population, 11,117 BarkPoints in family dogs, and 8760 BarkPoints in farm dogs). The non-representative sampling approach is most likely biased towards active people or those with a high interest in dog behaviour. In contrast, owners who perceived that they might under-exercise their dogs, may have been less likely to agree to participate in the study. Therefore, the effect found towards spending more time with 'higher' activity in family dogs compared to the other study populations may have been overestimated in this study.

We only captured the activity of the dogs over a maximum of one week. In Switzerland, data from all dogs included a full 7-day period to be able to compare activity during working days and weekends. Such data were not available for all dogs in Indonesia and Guatemala, where some dogs were tracked for two to three days only. However, we do not expect this limitation to impact much the main outcome of our study – the comparison of the activity pattern between the four study populations –because the FRDD in Indonesia and Guatemala showed a more repetitive daily pattern compared to the family dogs already within the short time period of data collection.

To conclude, we found that overall activity levels of FRDD, farm dogs and family dogs were comparable; however, a part of the family dogs showed a different activity pattern compared to the other study groups. FRDD and farm dogs, both partly independent from humans, were observed to have a bimodal activity pattern, like it is seen in other canine species, suggesting a natural activity pattern. Still, the findings that FRDD are preferentially active at times where we can expect human activity (Banerjee and Bhadra, 2019; Majumder et al., 2014) provide evidence for the influence of humans on the activity of owned FRDD. This is of course most pronounced with the family dogs, whose activity pattern did not always follow a bimodal rhythm because they are more dependent on the owner's daily routines. FRDD spent less time of their day resting compared to Swiss family and farm dogs and spent more time in 'moderate' activity, suggesting that dogs intrinsically avoid long lasting high activity periods. Family dogs spent more time with 'high' activity since owners take them on walks, and compensate this with longer resting periods. The results demonstrate the adaptability of the *Canis familiaris* species. Whether a more structured daily schedule would potentially be more beneficial for pet dogs constitutes a follow-up question for future research.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.applanim.2021.105449.

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