The relation between sleep and violent aggression

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Chapter 8

Sleep of highly aggressive violent and non-violent rats is similar at baseline but may differ during recovery from sleep deprivation and restraint stress

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ABSTRACT

Human studies show that violent traits are correlated to differences in sleep. Since many patients with antisocial traits suffer from sleep problems, and treatment of sleep disorders may resolve daytime aggressive behavior, it is important to have a better understanding of differences in sleep regulation between violent and non-violent individuals. Therefore, we investigated in an animal model whether violent and non-violent male wild-type rats differ in electro-encephalo-gram (EEG) measurements under baseline conditions and after exposure to 6h sleep deprivation and 1h restraint. No baseline differences were found, but violent animals appeared to have a delayed increase in REM sleep after sleep deprivation, whereas non-violent animals showed immediate increased REM. After restraint, violent animals tended to have more NREM sleep in the subsequent dark phase, an effect of restraint that was not seen in non-violent animals. These changes may reflect differences in sleep regulation and sensitivity to sleep disturbing events. Not only the type of stressor appears to be critical for the subsequent sleep period, individual or 'personality' characteristics must be considered as well. These findings may contribute to further understanding of the relation between sleep and violence.

INTRODUCTION

Disturbed sleep regulation is increasingly recognized as a critical factor for adequate emotion regulation and poor sleep seems to be a risk factor for insufficient control over aggressive impulses (Kamphuis et al., 2012). Interestingly, violent individuals often have sleep complaints. For example, 60-80% of patients with antisocial personality traits or disorder suffer from poor sleep (Semiz et al., 2008; Kamphuis et al., 2013). Nineteen male psychiatric patients with antisocial personality disorder, convicted for violent crimes, exhibited more night time awakenings and lower sleep efficiency than controls (Lindberg et al., 2003). They showed more slow wave sleep (SWS), during a night time electro-encephalogram (EEG). No differences in rapid-eye-movement (REM) sleep were found. Three female antisocial psychiatric patients charged for violent crimes (Lindberg et al., 2006) as well as preadolescent boys with conduct disorder (Coble et al., 1984) also exhibited more SWS in their EEG. One interpretation of this increased SWS is that violent individuals have difficulties in maintaining normal daytime arousal. This is supported by a study showing overall reduction of alpha power in the waking EEG of sixteen homicidal forensic psychiatric male patients (Lindberg et al., 2005). The authors speculate that perhaps the problem to maintain normal arousal levels exhausts these individuals, leading to more deep sleep during the night. Another possibility is that their daytime interactions, which may be different in nature or perceived in a different way by antisocial individuals, affect their night time EEG. Animal studies suggest that an aggressive interaction in itself can cause immediate changes in sleep architecture; increased slow wave activity and short-term suppression of REM sleep (Meerlo et al. 1997; Meerlo and Turek, 2001; Lancel et al., 2003; Kamphuis et al., 2015). Taken together, violent and antisocial individuals differ from non-violent populations in their waking and nighttime EEG. How this is causally related to their sleep quality and daytime problematic behavior is not yet clear.

Some case reports and clinical studies suggest that treatment of sleep problems and improving sleep quality contribute to a reduction of aggressive responses and violent behavior (Pakyurek et al., 2002; Haynes et al., 2006). This may be highly relevant in crime-preventing treatment programs for problematic aggressive behavior.

It is important to have a better physiological understanding of how violent individuals sleep and how this is different from non-violent individuals. We aimed to investigate this in an animal model, since this offers more possibilities for experimental manipulations than human studies. We used wild-derived rats, because these rats show much more

spontaneous and normal adaptive resident-intruder offensive aggression than the placid and docile laboratory bred strains (De Boer et al., 2003). In order to investigate violence, the aggression displayed needs to exceed normal species-typical levels. Thus this violent aggressive behavior is not subject to inhibitory control and has lost its adaptive function in social communication (De Boer et al., 2009). Earlier studies revealed that some of these wild-type rats may gradually develop violent tendencies when they are repeatedly involved in fights (De Boer et al., 2009). These animals rapidly attack an intruder without the normal investigatory and threatening behavior (immediate bites); often, they do not respond to submission signals of the opponent that normally inhibit aggressive behavior; and they may even attack opponents that normally do no trigger aggression such as females and anesthetized non-moving conspecifics. This sub-population of rats develop a form of violent behavior that is out of control and out of context, which allows us to study the relationship with sleep.

Therefore, in the present study we compared sleep architecture by EEG measurements in violent and normal-aggressive male wild-type rats under baseline conditions and in two challenging conditions: 1) they were subjected to 6h sleep deprivation in order to investigate their sleep homeostatic response, 2) they were exposed to 1h restraint stress, to test their sensitivity to stress-induced changes in sleep.

MATERIAL AND METHODS

Animals and Housing

The study was performed in adult Groningen wild-type rats. Animals were individually housed under a 12h light/ 12h dark cycle with lights on from 10.00 to 22.00 h. Housing rooms had stable temperature (21 ± 1 °C) and humidity (60 ± 2 %) and water and food were provided ad libitum throughout the experiment. Experiments were approved by the animal ethics committee of the University of Groningen.

Experimental procedure

For this study we selected high aggressive rats, which displayed comparable amounts of aggressive behavior. For assessment of sleep-wake patterns and sleep EEG, animals underwent surgery for implantation of EEG and EMG electrodes. In addition to 24h baseline sleep-wake patterns, we assessed sleep homeostatic responses to sleep deprivation (6h sleep deprivation by gentle stimulation) and sensitivity to stress-induced sleep disturbance (1h restraint stress).

To assess whether violent and non-violent rats differed in the homeostatic regulation

of sleep, all animals were subjected to 6h of sleep deprivation during the first 6 hours of the light phase, i.e., the main circadian rest phase. Sleep deprivation was achieved by gentle stimulation, which consisted of keeping the rats awake with as little disturbance as possible by tapping the cage and gently shaking the cage (see for procedure Meerlo and Turek, 2001, Van der Borght et al., 2006).

To test whether violent and non-violent rats differed in their sensitivity to sleep disturbance, they were subjected to 1h of restraint stress during the sixth hour of the light phase. Animals were enclosed in wire netting sealed with tape, with openings and both ends for tail and nose.

Selection of violent and non-violent animals

To obtain animals with a tendency towards escalated aggression, defined as out of context and out of inhibitory control (violent animals) and animals without this tendency (non-violent animals), we exposed three batches of 24 three-month old wild-type Groningen rats to ten resident intruder (RI) tests, in order to repeatedly permit them to dominate intruder conspecifics (Wistar rats). The RI test procedure is described in the video publication by Koolhaas et al., 2013. Attack latencies were scored in each test. The amount of aggressive behavior after the first attack was analyzed for ten minutes during the fourth and tenth test. This allowed us to characterize animals as low (< 15 % duration of aggressive behavior), medium (between 15% and 55%) or high aggressive (>55 %). After this, animals were exposed to another series of tests investigating out of context aggressive, violent behavior (test 11-13):

- Instead of a male Wistar intruder, an unfamiliar wild-type female was used as an intruder. Normally animals start sniffing and investigating this female or even try to mate. Attacking the female can be considered as a deviant form of aggression; the animal is not able to consider the context and type of opponent he is confronted with.
- The Wistar intruder was anesthetized. A non-responsive opponent will usually not trigger aggression, since they display no threat and do not need to be dominated. Attacking an anesthetized intruder is also a sign of loss of the ability to discriminate context.
- Animals were confronted with a Wistar rat in a novel cage. In a cage which is new to both animals neither of them owns the territory which will normally reduce the amount of aggressive behavior displayed. Although often the Wistar rat is still attacked by the wild-type rat, the duration of aggressive behavior is normally shorter than in their own cage.

Based on earlier findings in our laboratory we expected 8-12% of our animals to show

multiple violent characteristics (De Boer et al., 2009).
Our violent animals were required to meet at least three out of the following criteria:

- Average attack latency of the 7th, 8th, 9th and 10th RI test is lower than 15 seconds.
- Attacked a female.
- Attacked an anesthetized intruder.
- Time spent on aggressive behavior in the novel cage is higher than 65% of the time spent on aggressive behavior during the regular 10th RI test.

Non-violent animals were required to have no more than one of the above criteria, but have comparable aggression levels in the resident intruder test.

Sleep recordings

Selected animals were implanted with permanent electrodes to record cortical EEG and neck electromyogram (EMG) for assessment of sleep-wake patterns. Surgery was performed under Isoflurane (Pharmachemie BV, Harlem, The Netherlands) anesthesia. Three stainless steel screws (diameter 1 mm) through the skull served as electrodes. One screw was placed above the right hemisphere, 1 mm anterior and 2.5 mm lateral from bregma. The second screw was placed above the left hemisphere 3 mm posterior and 2.5 mm lateral from bregma. The third screw, which functioned as ground electrode, was placed 4 mm posterior and 2 mm lateral from bregma above the right hemisphere. Two insulated stainless steel wires were inserted subcutaneously on the neck muscle to record the EMG. The electrodes were attached to a connector, which was cemented to the skull with dental acrylic. After at least 2 weeks of recovery, animals were habituated to handling and hooking up to the recording cable. This cable was attached to a swivel, which allowed free movement throughout the cage. After at least 2 days of habituation, EEG and EMG recordings started. Signals were fed to an amplifier (Vitaport 0212-56 tecmec Bu © 2005), which was connected to a computer with the recording program (Columbus™ Version 1.09.05, TEMEC Instruments B.V) where data were collected and saved. This computer was located outside of the room where animals were placed, allowing checks without disturbing the animals. The EEG signal was amplified by 10,000, high-pass filtered at 1 Hz and low-pass filtered at 30 Hz. The EMG signal was amplified 5000 times, high-pass filtered at 1,5 Hz and low-pass filtered at 150 Hz. The signals were digitalized and stored at 128 Hz resolution. EEG and EMG were measured for 2 blocks of 2 consecutive days, consisting of a baseline day and the experimental day, starting at lights-on. The remaining 18 hours of the experimental day (the second half of the light phase and the following dark phase) were considered the recovery period. A new baseline recording preceded each experimental procedure. Two weeks were in between the sleep deprivation and restraint condition, all animals were first exposed to sleep deprivation.

Analysis of vigilance states

By visual inspection of the EEG and EMG signals, 10-s epochs were classified as either wakefulness, NREM sleep or REM sleep (Meerlo and Turek, 2001), using a sleep processing program (Vitascore v 1.30, Temec Instruments). The EEG signal was subjected to spectral analysis by fast Fourier transform and, for all NREM sleep epochs, the EEG power density in the delta or slow wave range (1-4 Hz) was calculated. To correct for inter-individual differences in the amplitude of the EEG signal, delta power densities were normalized for each animal by expressing them relative to their own baseline delta power density, i.e. the NREM sleep delta power values per time interval were expressed as a percentage of the average 24h baseline NREM sleep delta power value. These normalized delta power values are referred to in the text and figures as slow wave activity (SWA). For presentation and statistical analysis of the data, NREM and REM sleep time and NREM sleep SWA were calculated for 2h intervals.

Statistics

First, differences in NREM and REM sleep time, and NREM sleep SWA between violent and non-violent rats in the two baseline measurements (preceding sleep deprivation and restraint) were tested with a repeated measures ANOVA, with a between-subjects factor 'group' (violent vs non-violent) and a within-subjects factor 'time' (successive 2h intervals of the 24h baseline recordings). After this, the effects of sleep deprivation and restraint were assessed for, 1) the remaining 6h of the light phase following the experimental manipulations to investigate acute effects (3 x 2h intervals); and 2) the subsequent 12h dark phase to test for prolonged effects (6 x 2h intervals). For this we also used repeated measures ANOVA with a between-subjects factor 'group' (violent vs non-violent) and a within-subjects factor 'time' (successive 2h intervals of the part of the recovery period). Finally, differences between condition (sleep deprivation and restraint) and preceding baseline measurement were investigated separately for violent and non-violent animals, for the remainder of the light phase and the subsequent dark phase. Between-subjects factor in the repeated measures ANOVA was 'condition' (sleep deprivation vs baseline, and restraint vs baseline) and the within-subjects factor 'time' (successive 2h intervals of the recovery period) as used earlier. When the overall repeated measures ANOVA revealed a significant effect of condition or group or a significant condition / group x time interaction, post hoc *t*-tests were applied to determine at which 2h intervals the differences occurred. Significance level was set to $p < 0.05$. Data shown in text and figures are averages ± standard error of the mean (SEM).

RESULTS

After the selection procedure, eight violent and eight non-violent rats were included. The animals in both groups were equally aggressive and only differed in the occurrence of violent behavior (see Table 1 for animal characteristics).

In between the sleep deprivation condition and restraint condition one violent animal was lost due to detachment of the connector from its skull. After restraint, EEG measurement was not scorable for one non-violent animal. Thus, results for the restraint condition are based on seven violent and seven non-violent animals.

Baseline

Violent and non-violent animals did not differ in baseline values for REM sleep time, NREM sleep time and NREM sleep SWA (Table 2). The baseline measurement preceding sleep deprivation and the baseline preceding restraint did not differ either.

Table 1. Animal characteristics. Violent group N = 8, and non-violent group N = 8.

	Violent	**Non-violent**	***p***
Aggression in RI tests			
% aggressive behavior in 4th RI test	52.8 ± 24.6	42.8 ± 22.2	0.41
% aggressive behavior in 10th RI test	54.4 ± 18.0	57.0 ± 21.1	0.79
Criteria for violence			
N attack latency < 15 seconds	8	0	0.000
Average attack latency over last 4 RI tests	7.6 ± 4.6	56.9 ± 56.9	0.044
N attacks to female intruder	3	0	0.055
N attacks to anaesthetised intruder	8	3	0.007
N > 65% aggressive behavior in novel cage*	8	0	0.000
% aggressive behavior in novel cage *	83.1 ± 28.7	26.4 ± 16.4	0.000

* compared to aggression level in home cage

Table 2. Durations in percentages spent in NREM, REM and Wake during the 24h baseline preceding the sleep deprivation condition and the restraint condition.

	Sleep deprivation		Restraint	
	Violent	**Non-violent**	**Violent**	**Non-violent**
24h baseline				
NREM (% time)	43.6 ± 3.9	43.3 ± 4.4	43.7 ± 4.7	43.4 ± 1.3
REM (% time)	10.7 ± 1.8	9.7 ± 1.4	11.0 ± 1.1	9.9 ± 0.9
Wake (% time)	45.8 ± 4.9	46.6 ± 4.0	45.3 ± 5.1	46.7 ± 1.2
Light phase				
NREM (% time)	51.4 ±6.3	50.6 ± 5.8	51.5 ± 2.9	51.5 ± 3.1
REM (% time)	14.4 ± 3.4	13.7 ± 3.4	15.6 ± 1.2	14.2 ± 2.3
Wake (% time)	34.1 ± 8.3	35.6 ± 7.8	33.0 ± 3.5	34.3 ± 4.8
Dark phase				
NREM (% time)	35.7 ± 7.3	36.1 ± 3.9	35.9 ± 8.2	35.3 ± 2.9
REM (% time)	6.9 ± 3.5	5.6 ± 1.7	6.4 ± 1.8	5.5 ± 0.9
Wake (% time)	57.4 ± 9.9	57.6 ± 3.4	57.7 ± 9.0	59.2 ± 3.4

Sleep deprivation condition

Sleep deprivation-induced changes in NREM sleep SWA did not differ between violent and non-violent animals (light phase: $F_{1,13} = 0.04$, $p = 0.837$; dark phase: $F_{1,13} = 0.00$, $p = 0.966$; see Figure 1A). Both groups exhibited an acute enhancement of NREM sleep SWA, as indicated by significant condition effects when comparing the recovery light phase period to the corresponding baseline period of each group (violent group: $F_{1,13} = 9.13$, $p = 0.01$; non-violent group: $F_{1,13} = 6.26$, $p = 0.03$). In the subsequent dark phase NREM sleep SWA was no longer different from baseline (violent group: $F_{1,13} = 1.98$, $p = 0.18$; non-violent group: $F_{1,13} = 1.94$, $p = 0.19$).

Violent and non-violent animals did not differ in NREM sleep time during the remainder of the light phase ($F_{1,14} = 1.59$, $p = 0.228$) and the subsequent dark phase ($F_{1,14} = 0.07$, $p = 0.790$) (see Figure 1B). NREM sleep time was not statistically different from baseline for violent (light phase: $F_{1,14} = 1.08$, $p = 0.316$; dark phase: $F_{1,14} = 0.19$, $p = 0.670$) and non-violent animals (light phase: $F_{1,14} = 0.08$, $p = 0.778$; dark phase: $F_{1,14} = 1.92$, $p = 0.188$). No interaction effects were observed.

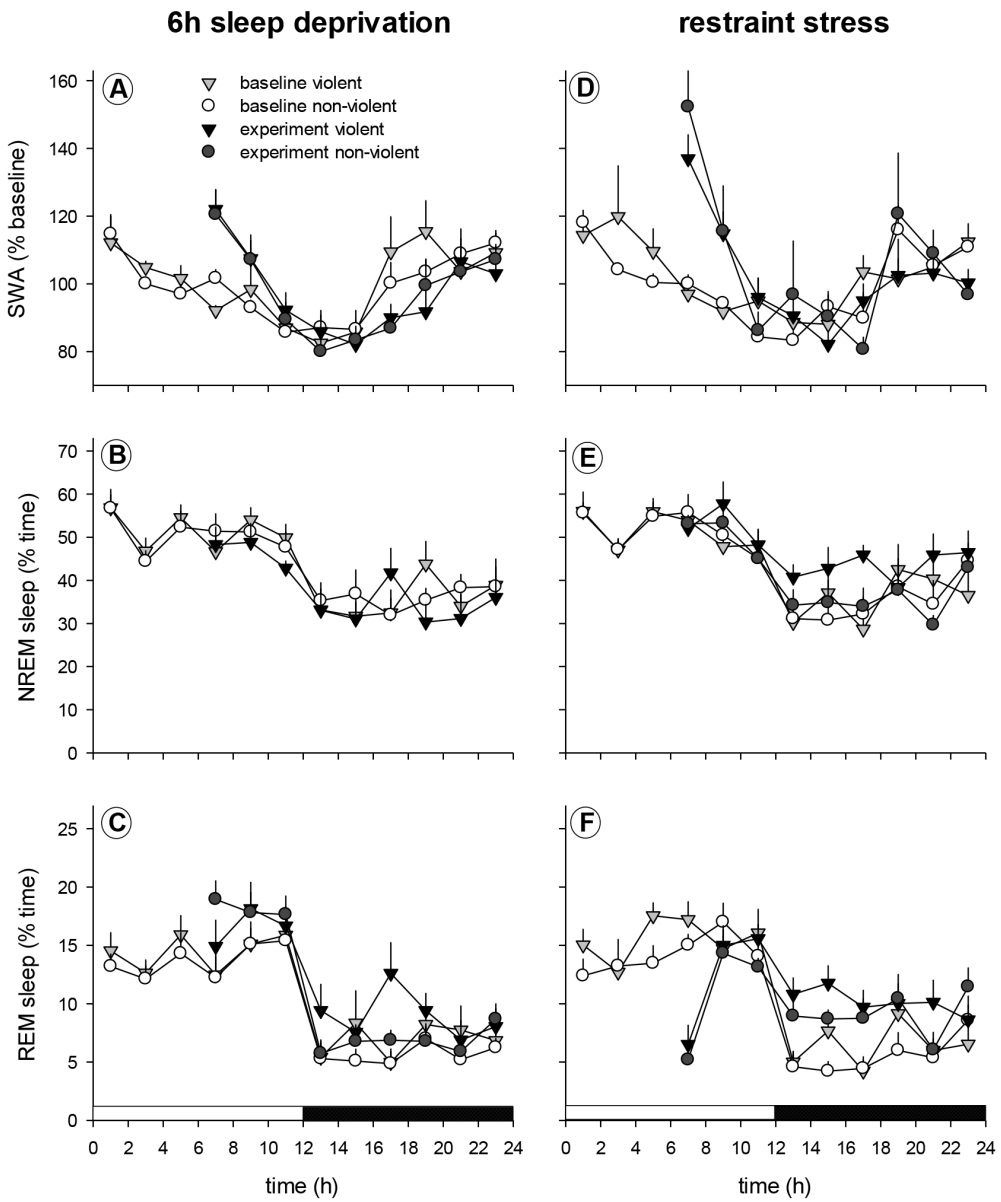

Figure 1. Two-hourly values of REM sleep, NREM sleep and NREM sleep SWA in male WTG rats subjected to 6h of sleep deprivation by gentle stimulation or 1h of restraint (N = 8 for the violent and non-violent group in the sleep deprivation condition and N = 7 for the violent and non-violent group in the restraint condition).

Even though no differences were observed in the amount of REM sleep during the recovery period when comparing violent and non-violent animals directly (light phase: $F_{1,14}$ = 0.69, p = 0.421; dark phase: $F_{1,14}$ = 2.76, p = 0.119), some subtle differences emerged when testing the groups against their own baseline (see Figure 1C). In the non-violent animals, a near significant effect was found for the remainder of the light phase ($F_{1,14}$ = 4.53, p = 0.052) and no effect was observed for the dark phase ($F_{1,14}$ = 2.34, p = 0.148). This acute REM increase in non-violent animals was not observed in violent animals. Rather than exhibiting an acute effect, it seems that violent animals compensated their REM sleep loss later in the recovery period, as suggested by a borderline significant condition x 2h interval for the dark phase ($F_{2,28}$ = 2.30, p = 0.054). No significant overall condition effects were found when comparing REM sleep after sleep deprivation for violent animals against their own baseline (light phase: $F_{1,14}$ = 1.21, p = 0.290; dark phase: $F_{1,14}$ = 1.40, p = 0.257).

Restraint stress condition

Violent and non-violent animals did not differ in their NREM sleep SWA after restraint (light phase: $F_{1,11}$ = 0.00, p = 0.997; dark phase: $F_{1,9}$ = 0.10, p = 0.758; see Figure 1D). While violent animals exhibited a significant immediate significant elevation of SWA as suggested by a significant condition effect for the remainder of the light phase ($F_{1,12}$ = 10.41, p = 0.007), this effect reached only a trend level in non-violent animals ($F_{1,10}$ = 3.88, p = 0.077).

There was no effect of condition (violent vs non-violent) for NREM sleep time in the remainder of the light phase following restraint ($F_{1,12}$ = 0.58, p = 0.462), but there was a trend for an effect of condition on the amount of NREM sleep during the subsequent dark phase ($F_{1,11}$ = 3.73, p = 0.080) suggesting that violent animals had a prolonged increase in NREM sleep as compared to non-violent animals (see Figure 1E). On the other hand, the amount of NREM sleep time in the dark phase after restraint did not differ significantly from their own baseline values during this period ($F_{1,11}$ = 2.61, p = 0.134), nor was there a significant condition x 2h interval interaction effect ($F_{5,55}$ = 0.95, p = 0.458). Also for the non-violent animals no differences from baseline were observed for the dark period ($F_{1,12}$ = 0.01, p = 0.916), nor for the light period ($F_{1,12}$ = 0.00, p = 0.970).

Violent and non-violent animals did not differ significantly in their REM-sleep pattern after restraint (light phase: $F_{1,12}$ = 1.07, p = 0.322; dark phase: $F_{1,11}$ = 1.40, p = 0.262; see Figure 1F). Both violent and non-violent animals had an immediate suppression of REM sleep after restraint, as suggested by significant condition effects for the light phase when

comparing to their own baseline (violent group: $F_{1,12} = 5.31$, $p = 0.040$; non-violent group: $F_{1,12} = 18.01$, $p = 0.001$). The loss of REM sleep seemed to be compensated in the dark phase as suggested by significant increases in REM sleep for this period in both groups (violent group: $F_{1,11} = 15.56$, $p = 0.002$; non-violent group: $F_{1,12} = 14.75$, $p = 0.002$)

DISCUSSION

In the present study violent and non-violent rats had largely similar sleep-wake patterns under baseline conditions, but seemed to differ slightly in their responses to 6h sleep deprivation and 1h restraint stress. Most of these differences did not reach the level of statistical significance. The experiments need to be repeated with a higher statistical power for conclusive results. Nevertheless, the results seem to indicate that after sleep deprivation the violent animals showed a delayed increase in REM sleep, whereas non-violent animals showed an immediate increase in REM. Also, after exposure to 1h restraint stress the violent animals displayed more NREM sleep during the subsequent dark phase compared to non-violent rats. This is an indication that the original hypothesis of an association between violence and disturbed sleep regulation may be true.

When extrapolating the results for our violent rats to studies in humans that have been characterized as violent, some remarks can be made. Human studies in violent offenders showed more SWS in their nighttime sleep compared to controls without pathological aggressive traits, and no differences in REM sleep (Lindberg et al., 2003). Importantly, the subtle differences found between our violent and non-violent animals only appeared after challenging conditions and not in baseline measurements. Even though in the human studies the differences were found without exposing tthe subjects to specific conditions, one must consider that for humans a 'baseline' situation may already be considered a challenge (i.e. coming to the laboratory, interactions with investigators, etc). It is tempting to interpret our finding of slightly more NREM sleep after restraint in violent animals as being in line with the increased SWS found in violent offenders.

With regard to the observation of more NREM sleep in the subsequent dark phase after restraint stress in violent animals, it is possible that the forced immobilization during this condition was a more stressful experience for violent animals than for non-violent animals. It is known that not only sleep loss, but also stressful events lead to increased NREM sleep and NREM sleep SWA (Meerlo et al., 1997; Meerlo et al., 2001; Meerlo and Turek, 2001; Lancel et al., 2003; Kamphuis et al., 2015), but how animal characteristics

influence the amount of increase is not quite clear. That violent and non-violent rats may differ in their way of coping with forced immobilization is suggested by the observation that animals with high levels of offensive aggression seem to have pro-active coping styles in reaction to several kinds of stressors (Koolhaas et al., 2010). For example, in the defensive burying paradigm, where animals are confronted with an electrified probe in their home cage, high-aggressive animals start actively bury the probe with cage bedding while low-aggressive animals more passively avoid the probe (Koolhaas et al., 2010). In the situation of restraint stress, having a pro-active coping style may be less successful and more stressful than a reactive coping style: a pro-active animal may try to fight its way out of the restrainer, while an animal with a reactive coping style might undergo the forced immobilization more passively. Whether such coping styles relate to the amount of experienced stress is not entirely clear, but speculatively, it is possible that our violent animals represent animals with a very inflexible, rigid, pro-active coping style (boldly stated, they attack whoever comes in their cage, without taking into account the context and type of opponent) for whom it is extra stressful not to be able to actively and successfully cope with a stressful situation. This may be one explanation for the NREM increase observed after restraint stress in violent rats, reasoned from a stress-compensation point of view. However, since there was no difference between violent and non-violent animals in NREM sleep after sleep deprivation and also no difference in NREM sleep SWA after restraint, it is also possible that restraint stress triggers sleep-promoting mechanisms in violent animals, not necessarily reflecting a homeostatic need for sleep.

REM sleep is suggested to have an important role in emotional memory processing, hypothetically being critical for the decoupling of strong emotions and memory of corresponding experiences (Goldstein and Walker, 2014). Furthermore, REM sleep may have a role in restoring optimal emotional reactivity for the next waking period, by reducing noradrenaline levels to baseline and in doing so restore the adrenergic locus coeruleus-medial prefrontal cortex-amygdala functional network (Goldstein and Walker, 2014). Sleep deprivation has been found to cause high background level of tonic locus coeruleus firing and, consequently increase noradrenaline concentrations, leading to a similar tonic firing profile of the amygdala, which results in a diminished ability to detect which stimuli from the surrounding are emotionally important and which are not (Mallick and Singh, 2011). REM sleep might be important to restore this balance. With this function of REM sleep in mind, it may provide an explanation for the delayed and more pronounced REM sleep after the sleep deprivation condition in violent animals. It is likely that our violent rats differ from non-violent rats in their monoamine brain

circuits. A study using Long-Evans rats selected for high aggressive and violent behavior showed that these rats have higher levels of norepinephrine and epinephrine in the prefrontal cortex and amygdala than non-aggressive Long-Evan controls (Patki et al., 2015). Although we do not have data for noradrenaline levels in wild-type rats, de Boer et al. (2009) showed that violent wild-type rats have a lower frontal cortical 5-HT turnover than non-violent rats. This observation supports the hypothesis that important monoamine brain systems differ between violent and non-violent rats. Speculatively, these differences may explain a greater need for restoration by REM sleep after sleep loss in violent rats.

The finding of different effects of two challenging conditions on subsequent sleep confirms that specific stressful events can have very different or even opposite effects on sleep depending on several situational factors (Sanford et al., 2015). Characteristics of the stressful stimulus, such as controllability and predictability, have received a lot of attention in literature. For example, animals receiving controllable stress in the form of an escapable shock show significant increases of REM sleep, whereas the uncontrollable stress of inescapable shock leads to significant REM sleep reductions (Sanford et al., 2010). In our study, 1h restraint stress induced a pronounced enhancement of NREM sleep EEG SWA and increase in REM sleep in both violent and non-violent rats that cannot be explained only by sleep loss, since the observed alterations were smaller or absent after sleep deprivation. This is in line with other studies investigating the effect of stressful events on sleep (Meerlo et al., 1997; Meerlo et al., 2001; Meerlo and Turek, 2001).

The differences, although subtle, found between violent and non-violent rats indicate that not only the stressor type is relevant to the subsequent recovery sleep. Characteristics of the individual undergoing the stressful event, seem to be important as well. Only few studies have investigated this. One example, the more vulnerable mouse strain BALB/cJ does not show an increase in REM sleep after restraint stress, whereas the more resilient C57BL/6J mice do (Meerlo et al., 2001). The present study reveals even minor differences in post-stress sleep within the same strain of rats, merely based on behavioral differences between animals.

In conclusion, this study suggests that there are differences in sleep regulation and sensitivity to sleep disturbances between wild-type rats behaviorally characterized as violent and non-violent. It is important to replicate our study with a higher number of animals per group, since the observed group differences did not reach the level of statistical significance. This might further emphasize the relevance of stressor

characteristics and "personality" characteristics of the individual receiving the stressor, for the subsequent sleep period.

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