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CLINICAL REVIEW

Sleep talking: A viable access to mental processes during sleep

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S U M M A R Y

Sleep talking is one of the most common altered nocturnal behaviours in the whole population. It does not represent a pathological condition and consists in the unaware production of vocalisations during sleep.

Although in the last few decades we have experienced a remarkable increase in knowledge about cognitive processes and behavioural manifestations during sleep, the literature regarding sleep talking remains dated and fragmentary. We first provide an overview of historical and recent findings regarding sleep talking, and we then discuss the phenomenon in the context of mental activity during sleep. It is shown that verbal utterances, reflecting the ongoing dream content, may represent the unique possibility to access the dreamlike mental experience directly. Furthermore, we discuss such phenomena within a cognitive theoretical framework, considering both the atypical activation of psycholinguistic circuits during sleep and the implications of verbal 'replay' of recent learning in memory consolidation.

Despite current knowledge on such a common experience being far from complete, an in-depth analysis of sleep talking episodes could offer interesting opportunities to address fundamental questions on dreaming or information processing during sleep. Further systematic polysomnographic and neuroimaging investigations are expected to shed new light on the manifestation of the phenomenon and related aspects.

Introduction

By definition, sleep is a reversible state characterised by various degrees of sensory unresponsiveness and behavioural inactivity. The investigation of mental activity during sleep has traditionally been performed using retrospective measures (e.g., dream reports) or non-invasive electrophysiological and neuroimaging techniques. Parasomnias, during which the subject experiences unusual events halfway between a wakeful and sleep state, constitute a unique opportunity to directly observe the phenomenology of mental processes that take place during sleep. This category of sleep disorders includes a broad spectrum of emotions, perceptions, movements or behaviours occurring episodically during any phase of non-rapid eye movement (NREM) and rapid eye movement (REM) sleep or transitional states [1].

The phenomenon of unaware production of vocalisation during sleep, generally defined as 'sleep talking' (ST) or 'somniloquy', represents one of the most common sleep behaviour in the general population [2]. The current definition of ST describes the phenomenon as a normal variant of parasomnia occurring during both REM and NREM sleep, as an isolated symptom or in comorbidity with other diseases [3].

The ability to talk during sleep has fascinated humankind since antiquity. However, a scientific approach to the examination of this type of parasomnia has long been neglected in favour of psychoanalytic or theoretical hypotheses. To date, studies specifically describing the manifestation of ST are still infrequent or date back to remote times.

The purpose of this review is to provide a general overview of the current scientific knowledge about the phenomenon of ST, emphasising the potential insights coming from the study of this parasomnia. In particular, we first give a synopsis of the current literature referring to somniloquy, focusing on some specific aspects such as historical and epidemiological frameworks, typical

Abbreviations: DRF, Dream recall frequency; EEG, Electroencephalographic; ICSD, International classification of sleep disorders; NREM, Non-rapid eye movement; REM, Rapid eye movement; RBD, REM behavior disorder; ST, Sleep talking; SWS, Slow wave sleep.

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features and finally, clinical and diagnostic issues. We then consider the relationship between ST and mental activity during sleep, with an attempt to evaluate the extent to which ST mirrors inner sleep mentation, the presence of any differences between the various stages of sleep and the possible consideration of the phenomenon as a study model to better understand dream phenomenology. We finish by discussing ST from a cognitive viewpoint, first describing the psycholinguistic correlates of verbal utterances in sleep and then evaluating the implications of ST episodes in learning processes during sleep.

In summary, the primary purpose of this review is both to provide a comprehensive understanding of ST starting from scarce and fragmentary literature, to underlining the heuristic potential offered by the study of this phenomenon.

Sleep talking: definition and clinical aspects

Background

Sleep talking is the utterance of speech or other psychologically meaningful sounds during sleep, without simultaneous and subjective critical awareness of the event [4].

The historical definition underlines that ST can be considered as a part of the larger family of 'sleep utterances', such as mumbling, laughing, groaning and whistling. However, the meaningful quality of the event is the discriminating feature.

Rechtschaffen and colleagues [5] proposed different sets of criteria to define somniloquy:

1. Vocal sounds had to be recognised by the experimenter as speech (intelligible or unintelligible). Nonverbal vocalisations are not included;
2. The electroencephalographic (EEG) record prior to the vocalisation had to be classifiable into EEG stages of sleep (REM or NREM);
3. The verbalisation had to be outside the context of the immediate social situation;
4. Two or more phrases in succession were counted as separate sleep talking incidents only when there was an intervening period of a sleeping EEG pattern which was free of muscle tension artefacts.

Despite ST being a common phenomenon known for millennia, scientific interest in this field has only developed in relatively recent years. Between the nineteenth and twentieth centuries, the first theories began to develop and to define ST as the outcome of activated cerebral speech areas occurring during a dream [6] or independently from dreaming [7].

In one of the first empirical studies, Kamiya [8] observed that ST usually accompanies body movements, and most of the body movement–vocalisation combinations occur during NREM periods rather than during REM periods. A few years later, MacNeilage [9,10] found that sleep talkers differed from non-talkers in frequency, duration and peak intensity of electromyographic activity in speech musculature during sleep, suggesting that ST may result from the co-occurrence of the verbal component of sleep mentation (prerequisite) and the motor activation (requisite for projecting these components to the peripheral musculature).

Epidemiology

ST seems to be a widespread phenomenon in the general population, especially among children, adolescents and young adults [11]. It has long been considered as quite frequent among parasomnias, but data concerning its epidemiology are very scarce and fragmentary.

The epidemiological framework of ST is unclear because different factors make it challenging to estimate the actual prevalence of the phenomenon. People are entirely amnesic or unaware that they are talking in their sleep unless somebody wakes them up or tells them the next day. Furthermore, most of the self-report questionnaires and demographic surveys do not take into account the standard criteria of ST or contain different items, leading to inconsistent estimates. As an example, the Los Angeles Metropolitan Area Survey used by Bixler et al. [12] reported reduced current prevalence compared to the telephone interviews used by Bjorvatn et al. [2] (2.4% vs. 17%), probably due to a different definition of the time of occurrence ('now' vs. 'at least once during the last three months'). Many sources of artefacts also affected results of laboratory studies: the setting is not ecological and could interfere with the natural manifestation of the phenomenon; experimental sleep interruption could stimulate sleep-speech production; auditory detection tools may not be sufficiently sensitive.

Over the years, several attempts have been made to estimate the prevalence of the phenomenon within the population, reflecting the high epidemiological heterogeneity. The results of the main epidemiological studies are summarised in Table 1.

As previously reported by Hublin [13], the substantial difference in prevalence rate among different studies may reflect the nature of the question about the specific frequency. Indeed, studies in which the frequency has not been asked, have yielded low prevalence (7–8%) [14,15]. In contrast, studies which have used frequency scales reported the same range (7–8%) for 'always' or 'often' items and a total prevalence greater than 50% [16,17].

One of the most recent cross-sectional epidemiologic studies found the lifetime prevalence of ST to be 66% and current prevalence to be 17% (in the past three months) and 6% (in the past week) [2]. This study, besides illustrating that more than half of all people have had the experience of speaking out loud while being asleep, has also suggested that ST is the parasomnia (normal variant) with the highest absolute prevalence (current and lifetime) in the general population.

Not surprisingly, like many other parasomnias, ST occurs more frequently in childhood and attenuates in the teen years, but it can also persist into or begin in adulthood [13]. In childhood, it occurs 'always or often' in 5–20%, but these percentages decrease to 6% and 1–5% respectively in young adults and in adults or elderly [18]. The phenomenon of the higher prevalence in childhood may be partly artefactual: sleeping children are more often overheard than adults. No significant gender difference has been observed in childhood ST. Some adult studies found higher rates in women [12,19] while others in men [13,20], confirming that ST seems to be a common trait both in males and females.

A recent investigation of quantitative features of ST and their influence on sleep quality has confirmed the high presence of declared ST in an Italian sample (55%) and a significant positive relation between frequency of ST and other altered nocturnal behaviours [21].

However, some limitations regarding these studies should be noted. First of all, most remote epidemiological surveys, in which REM behaviour disorder (RBD) diagnosis was not yet recognised as a sleep disorder, led to an overestimated prevalence. Furthermore, these disparate results are attributable to dissimilarities in the population sample, method of measurement and essential purpose of the study, rather than reflect actual differences in the occurrence of ST. All these considerations point out that it is difficult to make any cross-comparison, so those results need to be interpreted with caution.

Formal features of sleep speech

The basic differences between sleep and waking speech are not so clear. Like everyday speech, ST has some typical features, but the

Table 1
Summary of main epidemiological studies.

Study	Population subjects (gender, age)	Prevalence (%)
Self-report questionnaire and demographic surveys:		
Gahagan [22]	559 (mixed, ±19)	Current: 31.5%; Lifetime: 60.8%
Berdie and Wallen [23]	135 (male, adults)	Current: 10%
Goode [24]	359 (mixed, adults)	Lifetime: 54%
Thomas and Pederson [25]	1116 (mixed, ±22)	Current: 11.4% M, F 15.7%
Aird et al. [26]	164 (mixed, adults)	Lifetime: 12%
Bixler et al. [12]	1006 (mixed, adults)	Current: 2.4%; Lifetime: 5.3%
Pertinen et al. [27]	2537 (male, 17–29)	Current: 5.2% (often), 33.3% (sometimes)
Smirne et al. [19]	2518 (mixed, ±55)	Current: 3%
Hyyppa and Kronholm [20]	1099 (mixed, 29–79)	Current: 1.4% (often), 24.1% (sometimes); Lifetime: 28.6%
Hublin et al. [13]	9000 (mixed, 33–60)	Current: 49.3% M, 50.7% F; Lifetime: 66.4% M, 67.8%
Bjorvatn et al. [2]	1000 (mixed, ±47)	Current: 17% (past months) 6% (past week); Lifetime: 66%
Parent report questionnaire and demographic surveys:		
Abe and Shimakawa [28]	310 (mixed, 3)	Lifetime: 14.5%
Reimao et al. [29]	2022 (mixed, 3–10)	Current: 10%; Lifetime: 50%
Klackenberg [14]	212 (mixed, 5)	Current: 8%
Fisher and Wilson [16]	1695 (mixed, 5–18)	Current: 13.9%
Kahn et al. [15]	972 (mixed, 8–10)	Current: 7%
Saarepnaa-Heikkila et al. [17]	574 (mixed, 7–17)	Current: 59.8% (occasionally), 9% (often), 47% (sometimes)

high intra- and inter-individual variability makes it difficult to formulate an exact description.

Most vocalisations range from one to five words and, consistent with the briefness of the statements, the average duration is 1–2 s (regular episodes of ST occur for no longer than 30 s) [30].

Vocalisations also vary in volume from whispers to shouting, and there is general agreement that ST episodes are more emotional during REM speech and more flat and affectless during NREM [7]. However, many exceptions have been observed. Speech sounds are indistinguishable from regular waking conversational speech [31], but the voice is slightly different because the organs of hearing are mostly quiescent and consequently unable to guide the modulation of sound [4].

Changes in respiratory rate, depth and rhythm are followed by vocalisation, and sometimes cough, throat, clearing or gross body movements occur during NREM ST [30].

The intelligibility of ST is variable along a continuum: from meaningless sequences of words to long and articulated phrases. A proper syntax and grammatical inflection would seem more correlated with vocalisations taking place in REM rather than in the NREM stage: the linguistic production in NREM is characterised by a greater presence of neologisms, inexplicable words and disorganised eloquence, especially in NREM stages 3 and 4 [30]. Coherently with these findings, a recent investigation by Arnulf [32] has confirmed that most verbal utterances are grammatically correct and sometimes also contain subordinate clauses.

The purpose of many studies has been to investigate changes in EEG associated with ST episodes, in attempt to clarify the physiological correlates of this specific behaviour during sleep.

The electroencephalographic characteristics of most sleep utterance episodes are consistent with (Rechtschaffen and Kales's criteria 1968) for 'movement-arousal' episodes [30].

At variance with speech during wakefulness, sleep speech is associated with generalised body muscular tension and with higher amplitude and duration of associated movement artefacts [10].

There is high between- and within-subject variability in electroencephalographic correlates of sleep utterances. However, it is possible to identify some distinctive elements depending on the specific stage of sleep. For example, the frequent occurrence of gross muscle tension artefacts is a prominent feature of EEG records of NREM ST, whereas artefacts during the REM period appear less marked and are caused by the activity of facial muscles associated with talking [33].

Aetiology

The aetiology of ST is not yet elucidated. Genetic factors have long been suggested to be involved in the onset of the parasomnias [34], and different studies have confirmed that genetics may also play a role in the genesis and even the pattern of the phenomenon [13,35].

Results of a prospective family study appear to indicate that sleepwalking and recurrent ST are genetically related and, possibly, that the latter is a milder manifestation of a genetic factor which can cause sleepwalking under certain conditions [35].

Hublin and co-workers [13] conducted the first study on ST in twins. Considerable differences in concordance rates were found between monozygotic and dizygotic twin pairs, and between childhood and adulthood. The percentage explained by genetic influences was over 50% in both males and females in childhood ST and higher in females (48%) than in males (37%) in adulthood. The results indicate that genetic factors are strongly implicated in the occurrence of ST and the phenotypic stability from childhood to adulthood is high (the majority of adult sleep talkers had talked during sleep in childhood: 88.9% in men and 84.5% in women).

Another twin study [36] showed that the proportion of total phenotypic variance explained by genetic influences was 88–96% regarding ST and that the co-occurrence with 'sleep drunkenness' and night terrors were attributed partly to shared genetic or environmental factors for these three traits.

Going beyond the simple concordance within twin pairs should further clarify genetic contributions to the phenomenon; as an example, studying monozygotic pairs discordant for ST could be one useful method to evaluate environmental effects (i.e., differences in such pairs are interpretable in terms of environmental effects solely).

As for other parasomnias, in addition to an undisputable genetic influence, even various environmental circumstances and factors can trigger ST episodes. For example, it may be precipitated by emotional stress, febrile illness, alcohol, certain medications or sleep deprivation [37].

Diagnostic criteria and comorbidities

ST diagnosis has evolved through the years and different editions of the main criterion-based classifications of sleep disorders have been established by the American Academy of Sleep

Medicine: the *International Classification of Sleep Disorders* (ICSD) (PANEL A). All classification systems agree to define ST as an independent diagnostic entity or as an isolated symptom that belongs to the category of parasomnias. The phenomenon is not pathognomonic of any specific syndrome or severe psychiatric illness and is not related to any daytime consequence.

Unlike most other sleep disorders, ST is diagnosed mainly or exclusively on the basis on the patient's clinical history or is also frequently brought to the attention of the patient by a sleep partner, a roommate or a family member disturbed by hearing vocal sounds (subjects, as a rule, do not remember or are not aware of their ST).

From a nosological viewpoint, ST can be either idiopathic or associated with other disorders. It is not uncommon that simple vocalisations, intelligible speeches or shouting may be an integral part of the behaviours displayed by patients suffering from other parasomnias, especially NREM arousal disorders (sleepwalking, sleep terrors, confusional arousal) and RBD [38], or other sleep disorders such as obstructive sleep apnoea syndrome [37,39]. Given both the frequent co-occurrence of ST and NREM arousal parasomnias and the qualitative similarity of their verbal material, Arnulf and colleagues suggest a model in which idiopathic ST could represent a sort of attenuated manifestation of the latter [38].

Furthermore, sleep vocalisation episodes have frequently been observed to occur in association with psychiatric (anxiety, stress, post-traumatic stress disorder) or organic (headaches, epilepsy, fever) disorders [14,40].

A recent study suggests that somniloquy (especially loud vocalisations) may be helpful in the differential diagnosis of Lewy Body Dementia from Alzheimer's disease and other types of dementia [41].

PANEL A: Classification outline

ICSD (1990) – Revised (1997)
PARASOMNIAS – Sleep–Wake Transition Disorders – Sleep Talking (307.47)
Diagnostic Criteria:
A. The patient exhibits speech or utterances during sleep.
B. Episodes are not associated with subjective awareness of talking.
C. Polysomnography demonstrates episodes of sleep talking that can occur during any stage of sleep.
D. Sleep talking can be associated with medical or mental disorders (e.g., anxiety disorders or febrile illness).
E. Sleep talking can be associated with other sleep disorders (e.g., sleepwalking, obstructive sleep apnoea syndrome or REM sleep behaviour disorder).
Note: Sleep talking is only stated and coded as a sole diagnosis when it is the patient's predominant complaint. If sleep talking is a major complaint associated with another sleep disorder, state and code both disorders on axis A.
Minimal Criteria: A plus B.
Severity Criteria:
- Mild: Episodes occur less than weekly.
- Moderate: Episodes occur more than once per week but less than nightly and cause mild disturbance to a bedpartner.
- Severe: Episodes occur nightly and may cause pronounced interruption of a bedpartner's sleep.
Duration Criteria:
- Acute: One month or less.
- Subacute: More than one month but less than one year.
- Chronic: One year or longer.
ICSD 2 (2005):
ISOLATED SYMPTOMS, APPARENTLY NORMAL VARIANTS AND UNRESOLVED ISSUES – Sleep Talking (307.49)
ICSD 3 (2014):
PARASOMNIAS – Isolated Symptoms and Normal Variants – Sleep Talking
Produced by the American Academy of Sleep Medicine – International Classification of Sleep Disorders (ICSD)

Treatment

Although parasomnias are considered medical disorders because they may have adverse health effects and psychosocial consequences [42,43], ST represents an isolated symptom and a normal variant of sleep behaviour that tends to be harmless or disappears spontaneously.

The degree of severity depends on variables such as frequency, intensity of manifestation, meaning of discomfort (for the subjects or others). Bedpartners (or housemates, depending on volume) are often disturbed by the noise and suffer from insomnia as a consequence.

It is important to stress that ST is not a pathological symptom and usually treatment is not required. However, if ST persists over an extended period or affects the quality of sleep, certain remedies could be taken into account: practising proper sleep hygiene and following a regular sleep schedule can help reduce the frequency and severity of ST episode [44].

Sleep talking and dreaming

Relation between sleep talking and dream report – is ST a direct witness of sleep mentation?

Dreaming has been studied from multiple points of view: psychoanalytic, psychological and neurophysiological. Even if each approach focuses on specific aspects, the common methodological issue of dream research is the difficulty in investigating a phenomenon not directly observable because of the asynchrony between its generation (during sleep) and its investigation via recall and eventual report (after awakening) [45–47].

It is important to note that a dream report is considered not only an indispensable prerequisite for scientific dream research but is also methodologically trustworthy [48]. However, despite being considered reliable under certain conditions [49], a dream report remains an extremely fleeting measure to reveal subjective experience during sleep. Furthermore, the retrospective nature of all dream reports' collection may also generate some recall bias (such as omissions or distortions), resulting from the subsequent reprocessing of several memory sources. Spontaneous or provoked awakenings in the laboratory are considered the ‘gold standard’ in dream research [50]; however, a large number of dream reports contain clear bias due to the experimental setting [51].

ST, through the overt production of words during sleep, may represent an additional model in dream research, offering unprecedented access to ongoing mental activity in sleep. On this issue, one might wonder if it is possible to connect dream contents to ST episodes, considering ST as a valid account of the actual dream experiences. In any case, the causal link between covert dream mentation and overt sleep speech is difficult to demonstrate. Different studies have investigated the relationship between dreaming and ST to establish whether the words spoken during sleep can be considered the verbal component of dream content that finds expression in overt vocalisation [52,53]. On the other hand, it is also possible that sleep utterances are merely the result of sudden and complex motor activation (e.g., movement-arousal episodes) involving neural circuits subserving vocalisation and speech, as suggested by explosive utterances, very similar to ictal automatism [30,54]. These kind of studies focus on the possible parallelism between the recorded content of ST and the associated mentation as recalled in the waking state immediately after the speech or on the following morning. Data on this matter support two different hypothesis: 1) no degree of correspondence between sleep talking and sleep mentation, due to complete amnesia or to the absence of any obvious relationship between them [8]; and 2) different degrees of correspondence between sleep talking and sleep mentation [5,52,55]. In line with this second hypothesis, Arkin [52] identified various orders of concordance between sleep speech and later dream reports (detailed examples reported in Table 2).

The degree of concordance varies along a continuum: from a perfect match with dream content (first-order) to a preserved varying degree of the conceptual or emotional link (second- and third-order) to total lack of concordance.

Regarding the variability related to different sleep stages and time of night, it has been noted that concordance with dream reports upon awakening immediately after sleep speech is higher regarding speech during REM than NREM sleep [5,52,55,56]. Specifically, Arkin [52] found the absence of concordance in 16.7% of REM, 32.9% of stage 2 NREM and 40.4% of stages 3–4 NREM ST episodes. The high degree of concordance constantly observed during different sleep stages could reflect the lack of standardised criteria in the evaluation of such concordance between sleep speech and subsequent dream reports. Conversely, the disparate degree of concordance concerning the various stages of REM or NREM sleep could probably be explained by specific brain mechanisms underlying the retrieval of sleep mentation. Early studies have consistently shown that dream recall is more frequent after awakening from REM sleep (more than 80%) relative to NREM sleep (about 50%) [57–59]. Independent models have proposed a close relationship between dream recall frequency (DRF) and cortical arousal state [60–63]. This has also been recently demonstrated as a function of specific electrophysiological pattern of dream experiences [64–66]. In particular, these findings support the hypothesis that DRF is contingent on the electrophysiological milieu related to specific sleep stage, as demonstrated in studies investigating the EEG correlates of dream recall upon REM and NREM sleep awakenings [66–68].

As a consequence, the verbal reports following REM or NREM sleep stages also tend to be differently long and detailed [69,70], leading to a different probability of establishing concordance (predominantly based on the linguistic organisation analysis) with a concomitant ST episode.

Therefore, the different brain mechanisms underlying dream recall (for a review see [45]) and the consequent variability in total word count of corresponding dream reports [69,70] may have biased the assessment of degree of concordance between sleep speech and associated mentation content, explaining the various proportions of such concordance in REM and NREM sleep stage.

A comparison between a dream report elicited after NREM associated sleep utterances and NREM 'silent' sleep (without vocalisation) [53] showed both qualitative and quantitative resemblance of the two types of reports, with the sole exception that the subject was more likely to report dream experiences in which he/she was actively vocalising.

Further studies regarding the relation between dream activity and ST found that DRF is positively related to ST propensity [9], suggesting a close association between these two manifestations of sleep mentation.

In conclusion, we can state that ST is consistent with the content of dreams (a kind of 'overt' dream speech) because of its high level of concordance with subsequent dream reports.

The advantage of the hypothetical study model offered by ST is that it could overcome some traditional methodological constraints of dream investigation (e.g., it is not affected by the dream collection bias) but, on the other hand, it will never be considered the 'gold standard' by researchers as a consequence of the impossibility to generalise the model to the whole population and because of the intrinsic limitations of this method.

Content analysis of sleep talking

During the early stages of psychophysiological dream research, there was the assumption that dreaming was just an epiphenomenon of REM sleep [72–74]. However, subsequent studies have unequivocally demonstrated that NREM sleep awakenings yield reports of mental activity [57,75–77] and that REM sleep and dreaming can be doubly dissociated [78], confuting the equation 'REM sleep = dreaming'.

ST episodes, reflecting sleep mentation (see par. 2.1), can take place in both REM and NREM stages. The frequency of the phenomenon has been estimated through laboratory-controlled observations, to evaluate the rate of occurrence during the whole night, the association to sleep stages or to the time of night. The high variability in the amount of ST per night and between nights makes it difficult to estimate the average frequency accurately. The results have shown that ST occurs in REM as well as in NREM periods, but most ST seems to occur in NREM stages 2, 3 and 4 [5,8,52]. Such evidence reflects both the muscular atonia of REM sleep and the lower percentage of relative time spent in REM sleep (20–25% of total sleep time). All the above-mentioned studies are consistent in showing a random distribution of ST episodes overnight, with a slight upward trend in the early stages of the night (first 3 h of sleep), coherently with the high percentage of NREM sleep.

It should be noted that even if dreams occur not only in REM but also in NREM sleep, mental activity during the different stages of sleep varies regarding frequency, content and phenomenological characteristics [75,79]. Mentation in REM sleep, even defined 'dreamlike', is characterised by emotional load, bizarre content and vivid images [70,80–83]. Otherwise, mentation during NREM sleep, defined as 'thought-like', appears less vivid and emotionally

Table 2
Examples of different degrees of concordance between sleep talking and sleep mentation (as reported by Arkin 1981 [71]).

Degree of Concordance	Example
First-order of concordance	a subject was shouting 'No! No!' who dreamed of shouting these words when seeing her baby fall from the bed
Second-order of concordance	a nightmare patient repeatedly dreamed of trying to yell 'Burglars!' but actually called out 'Mama!'
Third-order of concordance	a mentation report elicited after speech describing someone as 'talking', 'saying', 'asking' etc.
No discernible concordance	concordance was not discernible by the manifest content

charged, and the contents are more realistic and fragmented than during REM mentation [5,80]. However, this phenomenological dichotomy also turned out to be inconsistent: a significant amount of dreams reported from NREM sleep show several features typical of 'dreamlike' mentation [60,78,84] and the control for length of the reports (e.g., word count), makes relatively similar REM and NREM qualitative features [70]. In order to reconcile the observed differences between mental experience during REM and NREM sleep stages, the so-called 'continuity hypothesis' suggested a common neurophysiological substrate [85–89] and some similarity of content (memory sources, personal concerns) between dreaming and waking cognition [90]. Dreaming, therefore, seems to be the result of continuous brain activity and differences between waking, REM and NREM mentation can be explained by stage-dependent physiological conditions of the brain [91].

Modern research has put substantial effort into the development of a comprehensive coding system to score the global and specific content of dreams [92]. Hall and Van de Castle published the most comprehensive and elaborated protocol for content analysis of dreams [93], containing eight main categories and over 300 subscales in their dream manual.

The content of ST, mirroring mental activity during sleep, could represent a supplementary model for the analysis of the dream content and a direct demonstration of the theories described above. Content analysis of ST attempts to overcome the boundaries of traditional dream research, which is mostly based on the subsequent dream report. But what kind of things are said during episodes of ST? And how could any variations in NREM and REM ST reflect different underlying mentation? In most ST episodes, the words spoken could not be recognised. The verbalisations vary from simple monosyllabic utterances to meaningless sequences of words to coherent and articulated sentences. A large number of sleep speeches merely consist of short expressions of assent or negation (e.g., 'OK', 'no' 'good' 'mm-hm' 'uh-huh' 'no!' 'stop!' 'don't!' etc.) and sound like half a conversation or an attempt to contact another person, often with pauses during which the 'other' replies [4]. A recent study performed by Arnulf and collaborators [32] has confirmed these results, finding that 'No' was the most frequent word among 882 speech episodes and that various forms of negation represented 9.1% of all words and 21.4% of the clauses (more frequently in NREM sleep).

The material of speech episodes covers a wide range: the content of ST is often emotional [6], refers to recent experiences of daily life [7] or relates to the experience of past traumas [94]; however, it can also be alarming, erotic and vulgar. The most exemplary and fascinating demonstration of ST is represented by the case of Dion McGregor, professional songwriter and sleep talker since the age of four. The content analysis of Dion McGregor's somniloquies reveals some divergences between ST and dreaming. Based on the Hall and Van de Castle Scales and Bizarreness Scales [95], ST content appears less bizarre but more agentic than dream content [96]. The author justified the results by arguing that those are consistent with what is known about the neurophysiology of ST, presumably characterised by EEG elements closer to waking (e.g., the presence of alpha activity) than dreaming. Moreover, the continuity hypothesis seems to be confirmed by the recurring correspondence between contents of somniloquies and Dion McGregor's daily experiences.

Although systematic and controlled sleep laboratory studies directly assessing the different nature of ST content in REM and NREM sleep stages are lacking, several studies have reported that sleep speech is at times 'rational and coherent' and at other times 'full of absurdity', or have shown that there is a specific relationship between the somniloquy produced in REM sleep and the presence of an affective tone [5,52]. Future, more systematic examination of the content of ST in REM or NREM will permit increasing our knowledge about the existence of different sleep mentation associated with different sleep stages. In addition to ST, other clinical manifestations involving the enactment of mentation are also believed to be guided by phenomenal dreamlike content. For example, RBD is widely thought to result from a dysfunction involving atonia-producing neural circuitry in the brainstem, thereby unmasking overt behaviour reflective of cortically generated dreams [97,98]. In addition, even during sleepwalking or sleep terror episodes, patients exhibit a complex motor behaviour associated with a corresponding dreamlike mentation [99]. These kind of episodes may help to overcome the well-known obstacles to exploring the dreamed situation, favouring the understanding of the functioning mechanisms of this type of mental activity, which is not directly measurable. Therefore, just as RBD is believed to be characterised by 'acting out' dreams, ST could also be described as a sort of 'speaking out' dreams.

Current data are too meagre to support any definite conclusion, but it would be interesting in future research to combine dream-content analysis with ST-content analysis, in order to increase the reliability and validity of the basic method of psychological dream research.

Sleep talking and cognitive functions

Psycholinguistic processes in sleep

Language behaviour during sleep represents an unexplored area of investigation, especially concerning linguistic production. Characterising ST from a linguistic point of view may, however, lead to significant progress in understanding both the language system and the sleep mechanisms.

Sleep is not incompatible with the activation of the language system, as suggested by the ability to perceive, process or produce linguistic material during the night [100,101].

Although studies specifically devoted to the manifestation of ST episodes are very scarce, several studies have been carried out to investigate the acoustic detection threshold and the degree of processing that linguistic stimuli undergo during sleep. These studies have reported that language detection in sleep is still present [102,103], but sleep-induced modulation is different along the specific hierarchy of linguistic processing [104–106]. Not only the ability to detect linguistic 'input', but also the production of verbal 'output' is possible during sleep. Along this line, several studies have investigated the phenomenon of 'dream speech', a commonly experienced situation in which the dreamer or other dream characters are involved in a speech [107]. In the literature, there is some evidence about the correspondence between dream content and related brain activity (for a review see [108]). Regarding the specific case of 'dream speech', several studies using a non-invasive recording of brain activity have suggested that brain networks involved in wakeful speech may also become activated while a person is asleep. Hong and collaborators [109] investigated the EEG correlates of 'dream speech', finding an alpha power decrease at the left Broca (C3) and Wernicke's areas (P3), respectively proportional to the amount of expressive and receptive language reported in dreams. The findings of a recent high-density EEG study [66] also confirm this regional specificity, showing increased high–frequency activity over a left posterior temporal region (Wernicke's area) associated with a dream report containing speech. In an attempt to look specifically at the language areas activated during sleep, further electrophysiological and neuroimaging studies would be appropriate.

Some phasic electromyographic discharges seem to be present in speech muscles even in 'dream speech' [110], but the activation of muscles specifically involved in language production constitutes a prerequisite for the occurrence of the verbal utterances.

From a methodological viewpoint, ST represents a unique opportunity to directly assess the effective ability of psycholinguistic programme planning in sleep. A recent study by Arnulf and colleagues [32] has shown that most of the decipherable verbal utterances are grammatically correct and that most sleep talkers continue to respect the usual turn in talking, leaving a moment of pause for their partner to answer. The findings show that even if the phonatory system is partially inhibited during sleep (about half of utterances are non-intelligible), the syntactic and pragmatic rules of conversation remain somewhat preserved. Besides, the absence of relevant problems in the grammatical structures of sleep utterances is further evidence of the automaticity of the syntax process, independent of other attention-demanding processes [111].

Together, the data presented so far suggest a possible engagement of 'higher' brain structures in linguistic production during sleep, but one might ask if the recruited language circuits are the same in the different stages of sleep. We have previously discussed the highest frequency of ST episodes in NREM [5,8,10] and the most proper and correct speeches in REM [52] (see par. 1). However, such evidence could reflect both the lower language emission threshold in NREM due to the absence of physiological REM-related muscle atonia and the more productive mental activity in REM, respectively, rather than differential activation of language circuits.

An accurate analysis of the type of recurring errors in the ST episodes could disclose relevant information about the psycholinguistic organisation of the brain. The most frequent errors seem to concern problems in searching for words, the correct encoding of sounds that make up a word and the apparent lack of thematic coherence of subsequent utterances [101]. Similar errors, especially those contained in NREM sleep utterances, are very common during daytime speech in certain forms of language impairment (e.g., aphasia) [112,113]. Unexpectedly, a single case study has shown that aphasic syndrome, resulting from a parietal-occipital infarct, temporarily resolved within the context of ST [114]. Such partial disappearance of symptoms during sleep is also observed for other diseases [115] and is probably due to a temporary bypass of the pathophysiological mechanisms [116]. These seemingly conflicting results could be explained by a hypothetical sleep-dependent 'alteration' or 'restoration' of diurnal physiological mechanisms in healthy and clinical populations, respectively.

In summary, spontaneous production of verbal utterances during sleep provides a unique opportunity to compare the two conditions of sleep and wake talking, in order to better characterise the mechanisms underlying psychological and neural aspects of language in both normal and pathological contexts.

Direct observation of learning during sleep

Sleep has been known for a long time to play a pivotal role in memory consolidation of recent learning (for a review see [117,118]).

The active system consolidation hypothesis assumes as a key mechanism the selective reactivation of memories encoded in wakefulness during subsequent periods of sleep [119]. According to this model of consolidation, the new information is at first encoded in parallel in neocortical networks and the hippocampus, and subsequently re-activated and integrated with pre-existing memories during succeeding slow wave sleep (SWS). This reactivation strengthens the connections within the neocortex forming long-term memories. Initially described for declarative memory [120,121], this beneficial effect of sleep has also been observed for procedural and emotional memories [122,123].

The recently highlighted role of sleep in promoting forgetting [124–126] does not necessarily stand in opposition to the hypothesis of memory reactivation during sleep. The models point to two different mechanisms of sleep-dependent memory consolidation, by selectively strengthening relevant memory traces (neuronal replay [127]) and by reducing interfering or unnecessary information (synaptic downscaling, as a renormalisation of overall synaptic strength, respectively [126]). In our opinion, these mechanisms are far from being alternative.

The first evidence for a neuronal 'replay' of recent memories in SWS has been obtained in animal studies investigating hippocampal place cell [128–130]. Dave and Margoliash [131] also showed a form of song 'replay' in birds learning to sing: the neuronal activity of the motor cortex observed during daytime singing matched the 'spontaneous' activity of those neurons during sleep.

Brain imaging studies have also found similar findings in humans [132,133], identifying learning-dependent regional increases in cerebral blood flow during sleep. From an electroencephalographic point of view, a robust learning-dependent increase in the coherence of the delta, low sigma and gamma activity, time-locked to the negative peak of slow oscillation (<1 Hz) has been observed [134].

The concept of dreaming as a natural extension of waking conscious experience was initially supported by Foulkes' [57,80] and Antrobus' [70] studies, leading to models of dreaming-as-cognition. The activation-synthesis hypothesis represents the first acknowledgement of a possible role of dreaming in cognitive processes involving memory reactivation [135]. Within this theoretical frame, the reactivation of recent waking experiences through dreams or sleep mentation could represent a sort of 'cognitive replay' [136,137]. Furthermore, performance in cognitive or emotional learning tasks executed before sleeping has shown a significant improvement the following morning, positively correlated to the 'incorporation' of task-related content into mental activity during sleep [138,139]. All these studies represent not only further confirmation of the well-established sleep-dependent memory enhancement [140] but also the evidence for the critical role of the 'overt' reactivation of learning experience in memory processing. Taken together, these findings lead us to the hypothesis that mental experiences in sleep could be a partial reflection of mnemonic processes in the sleeping brain and a possible scenario supporting stabilisation and reorganisation of labile memory traces into consolidated memories.

Compared to the neuronal and neurophysiological replay, the type of relationship between cognitive replay and memory consolidation has not been clearly established, due to the intrinsically limited nature of the object of investigation, which is not directly observable.

Given these methodological issues, the phenomenon of ST may provide an ideal window to directly observe the possible reactivation of newly acquired information in the sleeping brain. As described above, verbal utterances are likely to occur during both REM and NREM sleep and reflect fairly well the content of mental sleep experiences (see par. 2). In such a way, ST could represent a candidate model for investigating the 'overt' replay in humans, helping to address the question of whether cognitive replay is involved in memory consolidation.

Within this perspective, several studies have investigated the potential of dream-enacting behaviours in patients suffering from parasomnias as RBD or sleepwalking [141] to clarify how cognitive reactivation might facilitate memory processes during sleep.

In their study about the sleep effect on procedural learning, Oudiette and collaborators [142] have observed, for the first time, direct evidence for the temporally-structured replay of recently trained behaviour during one sleepwalking episode. The same research group [98] has recently repeated the experiment using a declarative verbal learning task in patients with RBD, in order to observe the possible incorporation and overt replay of words or sentences learned before sleep. They found a single verbal utterance during REM sleep, semantically (but not literally) related to the previously acquired material. Despite this result being obtained on a single patient, the study has the merit of having considered for the first time ST as a real-time source of information about the mechanisms of sleep-dependent memory consolidation.

Conclusions

Despite the available scientific literature about ST remaining dated and elusive, the findings reviewed provide a general overview of the current knowledge about ST, with the aim of shedding new light on this type of parasomnia.

Overall, the studies agree that ST represents one of the most frequent manifestations of overt behaviour during sleep, especially during childhood and adolescence.

The content of ST often refers to recent daily experiences [96], but it does not accurately reflect actual prior waking behavior or memories [3,136,143].

The nature of the relationship between sleep mentation and ST is not yet entirely defined.

In general, the studies are highly consistent with the idea that mental activity in both REM and NREM sleep stages is mirrored by verbal utterances during sleep, with a degree of concordance ranging from a perfect match to a total lack of concordance. These correspondences reveal the possibility to access dream content directly, without interfering with it. From a methodological viewpoint, ST represents an interesting opportunity in the direction of overcoming the methodological issue of the indirect investigation of dream recall.

Not only dream activity but also cognitive processes could be explored through ST. Specifically, an accurate analysis of verbal utterances occurring during sleep could reveal some mechanisms underlying the psycholinguistic processes in the sleeping brain. At the same time, a better understanding of such mechanisms may also clarify the functioning of the neural circuits implicated in daytime speech in both normal and pathological conditions (e.g., aphasic syndromes). Moreover, the role of dreaming in learning processes provides evidence that dreams could be possibly considered as a sort of 'cognitive' replay occurring during sleep. Given this assumption, it appears clear that ST episodes, mirroring dream content, could represent a window on the cognitive processes related to the incorporation and subsequent consolidation of memories during sleep.

Overall, this evidence supports the concept of sleep as a local rather than global phenomenon. The presence of local arousal in specific circuits underlying language production during sleep documents the coexistence of a sleep-like and wake-like activities in different brain areas [144]. Such dissociated state of being are typically observed in parasomnias, representing a common substrate of waking behavior arising out of sleep [145–147].

In the light of what has been discussed, we can consider ST as a possible study model in several fields of sleep research. Indeed, it offers a sort of practical access into brain functioning during sleep, unmasking the corresponding underlying mechanisms. Currently, there seems to be no doubt that a more in-depth investigation of the phenomenon could open fascinating perspectives on sleep and related mentation and cognition. Episodes of ST, crossing the boundaries between wakefulness and sleep, may represent an exceptional window into mental activity during sleep. In conclusion, it seems clear that this specific kind of parasomnia deserves more attention. With this in mind, the ultimate purpose of this review is to encourage the carrying out of future systematic investigations concerning the manifestation and pathophysiology of ST, aimed to paving the way for a better understanding of mental processes during sleep.

Practice points

- Sleep talking is the ability to produce vocalisations during sleep, ranging from unintelligible mumbling to elaborate speeches.
- As a normal variant of parasomnia, it occurs commonly in the general population (especially in childhood) and can arise during either REM and NREM sleep stages.
- Like everyday speech, there is high intra- and inter-individual variability concerning formal features (duration, volume, intelligibility, physiological correlates) of sleep speech.
- The analysis of the relation between sleep talking episodes and dream report reveals a parallelism between contents of verbal utterances and sleep mentation, suggesting that sleep talking can represent a unique window on dream activity.
- The ability to talk during sleep provides some relevant information about the functioning of psycholinguistic circuits activated in the sleeping brain.
- Sleep talking could represent a sort of explicit manifestation of memory reactivation mechanisms during sleep.

Research agenda

- Systematic epidemiological studies are needed to provide an updated estimate of the prevalence of sleep talking.
- Electroencephalographic features and neural correlates of sleep talking episodes should be investigated by combined video polysomnography, high-density EEG and neuroimaging techniques.
- Further genetic studies on twin samples could clarify the aetiological factors.
- The correspondence between sleep talking and sleep mentation should be addressed more precisely, taking into account the specific sleep stage of awakening.
- The activation of the language system during sleep should be explored in detail to identify the specific underlying mechanisms.
- Future studies should clarify the role of sleep talking in the context of memory consolidation through an overt behavioural replay during sleep.

Conflicts of interest

The authors do not have any conflicts of interest to disclose.

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