

Dreaming and REM sleep: History of a scientific denial whose disappearance entailed a reconciliation of the neuroscience and the cognitive psychological approaches to dreaming

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Summary. Since around 2010, important changes occurred in research on the neural bases of dreaming. From the 1960s until the end of the century, most sleep physiologists and some dream researchers continued to adhere to the view that rapid eye movement (REM) sleep was the functional state of the brain concomitant to dreaming, in spite of numerous published findings falsifying that view. At the beginning of the 21st century only, the idea that the neural basis of dreaming is not REM sleep was accepted by a new generation of sleep physiologists. The present article firstly presents how the REM sleep hypothesis of dreaming originated in the 1950s and became the received view on the neurophysiological bases of dreaming. Secondly, five categories of counter-evidence published during the following decades are summarized. The next section recalls the long-lasting denial of the body of counter-evidence. The Discussion section starts with two cognitive topics: dream recall and the definition of dreaming. We then discuss the relationships between the neuroscience and the cognitive-psychological approaches to dreaming. The main categories of current experiments on the neural bases of dreaming are then presented. They show that giving up the received view permitted neuroscience research on dreaming to enter a new era. The last part of the article proposes an explanation of the scientific denial by the psycho-physiological reductionism of many sleep specialists of the time. The main drawbacks of a reductionism stance are listed and the article ends on a lesson to draw from this historical episode.

Keywords: Dreaming (neurophysiology; cognitive approach; history of ideas), REM sleep, non-REM sleep, Dream recall; Definition of dreaming; Psychophysiological reductionism

1. Introduction

1.1. Aim of the paper

The history of ideas in the fields of sleep physiology and of dream research during the second half of the 20th century reveals an astonishing phenomenon regarding the thesis that rapid eye movement (REM) sleep is the functional brain state concomitant to dreaming. That hypothesis was presented as a valid scientific finding by the discoverers of REM sleep in the 1950s (Aserinsky and Kleitman, 1953, confirmed by Dement and Kleitman, 1957), but in the following years and decades, numerous experiments conducted in different laboratories and various countries revealed that the REM sleep view of dreaming could not explain the data. The surprising fact is that, in spite of these findings, most sleep neurophysiologists and some dream researchers continued, until the end of the century, to adhere to the erroneous conception and to teach it.

Why was a scientific error maintained for about 40 years in spite of counter-evidence? What should be done in order

to avoid in the future such a scientific denial which considerably hindered advances in the issue of the neurophysiological bases of dreaming? What are the current consequences of the rejection of that conception? Suggesting answers to these questions is the main aim of this paper. Before addressing these issues in the Discussion Section (below, 5.3 to 5.5), we will summarize some of the main experimental findings and topics of discussion about the relationship between dreaming and sleep stages which successively took place from the 1950s up to the present period. (For a more detailed review of the evolution of dream research between the 1950s and the 1990s, see the excellent paper by Foulkes, 1996). We will begin with the discovery of REM sleep and its specific links to dreaming and the fact that a hypothesis became the “received view” on the question. The next Section presents five forms of counter-evidence to the received view and the following one deals with the long denial of the counter-evidence to the REM sleep view of dreaming. The Discussion section starts with a definition of dreaming which applies both to most REM dream reports and to most Stage 2 reports of comparable length. We then present the main categories of current experiments on the neural bases of dreaming. They show that giving up the received view permitted neuroscience research on dreaming to enter a new era. In the next subsection, we present an explanation of the long scientific denial by the reductionist stance of many sleep neurophysiologists. In the conclusions, we recapitulate the reasons why the REM sleep hypothesis of dreaming was so successful and we propose to draw a lesson from the long-lasting denial of contradicting findings.

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1.2. Naming and classifying sleep stages

As our historical review will contain many references to sleep stages, this subsection will specify and justify the way we will name these stages. We will use the names attributed to these stages for about half a century, therefore in most of the publications to which we will refer, and not according to the new classification recommended by the American Academy of Sleep Medicine (Silber et al., 2007). The new terminology includes R for REM-sleep, Stage N1 for Stage 1 in the older terminology, Stage N2 for Stage 2, and Stage N3 for both Stage 3 and Stage 4. Moreover, we will avoid as much as possible to use the expression “non-REM sleep” (NREM), because, first, it is strange to name stages 1 to 4 which constitute 75% to 80% of a night of sleep as not being REM sleep, which makes up about 20% of the night and is an exception to the decrease of brain activation proper to sleep. Second, the category NREM conflates Stage 2 and Slow wave sleep (SWS) which are as different from each other as they are from REM sleep. SWS is characterized by many features which are not present in Stage 2 (Rechtschaffen and Kales, 1968; Silber et al., 2007): typical delta waves that do not comprise spindles and K complexes and that are four times slower and much more ample than the theta waves of Stage 2, rebound of SWS after sleep deprivation, much more important decrease of metabolism than in Stage 2, release of growth hormone and lastly, occasional occurrences of sleep terrors and sleepwalking. Moreover, the dichotomy REM – NREM does not take into account that Stage 2 is quantitatively the most important physiological state in a night of sleep (between about 50% and 60%), whereas REM-sleep and Slow wave sleep have a much shorter duration. We know only one author, Pivik (1978), who mentioned that the dichotomy REM/NREM resulted in neglecting the differences in duration and quality within the NREM category.

2. A hypothesis becomes the received view on how dreaming relates to cerebral functional states

2.1. The discovery of REM sleep and its specific links to dreaming

When Eugene Aserinsky, a doctoral student at the laboratory of the Physiology Department of the University of Chicago, observed for the first time intermittent rapid eye movements (REMs) during sleep, a hypothesis immediately came to his mind: These movements should correspond to the scanning of dream images by the sleeper. His supervisor, Nathaniel Kleitman, senior researcher at the Chicago laboratory, shared this hypothesis which, according to Antrobus (1990), had already been proposed in 1892 by Ladd. The two Chicago researchers tested their hypothesis by awakening ten participants during periods of REM and during periods of ocular inactivity (Aserinsky and Kleitman, 1953). Out of 27 awakenings during REM, 75% yielded detailed dream reports whereas the 23 awakenings during ocular inactivity produced 9% of dream reports. Other observations by the two authors revealed an increase of respiratory and heart rates. The conclusions of the paper were that, first, the physiological phenomena observed and probably dreaming were very likely manifestations of a particular level of cortical activity during sleep. Second, the recording of REMs

was the means of determining the occurrence and duration of dreaming.

In order to confirm this conclusion, a further investigation was conducted by William Dement, another doctoral student of Kleitman. The results of these experiments were presented in Dement and Kleitman, 1957. Here is a summary of the findings described in the paper. The authors claimed that three hypotheses were confirmed. First, there was significantly more dreaming during REM periods (80% of dream reports rate) than outside of this period (7%). In the latter condition, there were more than 7% of descriptions of mental content, but they were not taken into account because they were considered as not coherent or not enough detailed (this point will be developed below, section 3.2). Dement and Kleitman hypothesized that the dream reports outside of REM periods were the recalls of a dream of the previous REM episode. Second, participants were awakened sometimes after five minutes of REM sleep and sometimes after fifteen minutes and upon awakening they were asked whether they had dreamed during five or fifteen minutes. The estimated duration correlated significantly with the duration of REM sleep. Third, different categories of patterns of eye movements were distinguished, the two more clearly defined being mainly vertical and mainly horizontal. There was a significant relationship between the pattern of eye movements and the content of the reported dream. For example, after one minute of vertical movements, a participant was awakened and asked to report his dream. He reported that he was dreaming he was looking up and down while climbing ladders. The general conclusion was that the results confirmed the earlier findings and conclusions: the electrophysiological recording of REMs was an objective method for the study of dreaming.

Nobody questioned the fact that these results were based on the study of five participants. Nine persons participated in the experiment, but four of them produced a too small number of dream reports (from two to four in REM sleep) to have any influence on the general results, since the five other participants produced between 17 and 37 reports each. As far as the patterns of eye movements were concerned, there were very few instances of vertical and horizontal patterns. Moreover, the findings of Dement and Kleitman, which constituted a striking novelty in the fields of sleep and dream study, were confirmed only within one laboratory by the researchers who had made the hypotheses. It would have been more prudent to wait for a replication by other teams of researchers before considering the results of the two authors as validated scientific knowledge.

2.2. The success of the new ideas on the relationship between dreaming and brain states.

The findings of the Chicago laboratory had a very quick and wide dissemination. It was a novelty which raised many hopes. Researchers in physiology were delighted to know that, for the first time in their domain, a specific mental production could be inferred from physiological data. Commenting upon that discovery thirty years later, Hobson (1988) asserted that it had opened the door to an objective investigation of the issue of the relationship between brain and mind which might validate the idea that brain and mind are one and the same thing. On a more concrete level, many researchers were excited by the fact that a new domain – dreaming – was open to scientific investigation thanks to electrophysiological measurements. It seemed that the psy-

chophysiological approach would permit great advances in dream research, since it immediately provided answers to questions unanswered until then about the duration of dreaming and its continuous or periodical occurrence during a night of sleep.

For these reasons, the idea that REM periods of sleep were the moments when we dreamed was accepted with enthusiasm and it became the “received view”, that is, the predominant, if not the unique viewpoint on this issue and it was taken for granted, without critical examination. For many sleep physiologists, this view was understood as the equation: REM sleep = dreaming. A number of them used the term dream or dreaming when they actually referred to REM sleep. For example, Dement (1960) entitled a paper on the effect of REM sleep deprivation: “The effect of dream deprivation”. Jouvett (1992) wrote that there are two different states to be distinguished: sleep (referring to Stages 2 to 4) and dream (referring to REM sleep). In lectures about infant development, some professors asserted that infants dream for 15 hours a day, because they spend about 15 hours in a reactivated sleep which resembles REM sleep (see below, last paragraph of 5.4). Fiss (1986) seems to be the only author who criticized these conceptual amalgams.

An addition to the knowledge of the characteristics of REM sleep was provided by the French neurophysiologist Jouvett, who had started working on REM sleep in cats. Shortly after the publication of Dement and Kleitman, Jouvett and a colleague discovered that muscle tone was completely abolished during REM sleep (Jouvett and Michel, 1959). Consequently a third electrophysiological criterion of the presence of REM sleep periods was added to the data of EEG and EOG (electro-oculogram): the assessment of muscle tone (electromyogram, EMG).

The notoriety of the findings of Kleitman and colleagues was due to the correspondence of REM sleep with dreaming. The authors did not seem to foresee that their discovery would lead to a complete change and improvement of the conception of sleep: from the idea of a gradually changing state to that of a cyclical succession of very diverse functional states of the brain. Actually, at that time, for a decade at least, stages of sleep other than REM sleep were neglected. Hobson (1988) noted that Webb, one of the first researchers who studied thoroughly the successive sleep stages in a night of sleep, was the founder of a movement ironically named “Society for the prevention of cruelty to non-REM sleep”.

Dement continued for a few years his pioneering psychophysiological studies in order to confirm his previous results or to investigate new issues such as the effect of REM sleep deprivation (Dement, 1960) or the possibility to influence dream content with external stimuli (Dement and Wolpert, 1958). Researchers in other laboratories did not wait for a long time before following Dement’s example. In the 1960s and 1970s, studies investigating dreaming were conducted – occasionally or permanently – in more than a dozen laboratories in the United States. Later on, dream research became rather scarce in this country for lack of funding, but an important interest for this field of study developed in Canada. From the late 1960s until the end of the 20th century, research on dreaming was also conducted in Europe, mainly in Italy, and also in Switzerland. Since the beginning of the 21st century, dream research started in other countries and continents.

To sum up, the discovery of REM sleep had an enormous impact on the development of the experimental study of dreaming, a topic neglected by scholars during the first half of the 20th century. The discoverers of REM sleep spread new ideas about dreaming and its relationship with brain physiology. They claimed that rapid eye movements corresponded to the scanning of dream images by the sleeper, that consequently the occurrence and duration of dreaming could be inferred from electrophysiological recordings. They asserted that outside of REM sleep dreaming was extremely rare, with a maximum of 10% of dream reports upon awakenings in these periods. They hypothesized that dream reports outside of REM sleep were the memories of dreams of the previous REM period and they stressed differences in length and content of these so-called “NREM” reports. They were shorter, more fragmented, less narrative, and more ‘thought-like’ than ‘dream-like’. This set of ideas constituted the received view on these topics. They are still the ideas held by many medical practitioners (who learned them in their physiology manuals) and even by a few sleep researchers. Some of the latter did acknowledge many decades ago that we also dreamed outside of REM sleep (e.g., Rechtschaffen, 1967; Hobson, 1988), but it is only at the beginning of the 21st century that the REM-sleep view of dreaming started to be more generally rejected (Solms 2000).

3. Counter-evidence to the received view

3.1. A higher rate of dream recall than claimed in Stage 2 and in Slow-wave-sleep

The results of the new researchers on dreaming brought quite a number of surprises as far as the received view was concerned. Within a few years after the publication of Dement and Kleitman’s paper, several authors found a much higher rate of dream recall than expected outside of REM-sleep. For example, in the earliest article showing this result (Goodenough, Shapiro, Holden and Steinschreiber, 1959), the participants reported a dream for 34% of the awakenings outside of REM sleep and the rate amounted to 53% for the group of participants who frequently remembered dreams. Goodenough and colleagues considered that their findings did not contradict the conclusions of Kleitman and colleagues because they adopted the hypothesis that dream reports outside of REM sleep were the memories of earlier REM reports. A few years later, Foulkes (1962), in a study dealing with 56 participants and a total of 200 awakenings, obtained 54% of dream reports in Stages 1, 2 and Slow wave sleep after eliminating about 25% of the reports because they might be judged thought-like. The authors of the two articles did not intend to verify or challenge the REM sleep hypothesis of dreaming. They trusted it when starting their experiments. Goodenough and colleagues wanted to know whether people complaining of never remembering a dream had REM periods and whether they would remember dreams when awakened during these periods. They compared the rate of dream reports of these “non-dreamer” participants with the results of a control group (participants claiming to have frequent dream recalls), when awakened within and outside of REM sleep. Foulkes’ research aimed at observing how and when dreaming started within a period of REM sleep. According to the received view, the production of dreams starts during each period of REM sleep

Table 1. Mean percentage of dream reports outside of REM-sleep for the 21 publications listed in Hobson, Pace-Schott and Stickgold (2000), according to the decade when the experiments were published.

Group	Decade	Number of publications (n = 21)	Number of Subjects (n = 444)	Number of awakenings (n = 2268)	Mean percentage (36.5%)	Standard Deviation
Chicago group and colleagues	1950s	4	42	224	4.5% “dreams”	5.45
Other researchers	1960s	11	198	1401	38%	22.62
Other researchers	1979 to 1998	6	204	643	67%	12.68

after an absence of dream production in 90% of the cases in the preceding sleep period. Foulkes awakened the participants in REM sleep and in the Stage 2 or Slow-wave sleep period preceding an expected REM period. Since he obtained dream reports in at least 50% of the awakenings, he proceeded to earlier and earlier awakenings, but he found no point at which dream recall ceased. He concluded that dreaming might be more or less continuous through sleep. When Foulkes presented his results at a meeting of the Association for the Psychophysiological Study of Sleep (APSS), it provoked surprise and skepticism. Rechtschaffen, the co-founder of the APSS who had created a second laboratory of sleep research at Chicago University, conducted with Foulkes a study (Foulkes and Rechtschaffen, 1964). It confirmed the occurrence of a higher rate of dream recall outside of REM sleep than postulated in the received view. This finding, supported by a respected sleep physiologist, validated the fact that REM sleep was not the only physiological condition enabling dream production.

During the subsequent years and decades, numerous experiments had similar conclusions. Hobson, Pace-Schott and Stickgold (2000) gave a list of 21 experiments comparing the frequency of dream recall within and outside of REM sleep (see Table 1). We ordered these data chronologically instead of alphabetically, which separated the results of the promoters of the REM sleep hypothesis from those of the other researchers (see table 1). Organized this way, the data reveal two facts. First, the mean recall rates (4.5% of “true” dreams) for “NREM” reports found by the proponents of the REM sleep view of dreaming (four publications) were much lower than those obtained in further decades. Second, the longer the time elapsed since the publication of the first papers presenting the REM sleep hypothesis of dreaming in the 1950’s, the higher the rate of dream recall upon awakening in “NREM” sleep (papers published in the 1960s: mean rate of 38%, papers published from 1979 to the end of the 20th century: mean rate of 67 %.) This percentage corresponds to the results of experiments of the Hobson group conducted at the beginning of the 21st century when they rejected the received view (Stickgold, Malia, Fosse, Propper and Hobson 2001; Fosse, Stickgold and Hobson 2004). And Hobson cannot be suspected of underemphasizing the difference between dream reports within and outside of REM sleep. The rate of recall outside of REM-sleep of about 45% asserted by Nielsen (2000) and often cited in recent papers is not correct. This percentage is the average of the results of 35 experiments, but 21 of them were published before 1970 and they included the results of the proponents of the received view that no subsequent research replicated.

3.2. The difference of content between reports after REM-sleep and after the other sleep stages tends to disappear when the length is controlled

In the 1970s and 1980s, the issue for dream researchers was no longer whether dreaming occurs in REM sleep only but whether, as postulated by the received view based on the hypothesis of an isomorphism between REM sleep and dreaming, there were fundamental differences of content between REM sleep reports on the one hand and Stage 2 and SWS reports on the other hand. Everybody acknowledged that, outside of REM sleep, reports were on average shorter (for example, Antrobus, 1983; Foulkes and Rechtschaffen, 1964; Goodenough, Lewis, Shapiro, Jaret, and Sleser, 1965). Qualitative differences were also found between REM sleep and other stages reports. The most frequently mentioned difference was the “dreamlike” quality of REM reports, which was global and ill-defined (Antrobus, 1983) and varied according to the research team. The Kleitman group expected dreams to be coherent and detailed and they rejected short and fragmented reports. In contrast, several authors (Antrobus, 1983; Foulkes, 1985; Hobson et al. 2000) considered bizarreness as an important feature of dreaming, which implied lack of coherence and unexplained discontinuity. Most dream researchers agreed that three other important features characterize dreaming: visual vividness, story-like nature and hallucination. The problem was that these aspects, like the dream-like quality, could be defined differently, and might be absent only because the participants did not judge it necessary to mention them.

Antrobus (1983), comparing REM reports and reports from other stages, showed that these variables were dependent on the number of words of the report. Reports of comparable length had no significant difference of content. With a different methodology, Foulkes and Schmidt (1983) reached the same conclusion, also including narrative continuity. A recent study (Montangero and Cavallero, 2015) showed that, as far as narrative quality of a report is concerned, the proportion – and not only the number - of narrative features increases with length. The role of length can be explained by the hypothesis that longer reports result from a better memory retrieval of the dream experience. They contain consequently more details and more aspects typical of dream thought (Antrobus, 1983). This would also explain why longer “NREM” reports become similar to REM reports if, as hypothesized first by Pivik and Foulkes (1968), the differences between the two kinds of reports stem from a difference of accuracy of recall. In any case, it is necessary to control length when comparing the content of dream reports.

3.3. Quantitative and qualitative aspects of dream reports depend on the moment of the night

Beside length, another parameter influences quantitative and qualitative aspects of dream reports within the same stage. Several researchers who woke up participants at different moments of the night observed that the length of dream reports as well as their richness increased with the duration of sleep. Late night reports (i.e., during the third and fourth cycles of sleep) tend to be longer, to be more narrative and to contain more emotions and more originality. This transformation across the time of the night has been observed for non-REM reports since the beginning of experimental dream research (Goodenough et al., 1959; Pivik and Foulkes, 1968) as well as for REM reports (Foulkes, 1985). Other researchers showed that the differences between REM reports and reports from the other sleep stages diminished drastically or disappeared at the end of the night. Kondo, Antrobus and Fein (1989) concluded their comparison by asserting that the closer you get toward morning awakening, the more likely you are to get a REM-like NREM report. The results were explained with a central point of Antrobus' theory (1986): dreaming is linked to a cortical activation and a cognitive arousal coupled with a high perceptual threshold. The level of arousal increases with the hours spent sleeping and the result is longer reports, consequently reports with a richer content. Two experiments conducted toward the end of the 1990s yielded analogous results. Casagrande, Violani, Lucidi, Buttinelli, and Bertini (1996) compared Sleep onset, Stage 2 and REM reports collected in the early part of the night and during the late part. After partialling out the length of the reports, most differences between stages disappeared, however significant differences remained for bizarreness and in the description of visual imagery. Cicogna, Natale, Occhionero and Bosinelli (1998) compared Sleep onset reports and the last dreams of the night after spontaneous morning awakening. The latter were produced in Stage 2 (52% of the reports) and in REM sleep (26%). No difference, either quantitative or qualitative, was observed between REM and Stage 2 morning reports. Using a more analytical method, a recent study on the narrative quality of these morning reports, confirmed that there were no differences between REM and Stage 2 reports (Montangero and Cavallero, 2015). Within REM sleep, the results of Rosenlicht et al., (as cited in Feinberg, 2000) revealed a significant difference in reports length between reports of the second and fourth cycle of sleep, whereas within REM sleep periods of each cycle, the difference of report length after 5 or 10 minutes of sleep was not significant.

3.4. Absence of clear correspondence between eye movements and dream content

Considering the experiments conducted by Dement and colleagues about the correspondence of the pattern of eye movements during REM sleep and the characteristics of the visual dream images, a study pointed to the methodological weaknesses of these experiments and it concluded that these results were not replicable (Moskowitz and Berger, 1969). Similarly, Jacobs, Feldman and Bender (1972) answered negatively to the question asked in the title of their paper: "Are the eye movements of dreaming sleep related to the visual images of dreams?" They argued that no precise comparison of dream images and rapid eye movements was possible, since dream content varies enormously and

ceaselessly whereas REMs have an intermittent and not very variable nature. Further experiments on the same issue gave controversial or negative results (Pivik, 1978). Actually, the rapid eye movements during sleep are different from waking eye saccades, they are slower and have a longer duration (Aserinsky, Lynch, Mack, Tsankoff, & Hurn, 1985; Silber et al., 2007).

Following a suggestion of Aserinsky (1967), further research (for instance, Molinari and Foulkes, 1969; Bosinelli, Cicogna, & Molinari, 1974) dealt no longer with the supposed isomorphism between REMs and dream visual images. They compared reports upon awakening during a burst of rapid eye movements (phasic event) and reports also in REM sleep but during an absence of REMs (tonic, i.e., long-lasting physiological event). A review of the results of these experiments (Pivik, 1978) concluded that the role of phasic events was very weak on the visual content of dreams and that it was most often non-replicable.

3.5. Brain lesions studies show a dissociation between dream reporting and REM sleep

Solms (2000) noted that several studies of patients suffering from brain lesions showed that dream reports are preserved in spite of pontine brain stem lesions which suppress REM sleep. He also listed numerous publications, between the 1950s and the 1990s, describing cases with complete or nearly complete cessation of dream report associated with a focal brain lesion located to the forebrain, while the brainstem was intact and REM sleep was unaltered.

Solms therefore concluded that REM sleep was neither necessary nor sufficient to obtain dream reports, which confirms the conclusion of psychological research (Foulkes and Cavallero, 1993, p. 9). His neuropsychological investigation of dreaming (Solms 1997) highlighted two forebrain regions (see below 5.3), which seem to play a critical role either in dream production or in dream recall.

3.6. Summary

To sum up, counter-evidence to the received view was abundant and its amount and variety grew ceaselessly. Since the mid-1960s, most sleep and dream researchers knew that several experiments, including one conducted with a well-known sleep physiologist, had revealed that dreaming was much more frequent outside of REM sleep than postulated by the received view. This discovery falsified the main postulate of that view: the electrophysiological assessment of REM sleep was not a means to determine the occurrence and duration of dreaming. Subsequent experiments demonstrated that many other findings by Dement were not replicable. Reports outside of REM sleep did not contain a majority of thoughts, there was no clear evidence that REMs corresponded to the scanning of the dream visual content and REM sleep deprivation did not have deleterious psychological consequences (for this last point, see Vogel, 1975). In the 1980s and 1990s, two important causes of content differences between samples of dream reports were demonstrated. First, the length of the reported dream influences the richness of content, that is, its variety, originality, emotional and narrative aspects. Second, the duration of sleep before obtaining a report, in other terms the awakening time in the early part or late part of the night, has also a strong influence on the report content.

4. The resistance to the counter evidence

4.1. The long denial of the counter evidence

Scholars specialized in sleep physiology reacted very differently from dream researchers to the counter evidence contradicting the received view. Most of them simply decided to ignore these experimental findings. They continued to teach or write that REM sleep was the stage of sleep during which we dream, and that consequently we dream only at some recurring moments of the night. This view legitimized giving a physiological explanation of dreaming based on the characteristics of REM sleep. The scientific denial – or epistemological repression – of experimental findings contradicting the REM sleep view of dreaming lasted for a surprisingly long duration: around forty years. In the 20th century, it might be the unique case of such a long refusal to give up a paradigm proved to be erroneous.

At the beginning of the 1970s, Dement published a book on dream based on his research and meant for a lay public (Dement, 1972). This well-written short book dealing with interesting issues is outdated and contains questionable assertions. Yet it is still read and summed up in introductory psychology texts in the second decade of the 21st century! Another example is the best known physiological theory of dreaming, the activation-synthesis theory, first proposed by Hobson and McCarley in 1977. The theory received adjunctions several times but the most developed version published in 2000 still explained dreaming by features of REM sleep (Hobson et al., 2000). Yet Hobson (1988) was one of the rare sleep researchers who had acknowledged that dream reports indistinguishable from REM reports could be obtained outside of REM sleep. According to the activation-synthesis theory, chaotic signals produced by the brain stem during REM sleep randomly activate regions of the cortex and consequently unrelated images and ideas (step of activation). At the level of the cortex, there is an attempt to “produce a coherent experience” (Hobson et al., 2000, p. 823) from the result of the chaotic input (step of synthesis). In that paper, the percentage of dream reports obtained upon awakening in Stage 2 and SWS was clearly underestimated. It was supposed to be “at most 25% and possibly as little as 12%” (p. 854-855). The last figure is almost identical to that mentioned by Dement and Kleitman in the 1950s. In the same special issue, Nielsen (2000) proposed the concept of a ghost version of REM sleep, “covert” REM sleep, which is supposed to be present during other stages of sleep without being actually observable. Feinberg (2000) entitled relevantly his comments upon this paper and the one by Hobson: “Desperately seeking isomorphism” [between REM processes and dreaming]. Note that the content of the special issue of Behavioral and Brain Sciences was republished in 2003 as a book, enriched with a review of recent findings by Pace-Schott (Pace-Schott, Solms, Blagrove, Harnad, 2003).

Let us consider another example of late persistency of the received view: the conception of Jouvett, the specialist of sleep physiology in animals who discovered the loss of muscle tone (in cats) during REM sleep at the end of the 1950s (Jouvett and Michel, 1959). He also coined the terms “paradoxical sleep” to refer to REM sleep. At the beginning of the 1990s, he published a book on sleep and dreams (Jouvett, 1992) which had several re-editions and translations. In this book, he wrote that several decades had been

necessary to convince the most skeptical scholars that dreaming was not a continuous process during sleep but was strongly dependent on the periodical occurrence of REM sleep. Consequently, at the end of the 20th century, a lot of readers thought that the received view was an up-to-date theory.

What actually happened at the time was the disappearance of that theory. Since the beginning of the 21st century, a new generation of sleep researchers acknowledged that we also dream outside of REM sleep. Even the Hobson group eventually admitted that the idea that dreaming and REM sleep were identical, first published in the 1950s, “was soon disproved by the finding that significant amount of mentation, much of it distinctly dreamlike, is reported after NREM awakening” (Stickgold, Malia, Fosse, Propper and Hobson, 2001, p.171). In a later publication, they wrote that “in spite of objective difference in electrographically defined states, the brain supports cognitive function of a similar type [in early night REM and late night NREM]” (Fosse, Stickgold and Hobson, 2004, p. 302).

For a few years, this change in the conception of the relationships between REM sleep and dreaming did not prevent some sleep specialists to continue to explain features of dreaming by characteristics of REM sleep (Hobson & Pace-Schott, 2002; Maquet et al., 2005; Schwartz & Maquet, 2002). For instance, Maquet et al., (2005) attempted to relate cognitive aspects of dreams and regional patterns of decreased activity within frontal and parietal areas during REM sleep. But what is the point of establishing correlations between the peculiar distribution of regional brain activity during REM sleep and cognitive features of dreams, if you know that similar mental content also occurs in completely different functional states of the brain? Ruby, a co-author of Maquet et al. (2005), highlighted this point some years later in a review (Ruby, 2011) in which she defended the view that dreaming occurs also outside of REM sleep and that it must be taken into consideration when looking for the neural bases of dreaming. However, for many researchers studying currently sleep and dreaming, the findings and conclusions of dream researchers published thirty to fifty years ago seem to be still recent and/or not generally accepted. Here are two examples among others, in articles published in the second decade of the 21st century. First, the title “Dreaming without REM sleep” (Oudiette et al., 2012) seemed to be almost a scoop. Second, as far as the idea of continuity between waking and sleeping cognition was concerned, Wamsley (2013) asserted that it was suggested by “emerging evidence” whereas this idea had been adopted since the 1970s by several authors on the ground of experimental results obtained several decades ago (Antrobus, 1978; Foulkes, 1978; 1985). Finally, we will note that some authors, for instance Pace-Schott (2017), still think that it is important to study mainly REM sleep in order to find out what are the neural correlates of dreaming.

4.2. Arguments for ignoring the counter-evidence

When asked why they did not take into account the experimental findings contradicting the equivalence between REM sleep and dreaming, the resisting researchers gave one or several of the following arguments.

- *Dream reports outside of REM sleep are the recall of the content of a previous REM dream.* This idea, already mentioned by Dement and Kleitman (1957), is invalidated by two facts. First, people awakened during the first

cycle of sleep, before any REM period, produce dream reports (Cavallero, Cicogna, Natale, Occhionero, & Bosinelli 1992; Foulkes, 1962; Vogel, 1991). Second, we do not recall dreams if we do not wake up while having them (Koulack and Goodenough, 1976). Hobson (1988) noted that less than five minutes after the end of a REM period, the rate of reports obtained decreased to the expected rate of “NREM” reports. Recent confirmations of the importance of night awakenings in remembering dreams is provided in Eichenlaub, Bertrand, Morlet & Ruby (2014a) and in Vallat et al. (2017b). Participants with a high dream recall frequency (more than 3 recalls per week) had longer awakenings during sleep than participants with low dream recall frequency (1.90 ± 0.91 min vs 0.95 ± 0.40 min).

- *Dream reports collected outside of REM sleep are very different from REM reports, they are not really dream-like.* An example given below (5.1.3) will show that this idea is false and this demonstration could be made with innumerable dream reports collected upon awakening in Stage 2 by different researchers (for instance, Antrobus, 1983; Cicogna et al., 1998; Foulkes and Schmidt, 1983; Kondo et al., 1989; Strauch and Meier, 1996). When length is controlled, the differences are rare or in-existent.
- *Dream reports are not reliable. They can be invented upon awakening, intentionally or not. Participants in dream research are usually students of the professors conducting the experiment. They invent dream reports to please the professors. Or dream reports can be imagined when waking up and taken for a previous experience.* The latter idea was proposed by the logician Goblots (1896). According to him, dreams were produced during awakening, which he conceived as a long and gradual process. This counterintuitive idea was adopted by several philosophers during the 20th century (Wittgenstein, Malcolm, Dennett, see Crespino, 2015) and discussed by some physiologists and dream researchers (Rechtschaffen, 1967, Hall, 1981). Guénolé and Nicolas (2010) mentioned several findings that invalidate Goblots’s thesis. First, abrupt awakenings yield longer and richer content than gradual ones (Goodenough et al., 1965). Second, sensory stimulations during sleep can be integrated into dream content. It has been observed for stimulations presented from 30 s to 3 min before the awakening (Koulack, 1969). Third, a correspondence has been often observed between the behavior of people suffering from REM-sleep behavior disorder and the content of the dream reported after awakening (Schenk & Mahowal, 2005; Valli et al., 2011). We will add that Goblots’s thesis is incompatible with the fact that immediately on awakening from REM sleep, we recuperate reality testing: we differentiate the products of imagination and of perception. Most people have experienced that rapid recuperation when awakening from a nightmare. One last remark to conclude this paragraph on doubts about the validity of dream report outside of REM sleep: if you doubt the reliability of dream reports, you should not accept the received view, which was based on the idea that the presence of dream reports meant the presence of dreaming.

Concerning the samples of dream reports collected by researchers, despite their variability of content, specific characteristics compared to waking reports appear clearly if

one considers series of 20 or more reports. The density of events is higher, transitions are lacking; a minority of bizarre elements can be observed (for this last point, Willequet, 2000). Moreover, the length of dream reports was found to correlate with the stage of sleep preceding awakening (REM sleep reports are longer than Stage 2 ones) even if the participants had no idea of the sleep stage they were awakened from. Similarly, they ignored the duration of the REM period preceding the awakening in an experiment by Stickgold, Pace-Schott and Hobson (1994) which concluded that the length of REM reports correlates with the duration of the REM sleep period before awakening – except for a duration exceeding 45 minutes.

5. Discussion

5.1. Two questions to be considered when studying the neural bases of dreaming

Knowing the results of research on dream recall and having an explicit definition of dreaming seems to us a necessary condition for studying or discussing the neural bases of dreaming.

5.1.1 Forgetting and remembering dreams

The received view on dreaming comprised an inconsistency about the relationship between an absence of dream report upon awakening and the forgetting of the dream content. When Kleitman and his younger colleagues woke up participants in “NREM” sleep and did not obtain a dream recall, they concluded that there was an absence of dreaming. But they did not draw the same conclusion for the absence of dream recall upon awakening in REM sleep, which happened in 20% to 25% of awakenings (Dement and Kleitman, 1957 and Aserinsky and Kleitman, 1953). Admitting the absence of dreaming would have falsified a main implication of the received view, namely that the presence of REM sleep was an objective cue to infer the presence of dreaming. The only explanation left to account for the absence of report for REM awakenings was that dreams had been forgotten.

We forget most of the dreams we produce for hours during each night of sleep. The main reason is that a condition to remember a dream is, as already mentioned, to wake up during dreaming (Koulack and Goodenough, 1976; Eichenlaub et al., 2014a; Vallat et al., 2017b). A second condition is to turn immediately one’s attention to one’s interrupted mental production, because dream content is encoded in short term memory which lasts only few minutes (Cohen, 1979; Goodenough, 1991; Hobson, 1988). Two circumstances may prevent the retrieval of the memory of the dream. First, distractions at awakening have a devastating effect on dream recall (Goodenough, 1991). A strong perceptual stimulation, like switching on a bright light, or the fact of anticipating immediately the duties and concerns of the morning usually prevent the recall of the dream. A second circumstance detrimental to dream recall is a gradual rather than abrupt awakening (Goodenough et al., 1965). Other factors influence the rate of dream recall, both after forced awakenings in laboratory studies and after spontaneous awakenings in a home setting, for instance interest in dreams (Goodenough, 1991) and visual-spatial skills (Foulkes, 1999). Consequently, important inter-individual differences can be observed in rates of dream recall.

The absence of dream recall upon awakening outside of REM sleep as well as in REM sleep can be due to a problem of memory retrieval (Antrobus, 1983). This problem could occur more frequently after waking up in Stage 2 and SWS because of a greater difference in the neurophysiological state between the waking and the “NREM” conditions (Koukkou and Lehman, 1993). The hypothesis that the lower rate of dream recall outside of REM sleep may be due to a greater difficulty in the memory retrieval of something that has been experienced during sleep is supported by an experiment by Conduit, Crewther and Coleman, (2004). It demonstrated that it is possible to remember what has been perceived during sleep and that the recall is less frequent in Stage 2 than in REM sleep. In this experiment, participants trained to make an eye signal when hearing a certain sound could make the signal during their sleep when the sound was produced. When awakened shortly after the eye signal, they remembered having heard the sound and making the signal in 100% of cases when awakened from REM sleep and 65% when awakened from Stage 2. These considerations and the fact that dream reports have been collected during every cycle, every sleep stage and every part of a night of sleep render plausible the following hypothesis: dreaming can be a continuous process across each night, with variations in characteristics such as vividness of images and story-like qualities and types of waking life elements incorporation (Verdone, 1965; Stenstrom et al., 2012). Nineteenth century pioneers of dream research such as Hervey de Saint Denys (1995/1867) proposed that hypothesis and Rechtschaffen (1967) admitted that there were no strong objections to it. Recent findings (Schredl, Brenneke and Reinhard, 2013) support that hypothesis.

The process of reporting a dream and recapitulating its content involves the three strategies – rehearsing, translating into another modality and making a comment on the episode – which are necessary to encode an event into long-term memory according to Tulving (1983). Consequently, participants who reported one or several dreams during an experimental night remember them in the morning or, in case of forgetting one of them, they retrieve its whole content if they are read aloud the first sentence of the night report (Cipolli, Calasso, Maccolini, Pani, & Salzarulo, 1984). One of our studies showed, firstly, that the morning description of a dream, after reading the transcription of the night report of that dream, was more complete than the night report. Secondly, the morning additions were similar in quantity and quality to the additions produced in the morning when describing a video that had been presented and then described during the night. And for the video, we could check that almost 90% of the additions corresponded to the content of the video (Montangero, Tihon-Ivanyi and de Saint-Hilaire, 2003).

5.1.2 A cognitive definition of dreaming based on a variety of REM reports also applies to reports in other stages

Any study of dreaming is based on an implicit or explicit definition of what is a dream. Defining dream or dreaming is difficult, because of the extreme variety of content of dream reports. Here, we would like to present a definition of dreaming that deals more with general properties of dreaming than with specific content. It applies to most REM dreams of a certain length (over three or four temporal units). We claim

that it can also be applied to most Stage 2 and Slow wave sleep reports of similar length.

Dreaming is the product of our ability to evoke something, and even a whole non present world, by substitutes, including mental ones, like inner speech or mental images. This ability was dubbed by Piaget “symbolic” or “semiotic” function (Piaget and Inhelder, 1969). In the waking state, a spontaneous simulation of a non-present world occurs when there is nothing interesting to observe and no action to control or to plan (Foulkes and Fleisher, 1975). These two conditions are fulfilled during sleep and that is the main reason why we dream.

Dreaming is a spontaneous phenomenon during sleep which is a true phenomenal experience, i.e. it feels as an experience of the waking life (loss of reality testing). It is composed of “virtual” sensory perceptions and of emotions and it can evoke various and complex representations of the setting, characters, objects and circumstances. The dreamer is therefore both the unaware creator of the dream and its conscious observer and often actor.

Several general features of dream production can be inferred from the specificity of dream reports compared to reports produced by controlled thinking in the waking state.

- Dreaming is a *concrete* way of representing things: ideas, feelings, topics of interest or concern, inter-individual relationships, etc., are represented by short observable scenes. The concrete events can be accompanied with thoughts and abstract concepts.
- It is a condensed way of representing things and it seems to obey a principle of *parsimony*, i.e., expressing meanings with a minimum of signifiers (words, images or “virtual” sensations). Sequences of related events are usually short. Only a part of the elements of a dream scene is visualized clearly and completely (Rechtschaffen and Buchignani, 1983) hence a much lower total of pieces of information in a dream report than in the description of a video (Montangero et al., 2003). Steps of a script (e.g., the successive events when we go to the restaurant) are omitted and so are transitions in a spatial displacement.
- *Executive functions* are at least *partly deactivated* during dreaming, a fact concomitant to the deactivation of the dorsolateral prefrontal cortex during sleep (Maquet et al., 1996; Braun et al., 1997). Attentional resources are limited, hence the “single-mindedness” of dreams, that is, the extreme rarity of simultaneous thoughts (Rechtschaffen, 1978) and of reflexive consciousness. The fact that our goal may change during a dream and that an unexplainable change of situation may not elicit surprise reveals a poor working memory. The frequent discontinuity of dream reports can be attributed to the absence of cognitive inhibition.
- Dream content results from a completely or partly *original* way of combining elements of episodic and semantic memory. A dream scene is not the exact replay of a memory episode. Dream production processes suppress elements, modify other ones and often merge elements borrowed from different mnemonic sources. Originality can be extreme and become bizarreness – like abrupt discontinuities, condensations, incongruities or logical and physical impossibilities – in a minority of the dream content (Domhoff, 2007).
- Dream reports, with the exception of very short ones, are *organized as short sequences of coherently related*

events. This feature, as well as the presence of unexpected events and of living beings interacting or acting, give a narrative nature to dream reports. However, these reported mental contents lack an overall structure similar to that of canonical stories (Montangero & Cavallero, 2015).

Specific aspects of dream content are, first, that the *visual modality* predominates and hearing as well as kinesthesia (sensations of movement) range next, whereas somesthesia (sensations of touch), olfaction and taste are rarer. Second, imagining *change* is an important feature of dream production process: change of location, of topic or concern, appearance or disappearance of characters, and occurrence of entirely new situations and novel content. Third, dreams involve *active or reactive characters*, sometimes the dreamer only. Fourth, emotions are frequently felt during dreaming but some dreams are devoid of them (Strauch and Meier, 1996) and the mean intensity of emotions is low (Côté, Lortie-Lussier, Roy, & De Koninck, 1996; Vallat, Chatard, Blagrove & Ruby, 2017a).

5.1.3 Examples of dream reports to which the definition applies

The first example of reports was given by Rechtschaffen as cited in Jouvet (1992) and the second one by Strauch and Meier (1996, pp. 139-140).

Example 1, REM report

I was dreaming about exams. At the beginning of the dream, I had just finished taking an exam and it was a very sunny day. I was walking with a friend who attends the same courses as me. There was a kind of... break, someone mentioned a grade obtained in a sociology examination and I asked him if the grades in sociology were already known. He answered yes. I didn't know my grades because I had been away all day long.

This is the report of a dream, that is, an imagined sequence of life events where characters interact and some concrete events (walking on a sunny day, talking) take place. The last event mentioned (having been away all day) seems to contradict the fact of having just taken an exam, which can be explained by an impaired working memory. Note that this report is not strikingly "dream-like" (vivid, narrative, surprising) contrary to the received view of REM dreams. The content is mundane, descriptive elements are very scarce and thoughts – the evocation of the taken exam and of the absence during the day – are as numerous as actions (walking, talking).

Example 2, Stage 2 report, at 4 a. m.

I was at an exhibition, downstairs at an institute. There were frames of great depth, and if one didn't like a picture [painting], one could press down, the picture disappeared and the one below came up. Outside was a black piece, like iron, a button. What happened was that these pictures were totally different: if there was a romantic picture and one pushed, then an extreme[ly] modern, cold one came up, with few colored spaces [places]. And when the picture was one of those, then something like a Rubens came up. And then it was again at the institute, no longer an exhibition, but there were people who were relatives whom I had never seen before. And they kept

running around, terribly busy, saying: "Sure, that will have to be organized quite differently. The whole thing is terribly unprofitable. Crazy all that waste of time!" And I kept thinking: "What are they talking about? I don't understand what is bothering them." I was actually quite angry that they should suddenly turn up as managers trying to organize something I didn't understand.

Our definition applies very well to this Stage 2 report, which is an example of full-fledged dreaming, the imagination of short causal sequences of events. First a physical causality provoking perceptual changes described precisely, then a psychological causality provoking the anger of the dreamer. The narrative break between the two successive scenes is not unusual in REM reports as well as in reports from other stages. It can be explained by the lack of cognitive inhibition maintaining attention on a given situation. In this report, there is a lot of change and movement, of unexpected events and of visual elements. The content is very original. Moreover emotion is present in the second part. The attention is focused on a limited number of elements, according to the principle of parsimony.

5.2. Apparent incompatibility between the neuroscience and the cognitive psychological approaches to dreaming

For half a century, most dream research was conducted either with a neuroscience approach or with a cognitive psychological one. This raises the issue of the contributions of these two approaches and of whether they are incompatible or complementary.

5.2.1 The positive impact of the neuroscience approach on the beginning of scientific dream research

Dement's results in the late 1950s and early 1960s were pioneering, and even if inappropriately interpreted, they had a very positive influence on the development of a scientific study of dreams.

First, Dement's work showed that there was a new means to conduct research on dreaming: awakening participants during REM-sleep and obtaining a dream report without delay. Second, this method issued from neuroscientific studies (named at the time the psychophysiological approach) gave for the first time scientific credit to the study of dreams. The numerous experiments conducted outside Kleitman's laboratory in the 1960s and during part of the 1970s were mainly neuroscientific ones. They dealt with the relationship between a neurophysiological phenomenon and the frequency and the properties of dream reports.

The main often replicated result of that approach was that, upon awakening in REM-sleep, dream reports were on average more frequent and more detailed. Attempts at influencing dream content by sensory stimulation were successful in a minority of participants. The frequency of the integration into the dream content depended on the nature of the stimulus. For instance, the incorporation of verbal or tactile and electrical stimulations (Berger, 1963; Koulack, 1969) were more frequent than of visual ones (Rechtschaffen and Foulkes, 1965). During the decades when neurophysiologists were interested in the link between hemispheric predominance and cognition, divergent conclusions were drawn: dreaming was supposed to be linked first to the predominance of the right hemisphere (Galin, 1974), then to the

predominance of the left one (Greenberg and Farah, 1986). Eventually the idea that the two hemisphere play a role in dream production is the more convincing (Dumont, Braun & Guimond, 2007). The characteristics of REM sleep such as the predominance of a neurotransmitter (Hobson, 1988) or the specific regional brain activation (Maquet et al., 1996) were presented as coherent with features of dream reports.

5.2.2 *The turn toward a cognitive-psychological perspective*

The findings of dream researchers who were primarily interested in the characteristics of dream reports contradicted the idea that dreaming was an epiphenomenon of REM sleep, by showing that producing dreams was a psychological activity which required the use of many cognitive abilities. Foulkes (1982, 1999) showed that quantitative and qualitative aspects of children's dream reports correlated with their level of cognitive development. Kerr (1993) reviewed experimental results that revealed a correlation of mental imagery skills with the frequency of remembering dreams. Antrobus (1983) explained the greater length and richness of late night dream reports by attention and memory processes. Montangero (1999) underlined the basic role of the symbolic function (capacity to represent something by a substitute) and the influence of a deficit in working memory and other executive functions during dreaming.

Because of the importance of cognitive processes and of the abundant counter-evidence to the received view, most dream researchers, since the last years of the 1970s, were disappointed by the neuroscientific approach. Too many questions concerning dreaming had remained unanswered in twenty years of research. Many of these researchers decided to turn to cognitive psychology in order to explain both dream production processes and the specific characteristics of dreams (Antrobus, 1978; Foulkes, 1978). Some other researchers were more interested in the affective and clinical aspects of dreams (e.g., Cartwright, 1986; Hartmann, 1984; Kramer, 1993).

In the 1970s, the large number of dream reports collected at different moments of the night permitted observing that the content of the majority of dreams was not as bizarre and incoherent as believed until then (Snyder, 1970; Foulkes, 1981). The idea of a continuity between waking and sleeping cognition was born (Beck, 1971; Domhoff, 1996) and inspired research also in the 21st century (Schredl and Hofmann, 2003; Schredl and Erlacher, 2008). Content analysis of dream reports (Hall and Van de Castle, 1966; Strauch and Meier, 1996) showed that the majority of reports has a mundane topic and that "dreams are a good window into people's conceptions, concerns and interests." (Domhoff, 1996, p. 190). The contrasting conception of most sleep physiologists, which stressed the strange and incoherent aspect of dreams, was based on the long term memory of spontaneously remembered dreams. These memories constitute a biased sample: following the laws of memory encoding, we mainly remember experiences that are loaded with emotions, and/or very unusual and/or with very vivid sensations.

The continuity between some waking and dreaming mental content comforted the choice of researchers who turned to the cognitive-psychological approach. They addressed new topics of research that yielded numerous new findings. Here are a few examples of topics: children's development

of dreaming (Foulkes, 1982, 1999), the memory of dreams (Antrobus, 1983) and the memory sources of dream content (for a review: Baylor and Cavallero, 2001), the more or less coherent sequential organization of dream reports (Foulkes and Schmidt, 1983; Nielsen, Kuiken, Hoffmann, and Moffit, 2001; Cipolli and Poli, 1992), the difference of quality of dream reports according to their length or to the moment of the night, (Antrobus, 1983; Casagrande et al., 1996; Cicogna et al, 1998). Most experiments producing counter-evidence to the REM-sleep view of dreaming were conducted by researchers who adopted the cognitive approach. As their findings were deliberately ignored by most sleep researchers, the neuroscientific and the cognitive psychological approaches seemed to have become incompatible.

5.3. Consequences of the disappearance of the scientific denial: important changes in the current neuroscience approach to dreaming

Maintaining the REM-sleep view of dreaming has considerably hindered advances in the question of the neural bases of dreaming. In spite of impressive developments in sleep neurophysiology since the mid-20th century, we still ignore what are these bases. They could be very general neurophysiological conditions or more specific, but varying systems. Some interesting suggestions have been proposed since the beginning of the 21st century, but a gap of about half a century cannot be filled in a few years.

Solms (2000) suggested that the neurophysiological conditions enabling dreaming were various forms of cerebral activation and the engagement of dopaminergic circuits of the ventromesial forebrain. More specifically, he hypothesized that two forebrain regions, the temporoparietal junction (TPJ) and the white matter of the medial prefrontal cortex (MPFC) were involved in the cerebral processes generating dreaming. Eichenlaub and colleagues (2014b) tested this hypothesis by comparing brain activity (using positron emission tomography) in high dream recallers (participants having an average of five dream recalls per week) and low dream recallers (0.5 dream recall on average) during sleep and resting wakefulness. Results support Solm's hypothesis since the authors observed that high dream recallers showed an increase of regional blood cerebral flow in TPJ and MPFC as compared to low dream recallers both during sleep (REM sleep and Slow wave sleep) and wakefulness. However, they did not explain why no difference of activation was observed during Stage 2.

They also mentioned that those brain regions – TPJ and medial prefrontal cortex – were parts of the so called default mode network. This system is active during mind wandering, daydreaming, recall and anticipation, in other words when attention is focused on mental content and processes rather than on external stimuli (Buckner, et al., 2008). Some researchers, for instance Domhoff (2011) and Christoff et al. (2016), think that the substrate for dreaming may be based on a subsystem of the default network.

A renewal of the old line of research investigating the possible correlation between dream recall and some EEG characteristics in the few minutes preceding awakening in REM sleep and Stage 2 sleep has also been observed recently (e.g. Esposito et al., 2004; Chellapa et al. 2011; Marzano et al., 2011, Siclari et al., 2017). The latter study is in line with the currently accepted paradigm about dreaming and sleep stages: the authors investigated NREM periods as well as

REM periods. Moreover, their research included interesting novelties like the use of high density EEG (256 channels) and the fact of differentiating localized EEG cortical activation from overall EEG activation. One of their main findings was the correlation of dream recall with a decrease of delta power (1-4 Hz) in a parieto-occipital region, in N2, N3 and REM sleep. Another finding was that, during REM sleep, high frequency power in certain regions correlated with dream content (e. g., more thoughts than perception or presence of faces).

As far as the technics of investigating brain phenomena are concerned, Pace-Schott (2017) underlined a limitation of neuroimaging studies: fMRI provides a satisfactory spatial resolution but a poor temporal resolution. EEG events have a good temporal resolution but are difficult to relate to a dream report necessarily obtained subsequently. That author also comments the new technics presented in Cipolli, Ferrara, De Gennaro, & Plazzi, (2017) magnetoencephalography, high density EEG and transcranial magnetic stimulation.

Current research sometimes deals with general physiological factors rather than with specific EEG or regional activation characteristics. For instance, Wamsley and Antrobus (2008) found that a circadian activation cycle which approximates core body temperature is not adequate to explain the qualitative and quantitative variations of dream reports with the time of the night.

In spite of these interesting findings and suggestions, Ruby (2011) relevantly asserted that the neurophysiological correlates of dreaming remain unclear. This author also mentioned a number of diverging results about regional brain activity during REM sleep and she suggested that it could be explained by an intra- and inter-subject variability. On the whole, the rejection of the REM-sleep hypothesis of dreaming resulted in important changes in the neuroscience approach to that domain. First, in most contemporary publications the conclusions are about dream recall and not dream production. Second, the somewhat simplistic view of the relationships between brain states and dreaming proposed in the 1950s by Kleitman and his colleagues is replaced by more complex views. Multiple neurophysiological factors can have an impact on the production of dream reports. Moreover, intra- and inter-individual variability must be taken into consideration. Third, most current experiments aim at studying the correlation between neurobiological aspects and psychological ones. Such neuroscience studies involve therefore collecting both neurobiological and psychological data. Let us take as examples the two papers about differences between frequent and infrequent dream recallers mentioned above (Eichenlaub et al., 2014a, see above 4.2; Eichenlaub et al., 2014b, this section). The team of researchers collected electrophysiological and positron emission tomography data to assess brain reactivity, duration of intra-sleep wakefulness and regional cerebral blood flow. On the psychological level, they had to know that there is an important inter-individual variability of dream recall frequency, that dreaming occurs in all sleep stages and that a basic condition for remembering a dream is to wake up during dreaming, and so forth. They collected psychological information through a questionnaire in order to select participants and later they had to test cognitive and personality traits and also to interview participants after waking them up in order to obtain dream reports. The discussion of the results underlined interesting correlations and con-

tained inferences of psychological cognitive tendencies without conflating psychological and neurophysiological phenomena. Such contemporary neuroscience research on dreaming becomes perfectly compatible with a cognitive-psychological approach.

This stands in contrast to the method of authors having a reductionist stance. For example, the abstract of the paper by Fosse, Stickgold & Hobson (2004) ends with the assertion that biological evidence supports the hypothesis that the changes observed across the night in qualitative aspects of the dream reports are governed by processes at the level of the brain. However the experimental results did not include any data showing a correlation between brain phenomena with the psychological changes observed, namely the predominance of hallucination over directed thinking in "NREM" reports in the later part of the night. Yet, in the discussion section, the authors wrote that the similarity between REM and "NREM" reports "suggests that, as the night progresses, NREM approaches the neurocognitive characteristics of REM" (Fosse et al., 2004, p. 302). We do not know of any description of Stage 2 sleep and SWS which indicates that their characteristics become similar to that of REM sleep at the end of the night.

5.4. An explanation of the long-lasting scientific denial of the counter-evidence to the REM sleep view of dreaming. The role of reductionism

Nobody gives up easily an idea or theory in which s/he believed. The reluctance of adopting a new view usually happened in science when a theory had proved valid and fruitful for a long period. In contrast, the idea that REM sleep was almost exclusively the functional state of the brain corresponding to dreaming was very recent, based on the study of a few participants and validated by one laboratory only, when the first counter-evidence was published. A scientific attitude requires that a new theory should be validated by more than one team of researchers and that it should take into account contradictory findings. Why did most sleep physiologists of the second part of the 20th century not adopt this attitude?

In our opinion, the reason was that acknowledging the erroneous nature of the REM sleep hypothesis would have diminished the credibility of sleep physiologists and the importance of their field of study. The hope that advances in this field would entail advances in the knowledge of dreaming might have vanished. The REM sleep view of dreaming brought a new and extreme importance to neurophysiology of sleep: objective physiological data permitted researchers to infer the presence of a non-directly observable category of mental content. A scientific study of dreaming was becoming possible. This idea paved the way to a reductionist approach of the study of dreams. REM sleep would not only allow researchers to know when dreaming occurred. The characteristics of REM sleep would help to explain the causes and properties of dreams. Our explanation of the resistance to counter-evidence to the REM sleep view of dreaming is confirmed by Hobson's comments about the discovery of REM sleep and its correspondence to dreaming. Hobson did not underline the contribution of that discovery to the advance of sleep physiology or to the opening of a new field of research. In Hobson and Stickgold, 1994, p. 2, he wrote that "it opened a new era of research in the relation of brain to mind" (underlining by us). Earlier, he had

asserted that this new research might validate the idea that brain and mind are one and the same thing (Hobson, 1988). It is therefore not surprising that two of the researchers who continued to adhere to the REM sleep explanation of dreaming for the longest period – Jouvett and Hobson – had a reductionist viewpoint.

Reductionism has different flaws that seem incompatible with a scientific approach. First, it involves a tendency to consider that biological phenomena are at the origin of psychological events. In the activation-synthesis conception, dreaming is provoked by an activation originated in the pons. In the field of emotions, the neuroscientist Damasio (2003) concluded his study by defining feelings as the psychological result of body changes (a thesis existing in psychology since the 1880s). In both cases, a correlation between mind and brain activity was interpreted as a unidirectional causality. Considering concomitant neurophysiological and psychological events as correlates that can interplay is probably the most fruitful attitude. A second flaw of a reductionist stance is that it implies the existence of a univocal relationship between the activation of a brain region or system and a concomitant psychological event. This is not the case. The amygdala, for instance, is activated when we are afraid, but also during the remembrance of an erotic memory or because it regulates physiological aspects of sleep. Moreover, a cognitive ability can rely on different neurophysiological pathways. Third, from a philosophical viewpoint, it is plausible to adopt a monist conception considering psychological phenomena and neurophysiological ones as two aspects of a same global phenomenon. From a scientific viewpoint, it is impossible to use the same method and the same concepts in order to study both aspects. Ricoeur underlined the semantic heterogeneity between the descriptions and explanations of a psychological phenomenon and of its cortical basis (Changeux and Ricoeur, 2002). Let us consider the study of dreaming. It implies interviewing the participants and analyzing the form and the content of their reports. This analysis is conducted in terms of use of elements of episodic and semantic memory, of level of logic and thought control, of narrative features, of relationships with the dreamer's concerns and interests, and so forth. Answers in terms of electro-chemical processes and regional brain activation cannot be appropriate unless their correlation with one of these psychological aspects has been demonstrated beforehand.

Because of these flaws and of the tendency to ignore the findings of psychological research, a reductionist stance may easily lead to scientific errors. Defining REM sleep as the stage of sleep during which we dream was an error, the most substantial one in this field, according to Solms and Turnbull (2002). Attributing the cognitive skill of dreaming to infants because they have long periods of reactivated sleep is incompatible with what we know about their cognitive development. They are unable to imagine (Piaget, 1952) and have extremely limited sensory information about the external world – which dreams simulate with mental imagery. Asserting with determination (Hobson et al., 2000) or more cautiously (Maquet and Franck, 1997) that dreams are hyperemotional is another error which was made because the activation of the limbic system is increased during REM sleep. Actually, when Strauch and Meier (1996) asked participants how they felt during their dream, immediately after their dream report, the answers revealed that about a quarter of the 500 dreams were devoid of emotion. Finally, the

conceptual amalgam of NREM sleep (see above, 1.2) can also be considered as a result of the overemphasis on REM sleep due to the reductionist aspect of the “received view”.

5.5. Conclusions

The discovery of REM sleep in the 1950s was immediately followed by the spreading of the thesis that REM sleep was the stage of sleep during which we dream. The thesis became in sleep physiology the received view on the relationships between the functional states of the brain during sleep and the production of dreams, until the end of the 20th century. However, as soon as the 1960s, a body of counter-evidence to the REM sleep hypothesis of dreaming grew continuously in number and diversity. It was published by dream researchers with a psychological training and an extensive experience of collecting and analyzing dream reports and it showed that the received view was a scientific error. The fact that the REM sleep view of dreaming was maintained by the most influential sleep physiologists for decades in spite of glaring inadequacies is surprising. In contrast, the immediate success of the view proposed by Kleitman and his colleagues is easy to understand. First, it was based on a simple idea: the correspondence of one functional state of the brain with one specific category of mental production. Second, the alleged correspondence of REM sleep with dreaming made possible a physiological – therefore objective – assessment of an evanescent mental activity impossible to observe directly. Third, as a consequence, sleep physiology was going to play an important role in the scientific study of dreaming. A new domain of research was born. The equation of REM sleep and dreaming comforted the reductionist view of a number of researchers: studying the brain during sleep would allow them to understand the causes and properties of dreaming. The falsification of the REM sleep hypothesis threatened their belief. These different reasons explain – but do not legitimize – why most sleep physiologists resisted the counter-evidence to the received view. Fortunately, we are now in a new era of the neuroscientific approach to dreaming. Current research is no longer based on an equation between REM sleep and dreaming. The relationship between brain events and dream recall or dream production is considered to be complex. Multiple factors are involved and variations can be observed in neurophysiological phenomena as well as in individual physiological and psychological traits.

Lessons can be drawn from the history of the relationships between REM sleep and dreaming. We must not forget some basic rules of scientific research. First, a new hypothesis likely to bring important changes to the study of a domain must be validated by replications conducted by different teams of researchers. The creators of the REM sleep hypothesis of dreaming obtained rates of dream recall outside of REM sleep extremely low (from 0 to 11%) whereas dozens of experiments conducted during the last thirty years yielded rates over 60%. Second, reductionism leads to errors, as mentioned above (5.4). Psychological assumptions about dreaming based on neurobiological data must be validated on the psychological level before they can be presented as reliable findings. Ignoring the results of research falsifying a paradigm (cognitive research in case of dreaming) is not acceptable. Third, neuroscience studies of dreaming should involve collecting both neurophysiological and psychological data and analyzing the correlation between these data. As a consequence, teams of neuro-

science researchers should include one or more persons knowledgeable about the findings of psychological dream research and trained in interviewing participants and analyzing psychological data. Such neuroscience studies avoiding reductionism will further contribute finding out what are the neural correlates enabling dreaming. This discovery might help to find answers to unsolved and important questions, for example, to what extent the length of dream reports depends on memory retrieval or on dream production processes.

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