

Exploring and developing the concept of the dream as a threat monitoring-alerting mechanism

Comment on Gewargis, Y. A. (2016). The true meaning of dreams. *International Journal of Dream Research*, 9(2), 197-201.

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Summary. It is not clear that established dream theories adequately explain the purpose of something that accounts for such a substantial percentage of our time. Gewargis's innovative theory - that dreams function to safeguard the organism during sleep - seems plausible and to have the potential to make an important contribution to a better understanding of why we dream. There are, however, a number of possible problems with it. In particular, the published literature is not used to substantiate the empirical claims upon which the theory is built; and this could be a major issue, as some of these claims seem to be at variance with current scientific knowledge and/or to have limited face validity. This comment article draws upon the neurology literature to critique and suggest amendments to Gewargis's theory; and proposes additional hypotheses relating to why and how dreams might act as a monitoring-alerting mechanism and protect the sleeper from a range of internal and external perturbations during REM and NREM sleep; and not just, as Gewargis appears to suggest, guard against inadequate blood flow to the brain or "oxygen-deprivation" to the lungs during REM sleep. A central argument in this comment piece is that to perform a range of functions, such as memory processing, the dream is where the sleeper's consciousness is focused for much of the time asleep, and so it is also where the alerting-arousal messages need to be presented and processed during that time. In other words, and at variance with what Gewargis proposed, we don't dream so as to provide a sleep defence mechanism, but a Dream Sleep-Defence Mechanism (DSDM) is needed because we dream. In addition, it is argued that dreams - including through the use of broad categories (and, in particular, potential danger/not potential danger), rather than representational reflections of the reality in question - provide a cortical resource efficient mechanism. It is recognised, however, that support for a dream sleep defence mechanism is at best circumstantial and that the idea needs to be tested in experimental studies if it is to move beyond conjecture.

Keywords: Dreams, sleep, consciousness, Dream Sleep defence mechanism, arousal, oxygen

1. Introduction

We need sleep so as to be able to function when awake (e.g., Muzet 2007; Ruiz et al., 2012). But do we need to dream and why do we dream? As there are people who do not seem to dream (e.g., Ogden, 2003); its absence may not be fatal. There have, however, been numerous studies suggesting that dreaming fulfils important functions (e.g., Lara-Carrasco, Nielson, Solomonova, Levrier, & Popova, 2009). Indeed, bearing in mind that most people spend a substantial percentage of their time dreaming (e.g., Schredl & Montasser, 1996), it seems inconceivable that dreaming would be purposeless. Evolution is arguably too parsimonious for that.

There are a wide range of theories as to why we dream (e.g. Freud, 1900; Domhoff, 2001; Lansky, 2003; Schredl & Hofmann, 2003; Valli et al., 2005; Zadra, Desjardins, & Marcotte, 2006; Levin, Lantz, Fireman, & Spendlove, 2009;

Desseilles, Dang-Vu, Sterpenich, & Schwartz, 2011; Forrer, 2016; Hopkins, 2016; Schädlich, Erlacher, & Schredl, 2016). A long established possibility is that dreaming guards sleep, and (as referred to above) we need sleep so as to be able to function. As Guérolé et al. (2013, p. 1) note - "According to the classic theory framed by Sigmund Freud, the basic ... function of dreaming is to protect sleep from disruption ...". Guérolé et al., (2013, p. 1) go on to argue that - "This aspect of Freud's dream model ... leads to two empirically testable conjectures, ... thus allowing its scientific examination: (1) arousal during sleep triggers dreaming; and (2) non-dreaming causes sleep disruption". Based upon a review of what they argue is literature of relevance to assessing the validity of these conjectures, Guérolé et al. (2013, p. 2) conclude that "Freud's theory of the basic functioning of dreaming" "is corroborated...". However, some of the research they review appears, as the authors acknowledge, to provide evidence which contradicts the conjectures (Guérolé, Marcaggi, & Baleyte, 2013, pp. 2-3). In addition, evidence in support of the conjectures is not necessarily evidence in support of Freud's dream model. This is, in particular, because there are alternative explanations (other than dreams guarding sleep) as to why these conjectures may be correct. For example, the authors suggest (Guérolé et al. 2013, pp. 1-2) that the higher Dream Recall Frequency (indicating more dreaming) found in patients with panic disorders or OCD (Schredl, 2001; Kuelz, Stotz, Riemann, Schredl, & Voderholzer, 2010) supports the conjecture that arousal during

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sleep triggers dreaming - in essence on the grounds that “neurotic” patients have higher unsatisfied “drive demands” which lead to more dreams to protect the individual from the greater number of arousals that would otherwise result (Guénolé et al., 2013, pp. 1-2). But it does not necessarily follow that they dream more so as to guard their sleep from these arousals. Instead, for example, “neurotic” patients might dream more on account of having a greater need for emotional regulation, with dreaming, according to Lara-Carrasco et al. (2009), being implicated in such regulation.

A more recently developed group of theories argue that dreams provide a virtual reality model of the world (e.g. Hobson, 2009), which, according to the most influential version of these theories - Threat Simulation Theory (TST) - enables the development of skills relevant to survival (e.g. Revonsuo, 2000; Valli & Revonsuo, 2009). There are also, however, significant difficulties with these theories. In particular, it seems “far fetched” to assume that the sleeping human brain can create realistic working models of live external threats. There is no good reason, for example, to think that a tiger in a dream – which might, for instance, be disproportionately large compared to the dream surroundings – would prepare the dreamer for avoiding a tiger in real life. In addition, while some studies provide support for TST (e.g., Valli et al., 2005; Bradshaw, Lafrenière, Amini, Lortie-Lussier, & De Koninck, 2016), others contradict it (e.g., Malcolm-Smith, Solms, Turnbull, & Tredoux, 2008). A more generally accepted function of dreams is to assist in the development and maintenance of memories (e.g., Perogamvros, Dang-Vu, Desseilles, & Schwartz, 2013). However, much of the evidence on the processing of memories links it to REM sleep and not specifically or as convincingly to REM dreaming (e.g., Maquet et al., 2000; Perogamvros et al., 2013; Nakagawa et al., 2016; Cipolli, Ferrara, De Gennaro, & Plazzi, 2016). In addition, if memory processing was the principal function of dreaming then it might be expected that dreams would more often reflect what had occurred during the day of the dream - or at least within the preceding circaseptan rhythms of 7 ± 3 days (Nielsen, Kuiken, Alain, Stenstrom, & Powell, 2004, p. 328) - than empirical research around continuity theory suggests is the case (e.g., Schredl & Hofmann, 2003). There again, it may be that the processing of declarative memories - i.e. “consciously accessible memories for facts and events” (Rauchs, Desgranges, Foret, & Eustache, 2005) - occurs more in NREM dreams than in REM ones (Zhang, 2016, p. 2), and, since NREM dreams are less likely to be recalled (e.g., Nielsen, 2000), the reflection of recent events in dreams are also less likely to be recalled than would be the case if such processing was concentrated in REM sleep.

2. Gewargis’s sleep-defence mechanism

Including on account of the possible weaknesses discussed above, it is not clear that established dream theories fully or adequately explain the purpose of dreams. Gewargis’s innovative speculation on “[t]he true meaning of dreams” (Gewargis, 2016, p. 197) could have the potential to contribute to the explanation. Arguably, it turns on its head Freud’s theory (discussed above) that the “function of dreaming is to protect sleep from disruption” (Guénolé et al., 2013, p. 1), and seems to imply instead that dreaming protects or prevents disruptions (including hypoxia) from going unresponded to during sleep.

Gewargis writes (2016, p.197) - “Dream researchers have failed to solve the dream’s riddle. The main reason is that almost all have adopted the content-approach, initiated by ... Sigmund Freud and Carl Jung”. He continues, referring to his own article, - “In this study ... [d]reams are seen as a component of a more intricate mechanism ...” which “takes over the task of safeguarding the living organisms ... during ... sleep ...”. According to Gewargis (2016, p.198), if, “while the subject is in stage (IV) sleep”, the blood flow to the brain or oxygen to the lungs drop to a dangerous level, “the so far low-charged and comforting dreams, will instantly shift gears into a more charged nature, like suddenly followed by an assailant with a dagger in hand ... Such frightening charged dreams seen by the central brain as real threat to survival, will instigate the latter with instruction to the sympathetic involuntary nervous system to immediately pull the body from deep sleep to a shallower level, or even to a waking level ...”.

3. Addressing possible difficulties with Gewargis’s theory

Whilst plausible and arguably with the potential to make an important contribution to knowledge, there appear to be some significant problems with Gewargis’s theory, including:

- The published literature is not used to substantiate the empirical claims upon which the theory is built. Indeed, his article only cites three papers, one of which is methodological (Domhoff 1999), one theoretical (Hartmann, 1998), and one can not be found, as the only information provided in Gewargis’s reference section is “Okasha 2006”.
- This could be a significant issue, as some of Gewargis’s central empirical claims appear (as discussed below) to be at variance with current scientific knowledge and/or to have limited face validity.
- The theory has not as yet been empirically tested; nor has it been suggested what empirical testing might be indicated.

This article next draws upon the neurology literature to critique and suggest amendments to Gewargis’s theory; and proposes additional hypotheses relating to why and how dreams might act as a monitoring-alerting mechanism and protect the sleeper from a range of internal and external perturbations during REM and non-REM (NREM) sleep; and not just, as Gewargis appears to suggest (e.g. 2016, p. 198), guard against inadequate blood flow to the brain or oxygen to the lungs during REM sleep.

3.1. Claim that the sleep-defence mechanism operates in REM sleep

Gewargis argues that his proposed dream sleep-defence mechanism is needed during stage IV sleep - which he appears to equate (e.g. Gewargis, 2016, p. 198) with what is more commonly referred to as REM sleep (e.g. Klimes et al., 2019) and for clarity will be so called in this article - but not needed during NREM sleep. The reasoning appears to be that during REM sleep, “the blood/oxygen flows are barely reaching their respective destinations ...” and so “any irregularity ...” could result in “blood-starvation to brain or air-deprivation to the lungs”, whereas during NREM sleep “there is no fear of” these outcomes (Gewargis 2016, p.198). However, at variance with this claim, cerebral blood

flow (CBF) is “decreased during non-REM sleep compared with wakefulness and REM sleep” (Maquet, 2010). In addition, respiration can be precarious during NREM (e.g. Guyenet & Baylis 2015) (as returned to at para. 3.2). It is noted that, while Gewargis refers to “Stage IV sleep” rather than “REM sleep”, he refers (Gewargis 2016, p. 198) to “Rapid Eye Movement (REM) occurrence” at Stage IV, “and not in the other levels”, which seems to mean that what is called Stage IV sleep is REM sleep by another name.

I would suggest a number of alternative reasons - in place of “blood/oxygen flows” “barely reaching their respective destinations ...” (Gewargis 2016, p. 198) - as to why there could be a significant risk of hypoxia, and/or hypocapnia, during REM sleep (including, in some instances, a higher risk than during NREM) which might necessitate what I refer to in this article as a dream sleep-defence mechanism (DSDM), including:

- *Vital sign instability.* Greater fluctuations in respiratory rate and blood pressure (Fink, Bronas, & Calik, 2018, p. 4), during REM compared to NREM sleep, with the associated extremes and rapid changes, might at times pose a greater risk than moderately low average O₂ saturation levels or CBF.
- *Reduced autonomic nervous system homeostatic control* (Guyenet & Baylis, 2015) *and reduced chemosensitivity* (Burke et al., 2015, cited in Guyenet and Baylis, 2015, p. 955) *during REM sleep.* Of particular interest, there are indications that an as yet unidentified mechanism steps-in during REM sleep when the influence of the brainstem is attenuated. Guyenet and Baylis (2015, p. 954) write - “Despite the presumed loss of the stimulatory effects of wake-on modulator (e.g., orexin ...), the relative atonia of many respiratory muscles ... and a reduced tidal volume, overall ventilation is actually well maintained during REM sleep; this is due to an net increase in mean breathing frequency, with highly variable inspiratory burst intervals, of unknown origin (Orem, Lovering, & Vidruk, 2005) and no longer under RTN [retrotrapezoid nucleus] control ... (Burke et al., 2015)”. It seems not impossible that the proposed DSDM could be part of this mechanism. Indeed, Guyenet and Baylis state (2015, p. 955) that the cortex is “conceivably” implicated in governing the frequency of inspiratory bursts; and the cortex is known to be implicated in dreaming (e.g. Baird, Castelnovo, Gosseries, & Tononi, 2018).
- *Respiratory events.* It also seems possible that dreams could play a part in waking the individual in the event of respiratory events which can not be dealt with within sleep; and it has been noted that “[n]octurnal respiratory events are usually more frequent and of longer duration in REM sleep compared with non-REM (NREM) sleep ...” (Acosta-Castro et al., 2018, p. 2).
- *Atonia.* The loss of postural muscle tone during REM sleep (Arrigoni, Chen, & Fuller, 2016) impairs the ability of individuals to move in their sleep, including, it might be assumed, to address a potentially hypoxic threat, such as “the heavy blanket over their heads” that Gewargis (2016, p. 200) refers to.

In addition to hypoxia and hypocapnia, there are other dangers that might exist and in some cases be increased during REM sleep, including in relation to thermoregulation. As “[t]hermoregulation is mainly abolished during REM sleep ...” (Mascetti, 2018), potentially dangerous changes in temperature could require transition (perhaps entailing a DSDM) to

NREM sleep, where, for instance, the sleeper could shiver (e.g. Ungurean & Rattenborg, 2019, R. 664), or to wakefulness. There could also, of course, be dangers from intruders (discussed below at para. 3.3) throughout the sleep cycle.

3.2. Claim that the DSDM does not operate in NREM sleep

Why would we dream in NREM sleep, as studies indicate that we do (Suzuki et al., 2004; Siclari et al., 2017), if Gewargis is right about “the real function” of dreams (Gewargis, 2016, p. 199) being his proposed defence mechanism and about this defence mechanism only being needed in REM sleep (Gewargis, 2016, p. 198)? His theory would arguably need to be adapted to address this apparent contradiction. There seem to be a number of possibilities:

- *Non-DSDM function.* Dreams perhaps do not provide a DSDM in NREM sleep but instead serve a different purpose, such as memory processing (e.g. Wamsley and Stickgold 2019). However, reports (Siclari et al 2017, p. 2) of similar dream related EEG activity in the “cortical ‘hot zone’” in NREM and REM sleep are arguably supportive of the idea that dreams serve a similar function in both.
- *Different DSDM function.* Dreams might provide a DSDM in NREM but with it addressing different types of risk compared to in REM. For example, while the limited role of chemoreceptors in REM sleep can cause problems (as noted above), Guyenet and Baylis (2015, p. 955) write that “[t]he low level of breathing present during non-REM sleep and its heavy dependence on chemoreceptors explains why minor fluctuations of PCO₂ can cause apneas or periodic breathing and CNS-damaging hypoxemia”.
- *No function.* NREM dreams might be purposeless. However, as noted in the Introduction, bearing in mind how much time we spend in dreams (e.g., Schredl & Montasser, 1996), this seems implausible.

3.3. Claim that we need a DSDM at all

Why would we need the cognitive song and dance of dreams when we have brainstem controlled homeostatic mechanisms - such as the biphasic hypoxic ventilatory response (e.g. Funk & Gourine, 2018) - which perform a defence function more quickly and reliably than could be expected to occur through changes in dream narratives? It is notable, for example, that the awakening response to dreams appears (from personal experience) to be “dose” dependent, with the “dose” (such as in the form of being chased by an assailant) required to trigger the arousal threshold presumably being less if recent events in the “individuals waking life had left him/her more anxious.” This seems far too hit and miss for Gewargis’s proposed hypoxia defence, which would need to maintain a stable redox state within narrow parameters (e.g. Ramirez, Severs, Ramirez, & Agosto-Marlin, 2018). As discussed next, however, there are ways in which a DSDM might reasonably be hypothesized to have a role to play in sleep-defence; and, in particular, when waking from sleep is imperative.

Bearing in mind the regenerative importance of sleep (e.g. Elkhenany, AIOkda, El-Badawy, & El-Badri, 2018), it makes sense that hypoxia/hypocapnia is in general dealt with homeostatically within it. Further, it would be inefficient for arousal systems to wake individuals every time there was

a “bump in the night” or other external stimuli “signifying nothing”. This might be part of the reason why “the increase in sensory thresholds makes the subject progressively unresponsive to external stimuli as sleep deepens” (Mascetti, 2018, p. 221). There again, there will be occasions when internal perturbations (such as acute hypoxia), internal-external ones (such as choking on something), or external ones (such as an intruder), can not be dealt with within sleep. Arguably, such occasions require an arousal mechanism which goes beyond “unthinking” homeostasis and can make the “right call” as to whether or not to arouse the individual. It seems possible that the basal forebrain (BF) - which appears to be pivotal in the regulation of sleep arousals (McKenna et al., 2020) - communicating with the cortex, might facilitate this going beyond. The BF receives inputs from other parts of the interlocking arousal systems which constitute the ascending reticular activating system (ARAS) (McKenna et al., 2020, p. 2) - including from the brainstem, which promotes “behavioural arousal in the setting of hypoxia, hypercapnia, or other stressors”, (Benarroch, 2019, p. 54); while the BF “contains several neurotransmitter systems with projections to the cortex”, which are thought to be implicated in arousals (McKenna et al., 2020). Ways in which the BF connected cortex might be involved in arousal control include the following -

- *Intelligent filtering.* Studies indicate that the passage of sensory information to the cortex during sleep is filtered and its processing in some respects impaired (e.g. Strauss et al., 2015); and it has been suggested (Andrillon & Kouider, 2020, p. 55) that “[t]his partial suppression of information processing might be crucial for the preservation of sleep while still enabling sleepers to maintain a minimal form of vigilance, a stand-by mode allowing the quick reversal to wakefulness if necessary.” There seems to be a trade-off between the important work of sleep, such as memory processing (e.g. Perogamvros et al., 2013), and the need to not die during it. I would hypothesise that the cortex, with a major role for dreams (as returned to below), changes the terms of this trade-off; and, in particular, through ensuring that arousal from sleep depends upon a range of stimuli characteristics (such as whether a voice sounds familiar) and not just upon their intensity (such as how loud that voice is). In consequence, the intensity of stimuli reaching the cortex can be lowered during sleep while maintaining adequate threat surveillance. Arguably consistent with what might be called “the discerning sleeper” proposition, studies indicate that sleep arousal thresholds do not just depend upon the intensity of the stimuli but also upon its more nuanced nature, such as the “emotional tone” of voices (Blume et al., 217).
- *Cognitive habituation.* The brain can habituate to (e.g. Tassi et al., 2010), and so not in general be woken-up by familiar, unthreatening, stimuli, such as low-flying planes if you live under the Heathrow flight path. The, in that example, auditory habituation might in part result from “a long-lasting reduction in representations of the experienced sound by layer 2/3 pyramidal cells” in the primary auditory cortex, which Kato et al. (2015, p. 1027) found in mice subject to “daily passive sound exposure”. I would suggest that higher cortical processes could also be implicated in assessing new stimuli against a stored understanding of what constitute more or less benign stimuli; and that this process might take place to some

extent in dreams or at least its conclusions might be presented there. However, some study findings relating to the effect of odours on arousals and dreams appear to be potentially at variance with the idea of cognitive habituation. Of particular note, Okabe et al., (2020, p. 227) found that “[p]articipants who were familiar to the odor (of phenylethyl alcohol) reported more emotionally negative dreams during the odor presentation” (words in brackets added). In addition, bearing in mind the importance of olfaction to survival (Blumstein et al., 2002), it is not clear why odours rarely cause sleep arousal (Okabe et al., 2020, p. 227).

Of course, much of the above concerns the role of the cortex, and leaves largely unanswered the question of why the alerting messages are (according to Gewargis’s theory) presented within dreams and (according to this article) within dream-implicated cortical structures, such as the sensorimotor cortex (e.g. Noreika et al., 2020). One possibility is that dreams serve functions other than as a DSDM, such as memory processing (e.g. Perogamvros et al., 2013); and because (to perform these other functions) the dream is where the sleeper’s consciousness is focused for much of the time asleep, it is where the messages need to be presented during that time. In other words, and at variance with what Gewargis proposed, we don’t dream so as to provide a DSDM, but the DSDM is needed because we dream. Related to this, assuming that dreams corner “cortical resources” (Andrillon & Kouider, 2020, p. 55), dreaming may not leave sufficient “brain power” for a sleep defence mechanism to be adequately provided outside of dreams; thus a DSDM reduces cognitive duplication.

It also seems that cognition in dreams could fulfill this DSDM function; with, for example, Horton (2020, p. 2) noting that studies have found that dream cognition “is not deficient but rather different in only a few ways to waking cognition ...”. Indeed, dreams might provide a particularly efficient DSDM. In particular, it is hypothesised here that dreams might use broad categories (including potential danger/not potential danger), rather than representational reflections of the reality in question (such as of an intruder who has entered the sleeper’s home), and present these broad categories within the dreams (which, as noted above, is where the consciousness is; thus avoiding “inessential travel”). In addition, the consciousness when dreaming does not need to have the real nature of the danger explained to it (which might entail, for example, an improbable within sleep internal “discussion” around hypoxia); the dream just needs to provide any dream narrative which will wake the sleeper. The potential danger category might be manifested in numerous different ways which draw upon personal associations (including ingrained fears and anxieties) but the form it takes on a particular occasion might depend upon the content of the dream narrative which is “running” at the time that the potential danger arises - such, for instance, as a rucksack disappearing if the sleeper happens to be travelling in a dream.

This use of broad, simplified categories in dreams would seem to make sense on account of the nature of stimuli inputs to the cortex during sleep and how these stimuli are processed. As regards inputs, it has, for example, been suggested that Ponto-Geniculate Occipital (PGO) waves might “disrupt the encoding of external stimuli in favour of the emergence of endogenous oneiric contents ...” (Andrillon & Kouider, 2020, p. 54). I would suggest, instead, that PGO

waves might disrupt the detailed encoding of external stimuli in favour of their simplified but more effective (in terms of arousal when needed) encoding as dream narrative. As regards processing, there are indications that the cortex during sleep is less able to apply higher level areas to stimulus information - such as the inferior frontal and superior temporal gyri in the case of speech (Wilf et al., 2016). For example, Blume et al., (2018, p. 646) found that during NREM and REM sleep “the brain seems to continue differentiating between paralinguistic (emotional) aspects (i.e. familiar vs. unfamiliar voice) but not among the linguistic content of stimuli (i.e. own vs. other name)”. The use of simplified categories in dreams might render such higher level areas less important. It might also be wondered whether dreams (that can be subject to intense and troubling recall on waking) facilitate sustained awakenings (which might be required to deal with persisting threats such as a fire), compared to, for example, what McKenna et al. (2020, p. 5) report as the rapid but brief arousals that result from optogenetic stimulation of BF parvalbumin neurons.

However, while there appear to be good reasons for a DSDM to function through dreams, this, of course, is not strong evidence that it does. Providing some additional circumstantial evidence are the studies that indicate that changes in the external environment during dreaming can affect dream content (something which would presumably need to occur for the proposed DSDM to function). Of particular note, Schredl et al. (2009, p. 285) found that “olfactory stimuli affected significantly the emotional content of dreams ...”. Nonetheless, as returned to in the Discussion, empirical studies specifically aimed at testing the DSDM theory are needed before it can move beyond conjecture.

3.4. What happens when we are not dreaming

Gewargis’s propositions that the “real function” (2016, p. 199) of dreaming is to provide what is referred to here as a dream sleep defence mechanism (DSDM), and that a DSDM is only needed in REM sleep (Gewargis, 2016, p. 198), might need to be amended - perhaps along the lines suggested above (para. 3.2) - to take account of what appears to be the fact that we dream in NREM sleep (Siclari et al., 2017) and it not seeming credible that (as appears to be implied in Gewargis’s propositions taken together) dreaming in NREM sleep is purposeless or at most of limited purpose. We would still, however, be left with the problem of what happens when we are not dreaming (whether in NREM or REM sleep) if it was in fact the case that we need a DSDM to deal with hypoxic and other dangers during sleep. There seem to be a number of possible answers, including the following:

- *Sleep defence mechanisms are continuous.* Sleep defence mechanisms (including against external threats) can be assumed to be ongoing outside dreams. For example, Blume et al. (2018, p. 177) found “that evaluation of voice familiarity continues during all NREM sleep stages and even REM sleep suggesting a ‘sentinel processing mode’ of the human brain in the absence of wake-like consciousness”. However, there could be the need for a different kind of defence mechanism when dreaming (para. 3.3 above); which a DSDM might fulfil. Three possible (and not necessarily mutually exclusive) reasons for this might (in brief and then set out in more detail) include -
 1. Dreaming being required for other reasons (like memory processing) and a DSDM being required to

provide defence tailored to the particular conditions that occur when dreaming.

2. The principal purpose of dreaming being to meet particular threats during particular periods of sleep.
 3. A DSDM being advantageous throughout sleep but in essence needing to be “switched-off” for brief periods, when it becomes incompatible with other functions of sleep.
- *Dreaming for reasons other than sleep defence.* There might need (as suggested above at para. 3.3) to be a DSDM because the dream (when we are dreaming) is where our consciousness is “located” for reasons such as memory consolidation; and so the dream is also where alerting messages would need to be sent and processed. When not dreaming, other cortical mechanisms would presumably perform the sleep defence function. Related to this point, the impact of PGO waves, and the “cornering of cortical resources” (Andrillon & Kouider, 2020, p. 54) during dreaming, could mean that any alerting mechanism needs to be highly efficient; and dreams - including on account of simplified categories (proposed above at para. 3.3) - could provide such a mechanism.
 - *Dreaming is restricted to the periods of sleep when there are greater threats and so more need for a DSDM.* For instance, low arousal thresholds in light sleep (Stuck, Baja, Lenz, Herr, & Heiser, 2011) mean that individuals will tend to wake in response to external stimuli (which might present a potential threat) without the need for these threats to be presented within dream narratives, and so light sleep can be dream-light. There are, however, problems with the idea of dreams correlating with periods of increased threat, including -
 1. *Correlation/non-correlation between dreaming and threats.* Other than in the case of deep vs light sleep, sleep associated with more dreaming (such as REM compared to NREM) does not necessarily closely correspond with higher arousal thresholds and possible related higher potential vulnerability to threats. For example, Ermis et al. (2010, p. 400), referring to arousal thresholds, report that “[o]nly few studies actually find lowered responsivity in REM sleep”. In addition, within REM sleep, it is not clear that there is a correlation between periods of dreaming and periods of increased threat (such as breathing instability); although lack of findings on this could simply reflect the matter not having been studied. Further, some threats (such as intruders) are, of course, no respecters of sleep stage.
 2. *Correlation with other factors.* There are indications that there are factors other than threat which might correlate more closely with periods of dreaming. For example, Nielsen (2010) writes that “[t]he literature is ... consistent with the claim that the quantity and qualities of dreaming are influenced by ultradian, circadian, and sleep-dependent factors”.
 - *A two stage process might be hypothesized.* First, if there is an increase in the likelihood of danger (albeit without there being an immediate need for arousal) - such as on account of external sounds - the cortex switches to dreaming, which enables it to better monitor and assess any developing threats. Second, the threat reaches a point at which it triggers a dream narrative - such as Gewargis “assailant” (Gewargis, 2016, p. 198) - which leads to awakening. However, it might be wondered why

there would be a need for the cortex to monitor the external environment within the medium of dreaming if it could monitor that environment sufficiently well outside dreaming to register that it needed to switch to monitoring it within.

- *Dreaming needs to be intermittently “switched off”.* Dreaming might provide the most effective monitoring-alerting mechanism for all situations, but for unknown reasons - such as some non-dream implicated parts of the cortex having a high demand for cortical resources for brief periods and dreams “cornering” (Andrillon & Kouider, 2020, p. 54) those resources - dreaming might need to be occasionally “switched off”. In essence, there could be balancing of the need for monitoring-alerting and the need for other functions to be performed.

4. Discussion

Gewargis’s (Gewargis, 2016) innovative theory - that dreams function to safeguard the organism during sleep - seems plausible and to have the potential to make an important contribution to a better understanding of why we dream. However, in addition to the theory not having been (as far as is known) empirically tested, there are a number of other possible problems with it. In particular, the published literature is not used to substantiate the empirical claims upon which the theory is built; and this could be a significant issue, as a some of these claims appear to be at variance with current scientific knowledge and/or to have limited face validity. In this comment article, I drew upon the neurology and other literature to critique and suggest amendments to Gewargis’s theory; and proposed additional hypotheses relating to why and how dreams might act as a monitoring-alerting mechanism and protect the sleeper from a range of internal and external perturbations during REM and NREM sleep; and not just, as Gewargis appears to suggest (e.g. Gewargis, 2016, p. 198), guard against inadequate blood flow to the brain or “oxygen-deprivation” to the lungs during REM sleep.

Principal apparent problems with Gewargis’s theory, and suggestions made in this article as to how these might be addressed (and so leave the general concept intact), include the following:

4.1. Claim that the sleep-defence mechanism operates in REM sleep

- *The problem.* Gewargis argues that his proposed sleep defense mechanism is needed during “stage IV sleep” (which appears to be equated with REM sleep), but not needed during NREM sleep, on account of “the blood/oxygen flows ... barely reaching their respective destinations ...” during “Stage IV sleep”, and so “any irregularity ...” could result in “blood-starvation to brain ...”, whereas during NREM sleep “there is no fear of” this outcome (Gewargis 2016, p.198). At variance with this claim, however, cerebral blood flow (CBF) is “decreased during non-REM sleep compared with wakefulness and REM sleep” (Maquet, 2010).
- *How it might be addressed.* There appear to be a number of alternative reasons why there could be a particular risk of hypoxia, and/or hypocapnia, during REM compared to NREM sleep, including greater vital sign instability (Fink et al., 2018, p. 4), and reduced autonomic nervous system homeostatic control (Guyenet and

Baylis 2015). REM atonia (e.g. Arrigoni et al., 2016), and thermoregulation being “mainly abolished during REM sleep ...” (Mascetti 2018), could also necessitate what I refer to in this article as a dream sleep-defence mechanism (DSDM).

4.2. Claim that the DSDM does not operate in NREM sleep

- *The problem.* Why would we dream in NREM sleep, as studies indicate that we do, (Suzuki et al 2004; Sinclair et al 2017) if Gewargis is right about “the real function” of dreams (Gewargis, 2016, p. 199) being the proposed sleep defence mechanism and right about this defence mechanism only being needed in REM sleep (Gewargis, 2016, p. 198)?
- *How it might be addressed.* Of the possibilities (set-out in this paper at para. 3.2), I would suggest that the most credible is that dreams do provide a DSDM in NREM, although it would need to address a different risk-set compared to in REM sleep. For example, while the limited role of chemoreceptors can cause problems in REM sleep (Burke et al, 2015), a heavy dependence upon them in NREM sleep can cause “CNS-damaging hypoxemia” (Guyenet & Baylis, 2015, p. 955).

4.3. Claim that we need a DSDM at all

- *The problem.* As the arguments for why we might need a DSDM in NREM sleep appear to be as strong as those for why we might need one in REM sleep, the more important question becomes - why would we need a DSDM at all when we have brainstem controlled homeostatic mechanisms (e.g. Funk & Gourine, 2018) which perform a defence function more quickly and reliably than could be expected to occur through changes in dream narratives?
- *How it might be addressed.* I suggested in this article (para. 3.3) that there will be occasions when perturbations (from acute hypoxia to the sound of an intruder in the house) cannot be dealt with within sleep; and that, so as not to unnecessarily disrupt the regenerative work of sleep (e.g. Elkhenany et al., 2018), an arousal mechanism is needed which goes beyond “unthinking” homeostasis and can make the “right call” as to whether or not to arouse the individual. It seems possible that the basal forebrain (BF) connected cortex (McKenna et al., 2020) might facilitate this going beyond, including through has been referred to in this article (at para. 3.3) as “intelligent filtering”. This, however, leaves largely unanswered the question of why the alerting messages are (according to Gewargis’s theory) presented within dreams and (according to this article) within dream-implicated cortical structures, such as the sensorimotor cortex. Possibilities discussed in this article (at para. 3.3) include -
 1. *Dreams are where the consciousness is.* To perform functions such as memory processing (e.g. Perogamvros et al., 2013), the dream is where the sleeper’s consciousness is focused for much of the time asleep, and so it is also where the messages need to be presented during that time. In other words, and at variance with what Gewargis proposed, we don’t dream so as to provide a sleep defence mechanism, but a DSDM is needed because we dream.

2. *The cognitive efficiency of dreaming.* There is high level cognition in dreams (e.g. Horton 2020, p.2), and it seems possible that dreams could provide a particularly efficient sleep defence mechanism. In particular, it is hypothesised that dreams use broad categories (including potential danger/not potential danger), rather than cognitively more demanding representational reflections of the reality in question (such as of an intruder who has entered the sleeper's home), and present these broad categories within the dream. This use of broad, simplified categories in dreams would seem to make sense on account of the nature of stimuli inputs to the cortex during sleep. For example, it has been suggested that Ponto-Geniculate Occipital (PGO) waves might "disrupt the encoding of external stimuli in favour of the emergence of endogenous oneiric contents ..." (Andrillon & Kouider, 2020, p. 54). I would suggest, instead, that PGO waves might disrupt the detailed encoding of external stimuli in favour of their simplified but more effective (in terms of arousal when needed) encoding as dream narrative.

4.4. What happens when we are not dreaming.

- *The problem.* Even with the amendments to Gewargis's theory suggested above, we would still be left with the question of what happens when we are not dreaming if it was in fact the case that we need a DSDM to deal with hypoxic and other dangers during sleep.
- *How it might be addressed.* I argued in this article (para. 3.4) that sleep defence mechanisms can be assumed to be ongoing outside dreams, perhaps entailing what Blume et al., (2018, p. 177) refer to as a "sentinel processing mode" of the human brain ... ". I also argued, however, that when dreaming - which might well occur for a range of purposes such as memory processing (e.g., Perogamvros et al., 2013) - there is the need for a different kind of defence mechanism; which a DSDM might fulfil. In particular, this mechanism (as referred to above) needs to be particularly efficient on account of dreams "cornering cortical resources" (Andrillon & Kouider, 2020, p. 54); and the alerting to danger (arousal) messages need to be presented and processed where the consciousness is at that time i.e. within the dream. A DSDM would seem to be ideally suited to both purposes; and so would also be consistent with the parsimoniousness of evolution (e.g. Crisci, 1982).

While there appear to be good reasons for a sleep defence mechanism to function through dreams, this, of course, is not strong evidence that it does. Providing some additional circumstantial evidence are studies that indicate that changes in the external environment during dreaming can affect dream content (e.g. Schredl et al., 2009, p. 285) - something which would presumably need to occur for the proposed DSDM to function as hypothesised. What is still needed - to get closer to determining if DSDM is a "real function" of dreams (Gewargis, 2016, p. 199) - are experimental studies. Such a study might, for example, record, for each participant - brain activity (e.g., Jurysta et al., 2003, p. 2147); the nature and timing of experimentally introduced auditory (e.g., Issa and Wang, 2008) or other external stimuli or of internal vital sign perturbations; and dreams recalled on awakening when awakening occurs shortly after the occurrence of these. There again, the nature of human consciousness is such that solving what Gewargis calls "the

dream's riddle" (Gewargis, 2016, p. 197) - which has exercised human metacognition since at least Aristotle (Meier, 1999, cited in Schredl et al., 2016b) - could still be decades off; and the proposed DSDM could be (but hopefully is not) a blind-alley.

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References

- Acosta-Castro, P., Hirotsu, C., Marti-Soler, H., Marques-Vidal, P., Tobback, N., Andries, D., ... Heinzer, R. (2018). REM-associated sleep apnoea: prevalence and clinical significance in the HypnoLaus cohort. *Eur Respir J*, 52: 1702484, DOI: 10.1183/13993003.02484-2017.
- Arrigoni, E., Chen, M.C. & Fuller, P.M. (2016). The anatomical, cellular and synaptic basis of motor atonia during rapid eye movement sleep. *J Physiol*, 594: 5391-5414. doi:10.1113/JP271324
- Baird, B., Castelnovo, A., Gosseries, O., Tononi G. F(2018). Frequent lucid dreaming associated with increased functional connectivity between frontopolar cortex and temporoparietal association areas. *Sci Rep.*, 1, 17798. DOI: 10.1038/s41598-018-36190-w
- Benarroch, E. (2019). Control of the cardiovascular and respiratory systems during sleep. *Autonomic Neuroscience: basic and clinical*, 218, 54-63. <https://doi.org/10.1016/j.autneu.2019.01.007>
- Blume, C., del Giudice, R., Lechinger, J., Wislowska, M., Heib, D.P.J., Hoedlmoser, K., & Schabus M., (2017). Preferential processing of emotionally and self-relevant stimuli persists in unconscious N2 sleep. *Brain and Language*, 167, 72-82. DOI: 10.1016/j.bandl.2016.02.004.
- Blume, C., Del Giudice, R., Wislowska, M., Heib, D.P.J., & Schabus, M. (2018). Standing sentinel during human sleep: Continued evaluation of environmental stimuli in the absence of consciousness. *Neuroimage*, 178:638-648. doi: 10.1016/j.neuroimage.2018.05.056.
- Blumstein, D., Mari, M., Daniel, J., Ardron, J., Griffin, A., & Evans, C. (2002). Olfactory predator recognition: Wallabies may have to learn to be wary. *Animal Conservation*, 5(2), 87-93. doi:10.1017/S1367943002002123
- Bradshaw, S., Lafrenière, A., Amini, R., Lortie-Lussier, M., & De Koninck, J. (2016). Threats in dreams, emotions and the severity of threatening experiences in waking. *International Journal of Dream Research*, 9, 2, 102-109. DOI:10.11588/IJODR.2016.2.27214
- Burke, P.G., Kanbar, R., Basting, T.M., Hodges, W.M., Viar, K.E., Stornetta, R.L., & Guyenet, P.G. (2015). State-dependent control of breathing by the retrotrapezoid nucleus. *J. Physiol.*, 593, 2909-2926, <http://dx.doi.org/10.1113/JP270053>
- Cipolli, C., Ferrara, M., De Gennaro, L., & Plazzi, G. (2016). Beyond the neuropsychology of dreaming: insights into the neural basis of dreaming with new techniques of sleep recording and analysis. *Sleep Med Rev.*, pii: S1087-0792(16)30067-3 [Epub ahead of print]. doi: 10.1016/j.smr.2016.07.005.
- Jorge V., & Crisci, J.V. (1982). Parsimony in evolutionary theory: Law or methodological prescription?. *Journal of Theoretical Biology*, 97(1), 35-41. DOI: 10.1016/0022-5193-(82)90274-0.
- Desseilles, M., Dang-Vu, T.T., Sterpenich, V., & Schwartz, S. (2011). Cognitive and emotional processes during dreaming: a neuroimaging view. *Conscious Cogn.*, 20, 4, 998-1008. DOI: 10.1016/j.concog.2010.10.005.

- Domhoff, G. W. (1999). Using Hall/Van De Castle Dream Content Analysis to test new theories: An example using a theory proposed by Ernest Hartmann. Paper presented to the annual meeting of the Association for the Study of Dreams. Santa Cruz, CA.
- Domhoff, G.W. (2001). A new neurocognitive theory of dreams. *Dreaming*, 11(1), 13–33. <https://doi.org/10.1023/A:1009464416649>
- Elkhenany, H., AIOkda, A., El-Badawy, A, El-Badri, N. (2018). Tissue regeneration: Impact of sleep on stem cell regenerative capacity. *Life Sciences*, 214, 51-61.DOI: 10.1016/j.lfs.2018.10.057.
- Ermis, U; Krakow, K; & Voss, U. (2010). Arousal thresholds during human tonic and phasic REM sleep. *Journal of Sleep Research*, 19, 400-406. DOI:10.1111/j.1365-2869-2010.00831.x
- Fink, A. M., Bronas, U. G., & Calik, M. W. (2018). Autonomic regulation during sleep and wakefulness: a review with implications for defining the pathophysiology of neurological disorders. *Clin Auton Res.*, 28(6):509-518. doi: 10.1007/s10286-018-0560-9. Epub 2018 Aug 28. PMID: 30155794; PMCID: PMC6542468.
- Forrer, K. (2016). Dreams: The missing link in evolution. *International Journal of Dream Research* 9(2), 151-129. DOI: <https://doi.org/10.11588/ijodr.2016.2.29403>
- Freud, S. (1900/ 1997). *The Interpretation of Dreams*. Hertfordshire: Wordsworth Editions Limited.
- Funk, G. D., & Gourine, A.V . (2018), CrossTalk proposal: A central hypoxia sensor contributes to the excitatory hypoxic ventilatory response. *J Physiol*, 596, 2935-2938. doi:10.1113/JP275707
- Gewargis, Y. A. (2016). The true meaning of dreams. *International Journal of Dream Research* 9(2), 197-201. DOI: <https://doi.org/10.11588/ijodr.2016.2.32661>
- Guérolé, F., Marcaggi, G., & Baleyte, J.-M. (2013). Do dreams really guard sleep? Evidence for and against Freud's theory of the basic function of dreaming. *Front. Psychol.* 4, 17, 1-3. doi: 10.3389/fpsyg.2013.00017
- Guyenet, P.G., & Bayliss, DA (2015). Neural Control of Breathing and CO2 Homeostasis. *Neuron*, 87(5), P946-96. <http://dx.doi.org/10.1016/j.neuron.2015.08.001>
- Hartmann, E. (1998). *Dreams and nightmares*. New York: Plenum.
- Hobson, J. A. (2009). REM sleep and dreaming: towards a theory of protoconsciousness. *Nat Rev Neurosci.* 10(11), 803-813. doi: 10.1038/nrn2716. Epub 2009 Oct 1.
- Hopkins, J. (2016). Free Energy and virtual reality in neuroscience and psychoanalysis: a Complexity Theory of dreaming and mental disorder. *Front. Psychol.* 7(922), 1-18.
- Issa, E. B. & Wang, X. (2008). Sensory Responses during Sleep in Primate Primary and Secondary Auditory Cortex. *The Journal of Neuroscience*, 28(53), 14467–14480. doi:10.1523/JNEUROSCI.3086-08.2008
- Jurysta, F., van de Borne, P., Migeotte, P.-F., Dumont, M., Lanquart, J.-P., Degaute, J.-P., & Linkowski, P. (2003). A study of the dynamic interactions between sleep EEG and heart rate variability in healthy young men. *Clinical Neurophysiology*, 114, 2146–2155. doi: 10.1016/s1388-2457(03)00215-3
- Kato, H. K.; Gillet, S. N.; & Isaacson, J. S. (2015). Flexible Sensory Representations in Auditory Cortex Driven by Behavioral Relevance. *Neuron*, 88(5), P1027-1039. DOI:<https://doi.org/10.1016/j.neuron.2015.10.024>
- Klimes, P., Cimbalnik, J., Brazdil, M., Hall, J., Dubeau, F., Gotman, J., & Frauscher, B. (2019). NREM sleep is the state of vigilance that best identifies the epileptogenic zone in the interictal electroencephalogram. *Epilepsia.*, 60, 2404– 2415. <https://doi.org/10.1111/epi.16377>
- Kuelz, A. K., Stotz, U., Riemann, D., Schredl, M., & Voderholzer, U. (2010). Dream recall and dream content in obsessive-compulsive patients: is there a change during exposure treatment? *J.Nerv. Ment. Dis.*, 198(8), 593–596. doi: 10.1097/NMD.0b013e3181e9dd65
- Lansky, M. R. (2003). Shame conflicts as dream instigators: wish fulfillment and the ego ideal in dream dynamics. *Am J Psychoanal.* 63(4), 357-64. doi:10.1023/B:TAJP.0000004740.86355.55
- Lara-Carrasco, J., Nielson, T.A., Solomonova, E., Levrier, K., & Popova, A. (2009). Overnight emotional adaptation to negative stimuli is altered by REM sleep deprivation and is correlated with intervening dream emotions. *J. Sleep Res.*, 18, 178–187. doi: 10.1111/j.1365-2869-2008.00709.x
- Levin, R., Lantz, E., Fireman, G., & Spendlove, S. (2009). The relationship between disturbed dreaming and somatic distress: a prospective investigation. *J Nerv Ment Dis.* 197(8), 606-12. doi: 10.1097/NMD.0b013e3181b0bd65.
- Malcolm-Smith, S., Solms, M., Turnbull, O., & Tredoux, C. (2008). Threat in dreams: an adaptation? *Conscious Cogn.*, 17(4), 1281-91. <https://doi.org/10.1016/j.concog.2007.07.002>
- Malcolm-Smith, S., Koopowitz, S., Pantelis, E., & Solms, M. (2012). Approach/avoidance in dreams. *Conscious Cogn.* 21(1), 408-12. doi: 10.1016/j.concog.2011.11.004. Epub 2011
- Mascetti, GG. (2016) Unihemispheric sleep and asymmetrical sleep: behavioral, neurophysiological, and functional perspectives. *Nat Sci Sleep.*, 8:221-238 <https://doi.org/10.2147/NSS.S71970>
- Maquet, P. (2010) Understanding non rapid eye movement sleep through neuroimaging. *The World Journal of Biological Psychiatry*, 11(sup1), 9-15. DOI: 10.3109/15622971003637736
- Maquet, P., Laureys, S., Peigneux, P., Fuchs, S., Petiau, C., Phillips, C., ... Cleeremans, A. (2000). Experience-dependent changes in cerebral activation during human REM sleep. *Nature Neuroscience*, 3, 831 – 836. doi:10.1038/77744
- McKenna, J.T., Thankachan, S., Uygun, D.S., Shukla, C., Cord-eira, J., McNally, J.M., ... Basheer, R. (2020). Basal Forebrain Parvalbumin Neurons Mediate Arousals from Sleep Induced by Hypercarbia or Auditory Stimuli. *Current Biology*, 30(12), P2379-2385. DOI: 10.1101/766659
- Meier, C. A. (1966). "The dream in ancient Greece and its use in temple cures (incubation)," in *The Dream and Human Societies*, eds G. E. v. Grunebaum and R. Caillois. Berkeley: Universities of California Press, 303-319.
- Muzet, A. (2007). Environmental noise, sleep and health. *Sleep Medicine Reviews*, 11(2), 135–142. DOI: 10.1016/j.smrv.2006.09.001
- Nakagawa, S., Takeuchi, H., Taki, Y., Nouchi, R., Sekiguchi, A., Kotozaki, Y., ... Kawashima, R. (2016). Sex-related differences in the effects of sleep habits on verbal and visuospatial working memory. *Front. Psychol.* 7(1128), 1-8. doi: 10.3389/fpsyg.2016.01128. eCollection 2016
- Nielsen, T. (2000). A review of mentation in REM and NREM sleep: "Covert" REM sleep as a possible reconciliation of two opposing models. *Behavioral and Brain Sciences*, 23(6), 851-866. doi:10.1017/S0140525X0000399X
- Nielsen, T. A. (2010). Ultradian, circadian and sleep-dependent features of dreaming. In *Principles and Practice of Sleep Medicine*, 5th ed., M Kryger, T Roth, and WC Dement, eds, New York, Elsevier.

- Nielsen, T. A., Kuiken, D., Alain, G., Stenstrom, P., & Powell, R. A. (2004). Immediate and delayed incorporations of events into dreams: further replication and implications for dream function. *J. Sleep Res.* 13(4), 327–336. doi: 10.1111/j.1365-2869.2004.00421.x
- Noreika, V., Windt, J.M., Kern, M., Valli, K., Salonen, T., Parkkola, R., ... Lenggenhager, B. (2020). Modulating dream experience: Noninvasive brain stimulation over the sensorimotor cortex reduces dream movement. *Sci Rep* 10, 6735. <https://doi.org/10.1038/s41598-020-63479-6>
- Ogden, T.H. (2003). On not being able to dream. *The international Journal of Psychoanalysis* 84(1), 17–30. doi: 10.1516/1D1W-025P-10VJ-TMRW
- Okabe, S.; Hayashi, M., Abe, T., & Fukuda, K. (2020). Presentation of familiar odor induces negative dream emotions during rapid eye movement (REM) sleep in healthy adolescents. *Sleep Medicine*, 66, pp. 227-232. DOI: 10.1016/j.sleep.2019.11.1260.
- Orem, J. M., Lovering, A. T., & Vidruk, E. H. (2005). Excitation of medullary respiratory neurons in REM sleep. *Sleep*, 28, 801–807. doi: 10.1093/sleep/28.7.801
- Perogamvros, L., Dang-Vu, T. T., Desseilles, M., & Schwartz, S. (2013). Sleep and dreaming are for important matters. *Front. Psychol.*, 25(4), 474, 1-15. doi: 10.3389/fpsyg.2013.00474. eCollection.
- Ramirez, J. M., Severs, L. J., Ramirez, S. C. & Agosto-Marlin, I. M. (2018). Advances in cellular and integrative control of oxygen homeostasis within the central nervous system. *J Physiol*, 596, 3043-3065. doi:10.1113/JP275890
- Rauchs, G., Desgranges, B., Foret, J. & Eustache, F. (2005), The relationships between memory systems and sleep stages. *Journal of Sleep Research*, 14: 123-140. <https://doi.org/10.1111/j.1365-2869.2005.00450.x>
- Revonsuo, A. (2000). The reinterpretation of dreams: An evolutionary hypothesis of the function of dreaming. *Behav Brain Sci.* 23, 793-1121. DOI: <https://doi.org/10.1017/S0140525X00004015>
- Ruiz, F. S., Andersen, M. L., Martins, R. C. S., Zager, A., Lopes, J., & Tufik, S. (2012). Immune alterations after selective rapid eye movement or total sleep deprivation in healthy male volunteers. *Innate Immunity*, 18(1), 44–54. doi: 10.1177/1753425910385962
- Schädlich, M., Erlacher, D., & Schredl, M. (2016). Improvement of darts performance following lucid dream practice depends on the number of distractions while rehearsing within the dream - a sleep laboratory pilot study. *J Sports Sci.*, 22, 1-8. doi: 10.1080/02640414.2016.1267387.
- Schredl, M., & Montasser, A. (1996). Dream recall: state or trait variable? Part I: model, theories, methodology and trait factors. *Imagination, Cognition and Personality*, 16(2), 181-201. <https://doi.org/10.2190/RCAG-NY96-3D99-KA0G>
- Schredl, M. (2001). Dream recall frequency of patients with restless legs syndrome. *Eur.J.Neurol.*, 8(2), 185–189. <https://doi.org/10.1046/j.1468-1331.2001.00203.x>
- Schredl, M. & Hofmann, F. (2003). Continuity between waking activities and dream activities. *Consciousness and Cognition* 12(2), 298–308. [http://dx.doi.org/10.1016/S1053-8100\(02\)00072-7](http://dx.doi.org/10.1016/S1053-8100(02)00072-7)
- Schredl, M., Atanasova, D., Hörmann, K., Maurer, J.T., Hummel T., & Stuck, B.A. (2009). Information processing during sleep: the effect of olfactory stimuli on dream content and dream emotions. *Journal of Sleep Research*, 18(3), 285–90. doi: 10.1111/j.1365-2869.2009.00737
- Schredl, M., Adam, K., Beckmann, B., and Petrova, I. (2016). Health dreams, health-related worries, and being ill: A questionnaire study. *International Journal of Dream Research*, 9, 1, 82-85.
- Siclari, F., Baird, B., Perogamvros, L., Bernardi, G., LaRocque, J. J., Riedner, B., ... Tononi, G. (2017). The neural correlates of dreaming. *Nat Neurosci.*, 20(6), 872-878. doi: 10.1038/nn.4545. Epub 2017 Apr 10. PMID: 28394322; PMCID: PMC5462120.
- Solms, M. (2000). Dreaming and REM sleep are controlled by different brain mechanisms. *Behavioural and Brain Sciences*, 23, 793–1121. DOI: <https://doi.org/10.1017/S0140525X00003988>
- Strauss, M., Jacobo, D Sitt, Jean-Remi King, Maxime Elbaz, Leila Azizi, Marco Buiatti, Lionel Naccache, Virginie van Wassenhove, Stanislas Dehaene. Disruption of predictive coding during sleep. *Proceedings of the National Academy of Sciences Mar 2015*, 112 (11) E1353-E1362; DOI: 10.1073/pnas.1501026112
- Strauss, M., Sitt, J.D., King, J-R., Elbaz, M., Azizi, L., Buiatti, M., ... Dehaene, S., (2015). Disruption of predictive coding during sleep. *Proceedings of the National Academy of Sciences*, 112(11), E1353-E1362. DOI: 10.1073/pnas.1501026112
- Stuck, B. A., Baja, J., Lenz, F., Herr, R. M., & Heiser, C. (2011). Co-stimulation with an olfactory stimulus increases arousal responses to trigeminal stimulation, *Neuroscience*, 176, 442-446, ISSN 0306-4522, <https://doi.org/10.1016/j.neuroscience.2011.01.009>
- Suzuki, H., Uchiyama, M., Tagaya, Ozaki, A., Kuriyama, K., Aritake, A., ... Kuga, R. (2004) Dreaming During Non-rapid Eye Movement Sleep in the Absence of Prior Rapid Eye Movement Sleep. *Sleep*, 27(8), 1486-1490. <https://doi.org/10.1093/sleep/27.8.1486>
- Tassi, P., Rohmer, O., Schimchowitsch, S., Eschenlauer, A., Bonnefond, A., Margiocchi, F., ... Muzet, A. (2010). Living alongside railway tracks: Long-term effects of nocturnal noise on sleep and cardiovascular reactivity as a function of age. *Environment International*, 36(7), 683–689. <https://doi.org/10.1016/j.envint.2010.05.001>.
- Ungurean, G. & Rattenborg, N. C. (2019). Neurobiology: REM-Sleep-Promoting ‘Goldilocks’ Neurons. *Current Biology*, 29(13), R644-R646. DOI: 10.1016/j.cub.2020.07.025
- Valli, K., Revonsuo, A., Pääkäs, O., Ismail, K. H., Ali, K. J., & Punamäki, R. L. (2005). The threat simulation theory of the evolutionary function of dreaming: Evidence from dreams of traumatized children. *Conscious Cogn.*, 14(1), 188-218. DOI: 10.1016/S1053-8100(03)00019-9
- Valli, K., & Revonsuo, A. (2009). The threat simulation theory in light of recent empirical evidence: a review. *Am J Psychol.*, 122(1), 17-38. <https://www.jstor.org/stable/27784372>
- Wamsley, E.J., & Stickgold, R. (2019). Dreaming of a learning task is associated with enhanced memory consolidation: Replication in an overnight sleep study. *J Sleep Res.*, 28:e12749. <https://doi.org/10.1111/jsr.12749>
- Wilf, M., Ramot, M., Furman-Haran, E., Arzi, A., Levkovitz, Y., Malach, R. (2016). Diminished Auditory Responses during NREM Sleep Correlate with the Hierarchy of Language Processing. *PLoS One.*, 11(6):e0157143. doi: 10.1371/journal.pone.0157143. PMID: 27310812; PMCID: PMC4911044.
- Zadra, A., Desjardins, S., & Marcotte, E. (2006). Evolutionary function of dreams: A test of the threat simulation theory in recurrent dreams. *Consciousness and Cognition*, 15, 450–463. doi:10.1016/j.concog.2005.02.002
- Zhang, W. (2016). A supplement to self-organization theory of dreaming. *Front. Psychol.* 7, 332. doi: 10.3389/fpsyg.2016.00332