Rapid eye movement density during REM sleep in dogs (*Canis familiaris*)

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Published online: 27 September 2018
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Abstract

Dogs (*Canis familiaris*) are excellent models of human behavior as during domestication they have adapted to the same environment as humans. There have been many comparative studies on dog behavior; however, several easily measurable and analyzable psychophysiological variables that are widely used in humans are still largely unexplored in dogs. One such measure is rapid eye movement density (REMD) during REM sleep. The aim of this study was to test the viability of measuring REMD in dogs and to explore the relationship between the REMD and different variables (sex, age, body size, and REM sleep duration). Fifty family dogs of different breeds and ages (from 6 months to 15 years old) participated in a 3-h non-invasive polysomnography recording, and the data for 31 of them could be analyzed. The signal of the electro-oculogram (EOG) was used to detect the rapid eye movements during REM sleep, and REMD was calculated based on these data. The duration of REM sleep had a quadratic effect on REMD. Subjects' REMD increased with age, but only in male dogs with short REM sleep duration. Furthermore, in the case of dogs with short REM sleep, the interaction of body mass and REM sleep duration had a significant effect on REMD. No such effects were found in dogs with long REM duration. These results suggest that relationships may exist between REMD and several different variables.

Keywords Rapid eye movement density · REMD · REM sleep · Dogs

Most living creatures (from molluscs to mammals) spend a significant proportion of their time asleep despite its high costs (decreased sensitivity to environmental stimuli, inability to feed or breed, etc.) (Campbell & Tobler, 1984). Furthermore, sleep has been shown to relate to individual characteristics (e.g., personality: Gray & Watson, 2002) and waking behavior (e.g., pre-sleep learning: Wuyts et al., 2012). However, it is still not known how sleep evolved, and what the exact functions of sleep are (Krueger et al., 2016).

The most comprehensive method for studying sleep is polysomnography (parallel recording of electroencephalography (EEG), electro-oculography (EOG), electrocardiography (ECG), respiration, and electromyography (EMG)). It is widely used in humans to answer basic scientific questions (such as objective markers of self-perceived sleep quality: Akerstedt et al., 1994), and also in clinical practice to diagnose sleep disorders (Kushida et al., 2005).

In the last few decades dogs proved to be excellent models of human behavior since they have adapted to the same ecological niche (Hare & Tomasello, 2005; Miklósi & Topál, 2013). Up until recently, these claims were mainly based on dogs' awake behavior. However, recent canine cognition research has started to explore dogs' brain functioning both while awake (Andics et al., 2014; Kujala et al., 2013) and while asleep (Kis et al., 2014, 2017), suggesting further dog–human parallels.

When comparing the sleep of dogs and humans, several similarities and differences may be observed. Both species are diurnal and thus show increased activity during daytime, and decreased activity during night-time (Takahashi et al., 1978). Regarding their sleep structure, both species go through distinguishable sleep stages which – in the case of

Electronic supplementary material The online version of this article (<https://doi.org/10.3758/s13420-018-0355-9>) contains supplementary material, which is available to authorized users.

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humans – are: wakefulness, and three or four stages of NREM (non-rapid eye movement) sleep and REM (rapid eye movement) sleep. With the non-invasive polysomnography technique we use, the distinguishable sleep stages of dogs have been shown to be: wakefulness, drowsiness, NREM sleep, and REM sleep (Kis et al., 2014). Drowsiness is characterized by fast EEG activity, decreased EOG activity and decreased EMG activity. NREM sleep is characterized by delta activity on the EEG channel, no eye movements on the EOG channel, and decreased muscle tone. The characteristics of REM sleep are fast EEG activity, rapid eye movements on the EOG channel and no activity on the EMG channel. These sleep stages follow each other cyclically in a defined order. It has been shown that dogs' sleep is influenced by both pre-sleep experiences, such as memory consolidation (Kis et al., 2017) and emotional events (Kis et al., 2017), and individual characteristics such as age (Kis et al., 2014; Takeuchi & Harada, 2002; Zanghi et al., 2013).

Building on this research line, several further psychophysiological variables (that have already been well studied in humans) need to be explored in dogs. One such variable that is often used to characterize human sleep is rapid eye movement density (REMD).

To study dogs' REMD the present study used a non-invasive polysomnography technique previously adapted from a human protocol (Kis et al., 2014). There are numerous benefits of examining REMD: (1) it can be calculated more easily than other index-numbers obtained from EEG; (2) it is less sensitive to artefacts thus REMD provides information about the total length of the REM sleep; and (3) it has been studied in connection with human sleep for a long time.

The first human studies in this area discovered that REMD shows specific patterns through sleep (e.g., it increases in consecutive REM periods: Aserinsky, 1971). Some studies suggested that REMD might be related to the level of arousal (Barbato et al., 1994), and others investigated the effect of pre-sleep events (e.g., sleep deprivation decreases REMD; Feinberg, Floyd, & March, 1987). Relations between REMD and individual characteristics have also been found. For example, in connection with age, Darchia et al. (2003) found that as age increases REMD decreases. In connection with sex, different studies obtained different results. On the one hand, Marzano et al. (2011) studied men and women in their twenties and found that there is no significant difference between their REMDs. On the other hand, Wauquier (1993) found that REMD changes differently in women and men as they age – between the ages of 60 and 70 years the REMD of women is higher than that of men, while above the age of 70 years the opposite is true. Furthermore, studies that focus on the relation between REMD and different kinds of disorders and how REMD might be used for diagnostics have also been

carried out. For example, patients with post-traumatic stress disorder showed an increased REMD (Kobayashi, Boarts, & Delahanty, 2007), and it has been suggested that elevated REMD might be a biological marker of depression (Luik et al., 2015).

The aim of the present study was to carry out the first systematic analysis of REMD in dogs, focusing on both method description and on REMD's relation with individual characteristics such as sex, age, and body size. We hypothesized that: (1) the duration of REM sleep will have an effect on REMD, as a relationship has been shown in humans between sleep phase and REMD; we further expected (2) an interactive effect of sex and (weight-corrected) age, as complex relationships have been found in humans between these individual variables and REMD.

Methods

Ethical statement

According to the Hungarian regulations of animal experimentation our non-invasive polysomnography research does not qualify as an animal experiment. The Hungarian Scientific Ethical Committee of Animal Experiments issued permission (under the number PE/EA/853-2/2016) approving our non-invasive protocol. All owners volunteered to participate in the study and were informed about the procedure before beginning.

Subjects

Family dogs (N=50) participated in the research, but 15 of them did not enter REM sleep (we did not find any apparent characteristic differences that would justify the dissimilarity between the dogs that did not fall into REM sleep and dogs that did). In four cases there were some missing data (e.g., owners did not provide the age of the dog), thus the final sample consisted of N=31 dogs (16 males and 15 females). Their age ranged between 6 months and 15 years (median $\pm$ SD=4.17 $\pm$ 4.08), their height varied between 20 cm and 68 cm (mean $\pm$ SD=51.89 $\pm$ 10.71), and they weighed between 5 and 38 kg (mean $\pm$ SD=21.77 $\pm$ 8.47).

Our study was conducted within the confines of the Family Dog Project (Abdai & Miklósi, 2015). Participation was voluntary, the owners signed up through the internet. There were no requirements regarding what kind of dogs could participate, except that dogs needed to tolerate a stranger touching their head during electrode placement. There was no need for any kind of pre-training of the dogs. Additionally, we asked the owners to come to the recording session after an ordinary day (without any unusual occurrences that could possibly have an effect on the dogs' sleep).

Data acquisition

The study consisted of a single 3-h polysomnography recording (parallel monitoring of EEG, EOG, ECG, respiration, and EMG), which took place between 12:00 and 18:00 – since similar to humans, dogs are most prone to fall asleep during this time of the day (Tobler & Sigg, 1986). The recordings took place in a darkened room, where the owner could lay down on a mattress with his/her dog, read, or watch movies on a computer (with headphones) (Fig. 1).

After arrival, the owner allowed his/her dog to explore the environment and then the experimenter placed the respiratory belt and the electrodes on the dog according to a previously validated canine polysomnography procedure (Fig. 2) (Kis et al., 2014). During this time the dogs received social reinforcements from both the owner and the experimenter. They also received food treats when required. As per our protocol, no force was applied during the placement of the measuring equipment in any case. There were also no tranquilizers or soporifics used – the dogs fell asleep due to the absence of stimuli and movement.

Before attaching each electrode, we used PARKER® SIGNA® spray to clean the surface of the skin. Gold (Au) coated silver-chloride (Ag|AgCl) scalp electrodes were used (with a diameter of 10 mm), which were attached with NATUS® EC2® GENUINE GRASS® electrode cream and gauze.

For the present analysis data from the eye movement electrode was used (marked as EOG(+) on Fig. 2), which was placed on the left zygomatic arch and referenced to the central posterior electrode (marked as EOG(-) on Fig. 2). The recording and monitoring of the signals were done with SYSTEMPLUS EVOLUTION® (MICROMED®) software.

Data analysis

Sleep stage scoring (identification of the stages of awake, drowsiness, NREM sleep, REM sleep) was carried out with FERCIO'S EEG 0.8 (© Ferenc Gombos 2012) software in 20-

s epochs manually according to standardized criteria for dogs (Kis et al., 2014) based on a conventional scheme for humans (Rechtschaffen & Kales, 1968).

Rapid eye movements (excursions on the EOG with a minimum of 50 μ V) were manually detected in all the 2-s epochs initially marked as REM. REMD was calculated as the number of 2-s epochs that contained rapid eye movements divided by the total number of 2-s epochs of REM sleep (Table 1 shows REM data and basic demographic information for the sample).

Data analysis was done using R 3.3.1 statistical software (R Core Team, 2016). The effect of REM duration and different individual characteristics (age, sex, and body mass) on REMD was investigated by general linear models (GLMs). Since there was a strong correlation between the dogs' height and body mass (Pearson's product-moment correlation, $R=0.72$, $t_{25}=5.23$, $p<0.001$) only the effect of body mass was used as an explanatory variable. First a model that included the main effects and all two-way interactions was built. REM duration was included in the model as a second-order orthogonal polynomial due to the fact that when initially plotting the data before statistical analysis a strong quadratic relationship was apparent between REM duration and REMD (Fig. 3). Second, non-significant terms were removed by backward elimination. Third, the effect of the quadratic term of REM duration was tested by comparing the model with the polynomial term with a model containing a linear term. Fourth, since the quadratic term was significant (see Results), subjects were divided into two groups using the median of the REM sleep duration (15.33 min) as a cut-off. The short REM sleep duration group included the dogs that spent 15.33 min or less in REM sleep ($n=16$), whereas the long REM sleep duration group included the dogs that spent more than 15.33 min in REM sleep ($n=15$). We repeated the above GLM analysis separately for the two groups; however, in these models REM duration was included as a linear term.

Results

The length of the REM sleep was 22.19 ± 17.13 (mean $\pm$ SD) minutes with a minimum of 2.33 min and a maximum of 61 min. The mean REMD was 0.49 ± 0.17 (mean $\pm$ SD) with a minimum of 0.17 and a maximum of 0.78.

From the explanatory variables (REM duration as second-order orthogonal polynomial, age, sex, body mass) only REM duration was retained in the GLM after model selection and the duration of the REM sleep had a significant quadratic effect ($F_{(1,28)}=6.62$, $p=0.016$) on REMD (Fig. 3). In the case of dogs that spent less time in REM sleep there was a positive relation between the duration of REM sleep and REMD, while with dogs that

Fig. 1 Experimental setting

Fig. 2 Placement of electrodes and respiratory belt. The surface-attached scalp electrodes marked Fz, EOG(-), and G2 were placed over the anterioposterior midline of the skull. The electrode marked EOG(+) was placed on the zygomatic arch next to the left eye. The electrode marked G1 was placed on the left musculus temporalis. For

electrocardiography, electrodes were placed bilaterally on the second ribs under the elbows (ECG(-)). Respiratory movements were monitored by a respiratory belt (RSP) placed on the chest. For electromyography, electrodes (EMG(-)) were placed bilaterally on the musculus iliocastalis dorsi

Table 1 The data set used for analysis

Age (months)	Breed	Sex	Height (cm)	Weight (kg)	REMs	REMT (min)	REMD
9	Mix	Female	60	24	575	29.33	0.65
60	Mix	Male	NA	8	138	9.33	0.49
25	Spanish water dog	Male	NA	25	69	10.67	0.22
141	Whippet	Female	52	13	197	10	0.66
176	Mix	Male	55	38	277	13.67	0.68
124	Mix	Male	56	22	645	39.33	0.55
148	Mix	Female	60	25	51	6	0.28
24	Golden retriever	Female	45	28	443	49.33	0.3
133	Mix	Male	58	29	156	6.67	0.78
132	Mix	Female	43	14	480	42.33	0.38
16	Border collie	Male	52	17	158	14.67	0.36
127	Border collie	Female	43	19	541	23	0.78
51	Belgian shepherd	Female	58	21	111	6.33	0.58
19	Havanese	Female	20	6	355	16.33	0.72
27	Briard mix	Male	67	32	68	4.67	0.49
37	Border collie	Female	NA	22	252	20.33	0.41
66	Border collie	Male	53	22	476	36.67	0.43
82	Belgian shepherd	Male	63	27	457	20.33	0.75
31	Mix	Female	52	15	178	11	0.54
35	Mix	Female	48	15	86	8	0.36
11	Hovawart mix	Male	68	38	823	41.67	0.66
76	Malinois mix	Male	61	26	209	15.33	0.45
35	Golden retriever	Male	49	34	610	61	0.33
74	Cairn terrier	Male	32	9	429	31	0.46
30	Golden retriever	Female	NA	25	561	56.67	0.33
50	Border collie	Male	54	22	46	4.33	0.35
43	Chinese crested dog	Male	37	5	295	14	0.7
145	Border collie	Female	49	19	32	2.33	0.46
30	Golden retriever	Female	51	28	272	53	0.17
34	Mix	Male	65	25	65	9	0.24
53	Mix	Female	50	22	347	21.67	0.53

REMs (rapid eye movements) indicates the number of 2-s epochs that contained REMs (during the REM sleep stages of the entire length of the recording); REMT (min) indicates the time spent in REM sleep; REMD indicates the REM density, which was calculated as the number of 2-s epochs that contained REMs divided by the total number of 2-s epochs of REM sleep

Fig. 3 Rapid eye movement density (REMD) in relation to rapid eye movement (REM) duration in 31 dogs. The red curve indicates the fitted quadratic model, and the vertical line indicates the median REM duration that was used to separate the data into short and long REM duration groups (see [Methods](#))

spent more time in REM sleep there was a negative relation between the duration of REM sleep and REMD.

In dogs with short REM sleep we found that the interaction of sex $\times$ age had a significant effect on REMD ($F_{(1,9)}=14.13$, $p=0.005$). Based on visual inspection of the data in males, the REMD increased with age, while in females no similar relation was apparent (Fig. 4).

Furthermore, in the short REM sleep group the interaction of time spent in REM sleep $\times$ body mass also had a significant effect on the REMD ($F_{(1,9)}=8.31$, $p=0.018$). REMD was higher in heavier dogs with longer REM sleep (Fig. 5).

Fig. 4 The relation between rapid eye movement density (REMD) and age in male and female dogs with short rapid eye movement (REM) duration ($n=16$). The fitted line for males was calculated from a general linear model (GLM) that contained age, gender, and their interaction as explanatory variables

Fig. 5 The effect of the interaction of rapid eye movement (REM) duration and body mass on REM density (REMD) in dogs with a short REM duration ($n=16$). The fitted plane was calculated from a general linear model that contained body mass, REM duration, and their interaction

In the long REM sleep group only the duration of REM sleep had a significant effect on the REMD ($F_{(1,13)}=15.37$, $p=0.002$).

Discussion

Evidence was found for REM being a potentially viable sleep physiology measure in dogs as it was related to several individual characteristics such as age, sex, and body mass at least in a particular sub-group. However, it is important to note that we were not able to analyze REMD in nearly one-third of our subjects since they never entered REM sleep through our 3-h recordings. This limiting factor decreased the representativity of the sample, although no clear difference pattern emerged between dogs producing and not producing REM sleep during our recordings. Future studies aiming to use this method might consider conducting longer recordings in order to improve the ratio of usable data. In human sleep studies there is a well-known phenomenon called the first-night effect (a marked difference in sleep quality between the first and second occasion of laboratory sleep, due to decreased sleep quality and overall sleep duration on the first occasion (Agnew, Webb, & Williams, 1966)), thus another possible way to include all dogs in the analysis might be to repeat the recording and use data from the second recording. Similar to humans, on a second occasion the quality of the sleep might be better in dogs as well. In addition or in parallel to this, recordings conducted at the dogs' home environment might be more favorable for

REMD measurement, since it has been found that when not at home, REM sleep following a first NREM was less likely (Bunford et al., 2018).

It is known that in humans the REMD increases in the consecutive REM sleep periods during an overnight sleep (Aserinsky, 1973; Feinberg, Fein, & Floyd, 1980). We found a similar time-dependent REMD pattern, although in the opposite direction: for dogs that spent less time in REM sleep there was a positive relation between REM duration and REMD, while for dogs that spent more time in REM there was a negative relation between REM duration and REMD. Further studies using longer recordings might look into analyzing REMD in consecutive REM periods.

In dogs with short REM duration, age had a different effect for the two sexes. In males with short REM duration REMD increased with age, while in females there was no such relation. In connection with this, different human studies obtained different results. According to Wauquier (1993), the REMD of women between the ages of 60 and 70 years is higher than that of similarly aged men. However, above the age of 70 years the opposite is true (Wauquier, 1993). According to Marzano et al. (2011), there is no significant difference between the REMD of men and women in their twenties (Marzano et al., 2011).

In connection with age, Darchia et al. (2003) found that the REMD of older people was significantly lower than that of younger individuals. Furthermore they came up with the idea that this could be a part of degenerative aging and of the different kinds of changes that occur during sleep with age (Darchia, Campbell, & Feinberg, 2003). In our study there was a relationship between age and REMD only in male dogs; however, older subjects showed increased REMD, a finding that is contrary to that described in humans, and contradictory to the degenerative aging hypothesis. A further factor that needs to be taken into account is that different breeds of dogs age at a different rate (Greer, Canterberry, & Murphy, 2007), as there is a great variance in their expected lifespan. Our subjects were not exclusively pure-breds, therefore we did not have data on all of their expected lifespans. However, it is known that most of the differences between the expected lifespan of dog breeds lie in the difference in body size (Greer, Canterberry, & Murphy, 2007), thus we used this measure in our analysis, and the effect of the body size did prove to have a significant effect on REMD. Our results confirm that controlling for body size is essential when studying the changes that come with age, although there is still no universally accepted correction factor (e.g., Patronek, Waters, & Glickman, 1997) to rule out this problem.

In conclusion, REM density proved to be an easily measurable psychophysiological variable in dogs, and we showed that it can be used in relation to different individual traits. However, further adjustments to our method might be needed to increase the representivity of the sample.

Author note We thank Ádám Miklósi and József Topál for their support, and Ferenc Gombos for providing us with the FERCIO'S EEG 0.8 (© Gombos Ferenc 2012) software. The study was supported by Nestlé-Purina, the BIAL Foundation (grant no 169/16), and the Hungarian Scientific Research Fund (OTKA K112138).

Compliance with ethical standards

Conflict of interest The authors declare no conflicts of interest.

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