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Analysis of postarousal EEG activity during somnambulistic episodes

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SUMMARY Early studies found that electroencephalographic (EEG) recordings during somnambulistic episodes were characterized by a combination of alpha, theta, and delta frequencies, without evidence of clear wakefulness. Three postarousal EEG patterns associated with slow-wave sleep (SWS) arousals were recently identified in adults with sleepwalking and sleep terrors. The goal of the present study was to evaluate the distribution of these postarousal EEG patterns in 10 somnambulistic patients (three males, seven females, mean age: 25.1, SD: 4.1) evaluated at baseline and following 38 h of sleep deprivation. A total of 44 behavioral arousals were recorded in the laboratory; seven episodes at baseline (five from SWS, two from stage 2 sleep) and 37 episodes during recovery sleep (30 from SWS, seven from stage 2 sleep). There was no significant difference in the distribution of postarousal EEG patterns identified during baseline and recovery sleep. One pattern, comprised of diffuse rhythmic and synchronous delta activity, was preferentially associated with relatively simple behavioral episodes but did not occur during episodes from stage 2 sleep. Overall, delta activity was detected in 48% of the behavioral episodes from SWS and in 22% of those from stage 2. There was no evidence of complete awakening during any of the episodes. The results support the view of somnambulism as a disorder of arousal and suggest that sleepwalkers' atypical arousal reactions can manifest themselves in stage 2 sleep in addition to SWS.

KEYWORDS parasomnias, sleep deprivation, sleep electroencephalograph, sleepwalking, somnambulism

INTRODUCTION

Sleepwalking is a parasomnia characterized by behavioral manifestations of various degrees of complexity and duration arising from non-rapid eye movement (NREM) sleep (American Sleep Disorders Association, 1997). Episodes are usually characterized by misperception and relative unresponsiveness to the environment, mental confusion, automatic behaviors, and memory impairment for the event (Broughton, 1968, 2000; Keefauver and Guilleminault, 1994). Sleepwalking can result in injury to the sleeper or to others, and patients often consult because of a history of aggressive and/or injurious behavior during sleep (Moldofsky *et al.*, 1995; Schenck *et al.*, 1989). Somnambulism is believed to result from an abnormal arousal mechanism and is thus considered a disorder of arousal (Broughton, 1968). Although most episodes arise from sudden but incomplete arousals from slow-wave sleep (SWS) (Broughton, 1968; Jacobson *et al.*, 1965; Kales *et al.*, 1966; Kales *et al.*, 1980), episodes may also occur out of stage 2 sleep (Joncas *et al.*, 2002; Kavey *et al.*, 1990; Moldofsky *et al.*, 1995; Zucconi *et al.*, 1995).

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Early studies conducted on eight children and three adults reported that electroencephalograph (EEG) recordings during somnambulistic episodes were characterized by a combination of alpha, theta, and delta frequencies, without evidence of clear wakefulness (Jacobson *et al.*, 1965; Kales *et al.*, 1966). Experimentally induced episodes in children were found to be associated with continuous and diffuse nonreactive alpha rhythms or to patterns of low-voltage delta and beta activity (Broughton, 1968; Gastaut and Broughton, 1965). More recently, the EEG associated with confusion arousals in adults was described as a pattern of stage 1 sleep without evidence of complete awakening (Guilleminault *et al.*, 2001). Schenck *et al.* (1998) conducted a systematic review of the electrophysiological events surrounding 252 behavioral and nonbehavioral arousals from SWS in 38 adults with injurious sleepwalking and sleep terrors. Three postarousal EEG patterns were found to characterize the first 10 s of most arousals: (i) diffuse rhythmic and synchronous delta activity (≤4 Hz), most prominent in bilateral anterior regions, (ii) diffuse and irregular moderate-to-high voltage delta and theta activity intermixed with, or superimposed by, alpha and beta activity; this pattern included shifts from SWS to stage 2 or to stage 1 sleep, and (iii) prominent alpha and beta activity, at times intermixed with moderate voltage theta activity. Irrespective of specific EEG patterns, delta activity was found to be present in 44% of the postarousal EEG recordings, with no difference between nonbehavioral and behavioral arousals. Other researchers, however, have not investigated these postarousal patterns, and no attempt has been made to assess their pertinence for behavioral episodes arising from stage 2 sleep.

Our group recently showed that sleep deprivation significantly increases the frequency and the complexity of somnambulistic episodes recorded in the laboratory (Joncas *et al.*, 2002). Given the lack of information on EEG activity during somnambulistic events, the main goal of the present study was to use the data collected by Joncas *et al.* (2002) to evaluate postarousal EEG patterns associated with behavioral episodes recoded at baseline and following 38 h of sleep deprivation. Secondary goals were to assess potential differences in observed patterns as a function of sleep stage and behavioral arousal complexity.

METHODS

Subjects

Subjects were 10 adult sleepwalkers (three males, seven females, mean age: 25.1, SD: 4.1) who reported a minimum of two to three somnambulistic episodes per month over the past 6 months. Ten sex and age-matched controls were also investigated. Exclusion criteria consisted of the following: (i) the presence of another sleep disorder and/or an hourly index greater than ten for respiratory events (apnea, hypopnea) or periodic leg movements during sleep; (ii) the presence of a major psychiatric disorder; (iii) the presence or history of a neurological disorder; and (iv) use of medications that could influence sleep architecture or the EEG.

Procedure

Participants were recorded for three nights. A screening night ensured that they were free of any major sleep disorder. The second night served as baseline recordings. One week later, subjects returned to the sleep laboratory for the 38-h sleep deprivation protocol which proceeded as follows: after their normal morning awakening, subjects were instructed to go about their day as usual but were forbidden from taking any naps. They then came to the laboratory in the evening where an ambulatory device was installed and subjects spent the remainder of the night as well as the following day under constant supervision to ensure maintained wakefulness. Their sleep was recorded during their recovery night. To control for habituation effects, half of the subjects had the sleep deprivation on their third and last visit, while the other half had it during their second stay with the baseline recording occurring on the third visit.

Data acquisition

Polygraphic recordings were conducted on a 32-channel Grass polygraph (Grass Instruments, Quincy, MA, USA) (sensitivity at 7 μV, bandpass at 0.3–100 Hz). Signals were relayed to a PC, digitized at a sampling rate of 128 Hz, and digitally filtered with an upper cutoff frequency of 64 Hz. EEG recordings and electrode placement were performed according the 10–20 system (F3, F4, F7, F8, C3, C4, P3, P4, O1, O2, T3, T4, T5, T6) with a linked-ear reference. EMG, EOG, ECG, respiration, and oxygen saturation were also recorded. Twenty-second epochs from the C3/A2 lead were used to visually score sleep stages according to established criteria (Rechtschaffen and Kales, 1968).

Scoring of postarousal EEG activity

Postarousal EEG activity for each behavioral arousal was categorized according to the three patterns identified by Schenck *et al.* (1998): (i) diffuse rhythmic and synchronous delta activity (≤4 Hz), (ii) diffuse and irregular moderate-to-high voltage delta and theta activity intermixed with, or superimposed by, alpha and beta activity; this pattern includes shifts from SWS to stage 2 or to stage 1 sleep, and (iii) prominent alpha and beta activity, at times intermixed with moderate voltage theta activity. EEG tracings were assessed on the scoring channel (C3/A2) and the same eight bipolar leads employed by Schenck *et al.* (1998) (F3-P3, F7-T3, T3-T5, T5-O1, F4-P4, F8-T4, T4-T6, T6-02) over the duration of each behavioral arousal. If two predominant patterns were observed in succession, a combination of the two was used to categorize the postarousal activity. Episodes during which movement and/or muscle artifacts obscured the EEG were rejected if the EEG contained less than 10 consecutive seconds that could be clearly scored on C3/A2. In all cases, the EEG was visually analyzed and described by a board certified electroencephalographer (SR) and subsequently scored according to the pre-established patterns by the second author (MP). To assess whether the complexity of the behavioral arousals was differentially related to one of the three postarousal EEG patterns, each behavioral episode was scored on a three-point scale: one for simple behaviors (e.g. resting or turning on one's hands), two for complex behaviors (e.g. attempting to leave the bed), and three for actually leaving the bed (for details, see Joncas *et al.*, 2002).

Statistical analyses

Chi-squares were used to compare the distribution of post-arousal EEG patterns for episodes recorded at baseline versus during recovery sleep, between episodes from SWS and stage 2 sleep, and between simple and complex episodes.

RESULTS

Effects on sleep deprivation on somnambulistic episodes

The effects of the 38 h of sleep deprivation on the frequency of somnambulistic events as well as polysomnographic data have been previously reported (Joncas *et al.*, 2002). None of the controls had any behavioral manifestations on either of the two nights. A total of seven behavioral episodes (five from SWS, two from stage 2) were recorded from four sleepwalkers at baseline while 37 episodes (30 from SWS, seven from stage 2) from nine sleepwalkers were recorded during recovery sleep. Sleep deprivation also increased the complexity of the behavioral episodes; whereas none of the baseline episodes were more complex than type 1, eight of the behavioral manifestations from recovery sleep (all from SWS) were of types 2 or 3.

EEG patterns during somnambulistic episodes

The distribution of predominant postarousal EEG patterns during somnambulistic episodes recorded during baseline and recovery nights is presented in Table 1. Every episode contained at times at least a few seconds of movement or muscle artifacts, and artifacts prevented the detection of a clear EEG pattern in about 20% of all episodes. A visual filter for ≥15 Hz activity was applied to the nine rejected episodes and revealed the presence of pattern II in three episodes; the other six remained unreadable. Because of their uncertain nature, these data were excluded from the pattern tabulations presented in Table 1. There was no significant difference in the distribution of postarousal patterns identified for normal and recovery sleep nor for episodes arising from SWS versus stage 2 sleep ($P > 0.05$). A combination of two patterns was required for the classification of 18% of somnambulistic events from SWS but none from stage 2. Overall, delta activity (patterns I, II, or any combination containing patterns I or II) was detected in 48.6% (17 of 35) of arousals from SWS and in 22.2% (two of nine) of those from stage 2. A continuous multichannel hypersynchronous delta activity (>150 μV) which lasted for 10 s was observed after the onset of one episode during recovery SWS. This hypersynchronous EEG pattern was preceded by 16 s of delta and theta activity, superimposed by alpha rhythms (pattern II). Continuous (i.e. ≥5 s) hypersynchronous delta activity was not observed during any of the other postarousal EEG recordings. There was no evidence of complete awakening during any of the behavioral episodes.

The distribution of principal postarousal EEG patterns as a function of episode complexity from SWS is presented in Table 2. There was no significant difference in the distribution of postarousal patterns identified during simple episodes (type 1) as compared with relatively more complex ones (types 2 and 3). Overall, delta activity was detected in 59.1% (13 of 22) of the somnambulistic episodes of complexity 1 and in 25% (two of eight) of those classified as types 2 and 3.

Although pattern III was described by Schenck *et al.* (1998) as containing prominent alpha and beta activity, at times intermixed with moderate voltage theta activity, all 16 episodes classified according to this pattern in the present study contained theta activity.

An example of each of the three main postarousal EEG patterns is presented in Figs 1–3. Fig. 4 presents a behavioral episode during which two EEG patterns (II and III) were observed in succession.

DISCUSSION

Approximately 80% the EEG tracings recorded during somnambulistic events were readable. This proportion is consistent with previous findings (Schenck *et al.*, 1998). The two more frequently observed forms of postarousal activity were patterns

Table 1 Distribution of postarousal EEG patterns during somnambulistic episodes

	Baseline night		*Recovery night*		*Baseline and recovery nights combined*		
EEG patterns	*SWS (n = 5)*	*Stage 2 (n = 2)*	*SWS (n = 30)*	*Stage 2 (n = 7)*	*SWS (n = 35)*	*Stage 2 (n = 9)*	*SWS + stage 2 (n = 44)*
I	0 (0)	0 (0)	1 (3.3)	0 (0)	1 (2.9)	0 (0)	1 (2.3)
II	0 (0)	0 (0)	8 (26.7)	2 (28.6)	8 (22.9)	2 (22.2)	10 (22.7)
III	2 (40)	2 (100)	9 (30)	3 (42.9)	11 (31.4)	5 (55.5)	16 (36.4)
I and II	0 (0)	0 (0)	3 (10)	0 (0)	3 (8.6)	0 (0)	3 (6.8)
I and III	2 (40)	0 (0)	1 (3.3)	0 (0)	3 (8.6)	0 (0)	3 (6.8)
II and III	0 (0)	0 (0)	2 (6.7)	0 (0)	2 (5.7)	0 (0)	2 (4.5)
Movement artifacts	1 (20)	0 (0)	6 (20)	2 (28.6)	7 (20)	2 (22.2)	9 (20.5)

Percentage values are given in parentheses.
See text for a description of each of the three EEG patterns.

Table 2 Distribution of postarousal EEG patterns for episodes from SWS as a function of complexity

EEG pattern	*Baseline night Complexity 1 (n = 5)*	*Recovery night Complexity 1 (n = 22)*	*Complexities 2 and 3 (n = 8)*
I	0 (0)	1 (4.5)	0 (0)
II	0 (0)	6 (27.2)	2 (25)
III	2 (40)	6 (27.2)	3 (37.5)
I and II	0 (0)	3 (13.6)	0 (0)
I and III	2 (40)	1 (4.5)	0 (0)
II and III	0 (0)	2 (9.2)	0 (0)
Movement artifacts	1 (20)	3 (13.6)	3 (37.5)

Percentage values are given in parentheses.
See text for a description of each of the three EEG patterns.

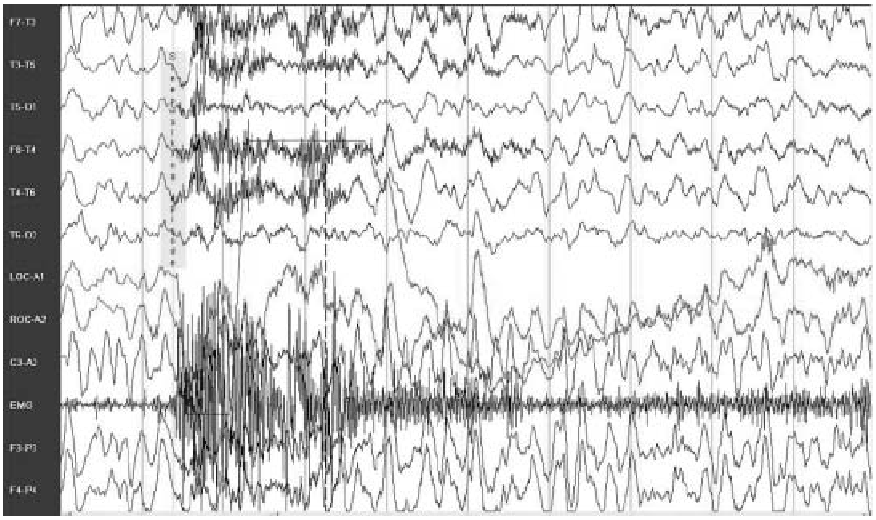

Figure 1. Example of postarousal EEG pattern I during a behavioral episode from stage 4 sleep in a 19-year-old man. The EEG shows diffuse and rhythmic delta activity and is most predominant in the anterior regions.

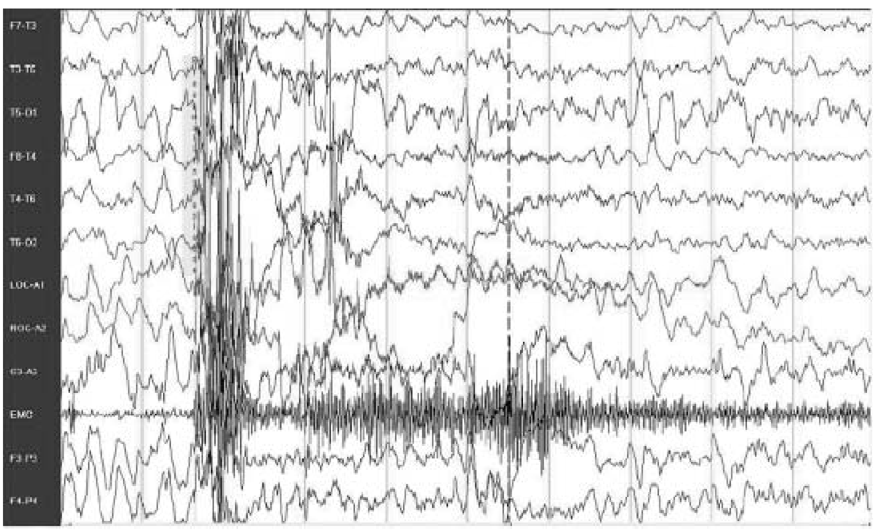

Figure 2. Example of postarousal EEG pattern II during a behavioral episode from stage 4 sleep in a 23-year-old woman. The EEG shows irregular delta and theta activity intermixed with faster activity.

II (i.e. diffuse and irregular moderate-to-high voltage delta and theta activity intermixed with, or superimposed by, alpha and beta activity) and III (i.e. prominent alpha and beta activity, at times intermixed with moderate voltage theta activity). These patterns were also the only two that occurred during episodes emerging from stage 2. When postarousal EEG activity contained two patterns, temporal changes always showed a progression from a slower pattern to a faster one (e.g. pattern II followed by pattern III), except for the one episode containing hypersynchronous delta activity. Taken together, our results indicate that delta activity is present in almost 50% of all episodes from SWS and approximately 20% of those from stage 2. These data are consistent with those of Schenck *et al.* (1998) who found that nearly half of all postarousal recordings from SWS contained delta activity. These percentages represent conservative estimates as they are based on all the episodes recorded (i.e. including those rejected because of muscle or movement artifacts). The fact that the application of a high frequency filter allowed the detection of pattern II in three of the nine rejected episodes suggests that an important proportion of episodes with artifacts also contain delta activity.

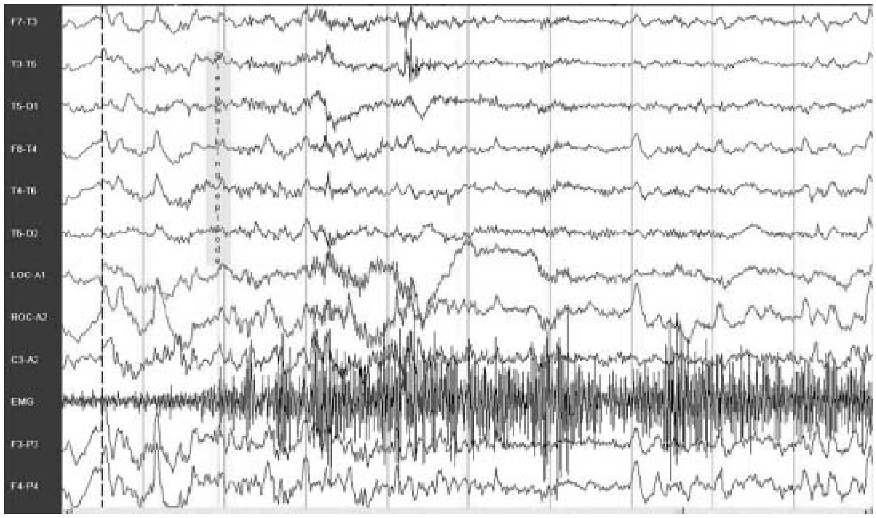

Figure 3. Example of postarousal EEG pattern III during a behavioral episode from stage 3 sleep in a 22-year-old man. The EEG shows relatively low voltage, fast frequencies, intermixed with theta activity. Alpha activity is predominant in the posterior regions.

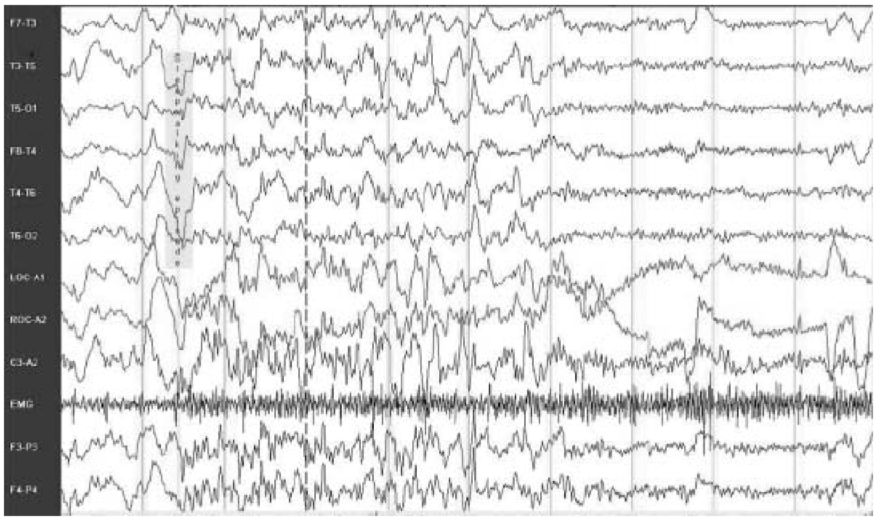

Figure 4. Example of postarousal pattern II followed by pattern III during a behavioral episode from stage 4 sleep in a 28-year-old woman. At the beginning of the episode, the EEG shows diffuse and irregular delta and theta activity. Later, there is a flattening of the EEG, with low-voltage, fast frequencies, intermixed with theta activity.

Although sleep deprivation is known to intensify SWS and resulted in a fivefold increase in the frequency of somnambulistic manifestations, there was no evidence for a differential effect on postarousal EEG activity. Our results show that EEG activity associated with somnambulistic events arising out of stage 2 can be classified according to the same patterns that characterize episodes from SWS.

When postarousal activity for simple behavioral events (type 1) was compared with relatively more complex episodes (types 2 or 3), it was found that pattern I (diffuse rhythmic and synchronous delta activity) was present in the former but absent from the latter. These findings are consistent with the results of Schenck *et al.* (1998) who found that pattern I was sometimes present during arousals with nonvigorous behaviors but never during arousals with vigorous behaviors. These results suggest that diffuse rhythmic and synchronous delta activity is more likely to accompany simple somnambulistic episodes than complex ones, and that it only occurs during events emerging from SWS as opposed to stage 2 sleep.

As was the case in previous studies (Broughton, 1968; Guilleminault *et al.*, 2001; Kales *et al.*, 1966; Schenck *et al.*, 1998), none of the somnambulistic episodes contained evidence of clear wakefulness although complex behavioral events were recorded during recovery sleep, including sitting up in bed, attempting to leave the bed, and actually jumping out of bed. The postarousal patterns highlight the dissociation between cortical and motor activities during such episodes as sleepwalkers can perform motor activities (normally associated with wakefulness) while showing EEG patterns indicative of sleep or partial sleep. These results support the conception of somnambulism as a disorder of arousal and suggest that sleepwalkers' atypical arousal reactions can manifest themselves in stage 2 sleep as in SWS.

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