Functions of Spontaneous Yawning: A Review

Duruo Jin[1,*]

[1]*Beijing National Day School*
[*]*Corresponding author. Email: jinduruo@outlook.com*

ABSTRACT
Yawning is an important prehistorical physiological mechanism that exist in animals across a variety of species. In the past 50 years, investigation of spontaneous yawning and contagious yawning has been ongoing. Several hypotheses were introduced to this field, such as the circadian hypothesis, brain-cooling hypothesis, and oxygenation hypothesis. These theories now trigger growing debates, and each theory are supported by their own evidence. Here, this review examines three popular hypotheses and reveals the arguments among them. Conversely, one novel hypothesis of mental stress seems more convincing than the other three hypotheses, and needs to be examined by empirical studies.

Keywords: *Yawning, Thermoregulation, Airway, Arousal, Circadian Rhythm, Stress, Physiological, Evolution*

1. INTRODUCTION

Yawning is an involuntary, paroxysmal breathing movement. It involves three phases that include slow-opening of the mouth, nostrils dilating, inspiration, and sometimes stretching of limbs [1]. Humans' averaged yawning duration within a 30-min period is 5.9s, almost once per minute. Yawning is a cyclical and stereotypical action that occurs periodically. In 31 participants, there is an averaged inner-yawn interval of 68.3 ± 33.7s [2]. A similar movement of spontaneous and deep inhalation of air can also be observed widely in other vertebrates. The fact that yawning is widespread among different species implied its evolutionary significance. Although the evolution of traits does not directly imply its functionality, the high frequency of yawning and the changing of mental state after yawning strongly suggest its primitive functions.

However, whether yawning is functional has already been studied extensively. Scientists already found evolutionary evidence of yawning in old black apes as a facial communication behavior to reveal anger, anxiety, or leadership [3], indicating its association with social situations. Moreover, some recent analyses of brain sizes among different species clearly show a relationship between brain mass and the duration of yawning, implying the neurophysiological function of yawning [4]. Yet, the specific functionality of yawning is still elusive.

Recent studies of yawning generally focus on its contagious properties. Contagious yawning is shown to have a strong relationship with social stimuli, such as facial recognition, auditory senses, and empathy [5]; [6]; [7]. On the other hand, contagious yawning is also believed to share the same physiological effect as spontaneous yawning [8]. Thus, illuminating the functions of spontaneous yawning appears to be more essential than contagious yawning. In fact, there is little evidence to support that contagious yawning has the exactly same mechanism as spontaneous yawning. However, contiguous yawning is its own complex topic and is beyond the scope of the current review.

This review will examine the current theories of the functions of spontaneous yawning, as well as proposes a novel hypothesis, and offers suggestions for future investigations. Current explorations of spontaneous yawning are generally divided into three main categories: circadian hypothesis [9], brain cooling or thermoregulatory hypothesis [10], and respiration or airway hypothesis [11]. Each hypothesis is supported by numerous empirical evidence, but there still exist heated debates and the exact mechanism of yawning remains inconclusive.

2. CIRCADIAN HYPOTHESIS

The most popular hypothesis is the circadian hypothesis. For a long time, the relationship between sleepiness and yawning is believed by the general public based on daily observations. The circadian hypothesis tested this

commonsense using experimental methods. It is suggested that both humans' and animals' yawning behaviors are more frequent during sunrise and sunset. Thus, yawning seems to be associated with both arousal and sleepiness [9].

2.1. Evidence:

In wild animals, patterns of yawning reserved a clear association with the time of the day. In the analysis of mangabey and macaques, yawning was associated with the time of the day, showing that there is a small peak in 1000 to 1100 hours, and another peak after 1800 hours for mangabey, similarly a peak in 900 hours and 1400 to 1500 hours in macaques [12]. Meanwhile, yawning pattern is also affected by postures, boredom, and sleepiness. In the same study, there is always a percentage of yawning above 80% while sitting and less while walking, and the least while lying [12]. For freely moving rats, yawning is also shown to be related to changing in sleep and sober phases [13].

There is also a lot of literature in humans. Similar temporal patterns of yawning frequency can be found in a group of 22 students that in the early morning of waking, the yawning increases, while in later the day, yawning decreases. The pattern is also shown to be correlated with subjective sleepiness evaluations [14].

2.2. Arguments:

Since arousal involves the activation of brain activity, EEG activity is usually be accelerated during arousal. After yawning, however, studies disapproved of this hypothetic pattern of EEG changes. Although the study found that a decrease in Delta and an increase in Sigma, Theta, and Beta are detected 5 sec before or after yawning, the changes are no longer detectable10 secs before yawning. Hence, subjective to FFT analysis, there is no difference in EEG activity over the long term. [15]. In another analysis of EEG power spectra from MWTs patients who are not able to stay alert, the results showed that the power spectra are almost the same before and after yawning, thus indicating that yawning cannot reverse sleep pressure caused by MWT disorder. The research also showed that there is a slowing of alpha oscillations after yawning. Since the alpha oscillations decelerated during drowsiness [16], yawning might only be induced by drowsiness rather than arousal [17].

In addition, the circadian hypothesis cannot exclude other essential confound factors, such as stress and temperature. A possible explanation for increasing in yawning in the morning is that the stress level of individuals is relatively high just after awake [18].

Moreover, the circadian hypothesis does not fully explain the functions of yawning in other times besides morning and evening. For instance, the yawning in midday cannot be explained by the effect of circadian rhythm. Hence, more research are still required.

3. AIRWAY OR RESPIRATION HYPOTHESIS

Some scientists suggested that yawning is for long-term oxygenation. Specifically, yawning creates an enlarged airway by muscle repositioning in the upper airway to anticipate airway collapse [11].

3.1. Evidence

The airway hypothesis is supported according to the investigation by [19], who shows the choking children yawned frequently and the yawning frequency was reduced after the choking problem was solved. This evidence suggests that yawning prevents airway construction or choking. The muscle repositioning is in response to regain muscle balance during choking. Also, based on the review of Dowleman and Rijken (2022), seven studies demonstrated that during the induction of anesthesia, there is an increase in yawning in a large number of patients, indicating yawning is associated with oxygenation. In addition, healthy children also yawn more frequently than adults. The scientists proposed it can be explained by their relatively narrow airway, which in turn makes yawning as anticipation of airway collapse, more crucial and more frequent [11].

3.2. Disagreements

Despite the stringency of the airway hypothesis regarding tones of supporting evidence, other scientists criticized its credibility. Massen and Gallup (2022) question the validity of the literature that Doelman and Rijken chose for analysis. They argued that Doelman and Rijken eliminated the research that falsified their own hypothesis [20]. They also argued that anesthesia not only induced airway collapsing, but also other physiological changes, which could also be used to explain functions of yawning, and the airway hypothesis is not able to rule out these confounding variables.

4. BRAIN COOLING HYPOTHESIS

Recently, some scientists argued that yawning functions as a regulator of brain temperature. Specifically, they argued three processes of brain cooling. Firstly, yawning will increase blood flow in the neck, head, and face. The inspiration during yawning will cause the lateral pterygoid muscle to contract, which will then squeeze blood from the plexus, thus, will cool down the brain temperature. In addition, the cooler environmental air people inhaled during yawning will also cool the brain through convection. Lastly, the structure of the posterior wall of the maxillary sinus allows the thin sinus walls to

flex and ventilate during yawning, which then accelerates the rate of evaporation of the mucosa of the sinus, inducing a decrease in brain temperature [10].

4.1. Evidence

It appears there are numerous empirical evidence supporting this theory, even though some of them still remain debatable. Melopsittacus undulatus were studied as an example animal, and the evidence showed that they will yawn more frequently when they have a higher facial temperature, and there is a significant decrease in temperature after a 20-sec interval of yawning in temperature, specifically dropping from 40.08 C to 39.83 ± 0.13C [21]. They also found similar results in Sprague-Dawley rats [22].

Consistent with animals, human yawning behavior correlated with changes in ambient temperature. Gallup (2014) outlined that yawning frequency is low in extreme temperatures and high when temperatures are in correspondence with body temperature. They explained this phenomenon by arguing that when the ambient temperature is higher or lower than body temperature, the heat exchange will either stimulates a counterproductive consequence or result in deviations below homeostasis.

4.2. Arguments

There are many flaws in the supporting evidence. The experiments of both humans and animals cannot exclude the effect of other confound factors, such as mental stress, circadian rhythm, or social factors. Because there is a significant difference between individuals' manifestations under these potential factors, the thermoregulation or temperature factor could be just one of these factors and may cause similar extent effects. Therefore, it is inappropriate to simply conclude one of the factors, temperature, is the function of spontaneous yawning.

In addition, there is still an unresolved mystery of fever against brain cooling theory. Since the elevation of body temperature can occur due to fever, according to thermoregulation theory, the yawning will increase during fever. But the results showed the opposite. Since the intent of fever is a defense response to an infected virus or bacteria, brain temperature will not be changed by any thermolytic mechanisms during fever [24]. Hence, this seems to reject the hypothetic mechanism of brain cooling. Some scientists argue that fever is not a homeostatic response, which should not account for the situation of yawning according to the brain cooling hypothesis since yawning only responds to maintain homeostasis. Despite different arguments, the reason for decreasing in yawning during fever is still under debate, indicating the uncertainty of the brain cooling hypothesis.

Moreover, a recent study of hemiplegic patients showed a movement in the hemiplegic limbs during yawning. Accordingly, 78.6% of movements in hemiplegic limbs are noticed in males and females aged a median of 48 and 47 [25]. The yawning in those patients presented not to be associated with temperature changes in the brain, and the yawning is not aimed to cool the brain.

5. MENTAL STRESS HYPOTHESIS

A novel hypothesis states that spontaneous yawning is a stress or anxiety regulator. Spontaneous yawning behavior tends to be related to emotion regulation. It is observed that Olympic athletes will increase their yawning before the competition, musician yawns frequently before the performance, and paratroopers do similarly [26].

There seems to be a specific time range before those stressful events when yawning frequency increases. And there is evidence that suggest that stress regulates yawning through neuropeptides [27].

5.1. Evidence

A few experiments conducted on a diverse array of land mammals revealed a relationship between stress and yawning. 24 hours after some rats were stressed by electric foot shocks 5 times, and when they were placed in the foot shock chamber, again the number of entries to the shocking center decreased and the number of yawning significantly increased. The research also showed that there is an increase in the activity of CeA neurons, OT, and CRF neurons in PVN, which plays an essential role in controlling stress [28]. In Nazca boobies, a bird species, researchers found that the acute stressors initially reduced and later increased their yawning frequency [29]. Similar results can also be found in budgerigars [30]. Hence, yawning tends to increase as the stress condition arises, indicating its function as a stress regulator.

In humans, it's more difficult to manipulate stress levels under the regulation of IRB, and the endurance of stress may vary among each individual. Fewer experiments are done on humans to test this hypothesis. Some indirect investigation provided viewpoints to support this statement. Dopamine is shown to facilitate yawning, at the same time, the dopamine D2 receptor is involved in this process, and the incertohypothalamic and nigrostriatal neuronal systems are involved [27]. Since DA is associated with stress regulation, DA turnover increases in rats when there is a stress exposure, as assessed by DOPAC-to-DA ratios [31]. Acetylcholine also seems to facilitate or induce yawning. As proposed, acetylcholine is involved in the septohippocampal system in this case [27]. Meanwhile, the inhibition of anxiety-related drugs and some experiments on animals show the correlation between anxiety and septohippocampal, suggesting that the septohippocampal system is responsible for anxiety regulation [32]. Moreover, a study on factors that affect yawning frequencies in preterm neonates found that be-

fore feeding there is a significant increase in yawning frequencies, while after feeding the frequencies decreased. Their results are consistent with the stress hypothesis that yawning frequency could possibly be related to ACTH-mediated and autonomous cholinergic processes [33]. However, they argued that the phenomena can also be explained by the brain-cooling hypothesis, but since there is not enough evidence to support either, more studies need to be done to decouple these two theories.

Hence, the production of peptides in the brain that are inclined to induce yawning are proved to coalesce with anxiety and stress, providing lateral evidence for the stress hypothesis.

5.2. Arguments

The main argument for this hypothesis is a study that showed a lack the effect of acute physical stress on yawning participants. Specifically, they asked participants to twist their non-dominant hands and immerse the hand in ice water for 2-4 °C. The result shows no main effect of stress on yawning [34] However, one may argue that physical stress is not exactly the same as mental stress.

Similar to the three hypotheses mentioned in the article, confounding factors are still inevitable. The change in mental stress levels is indispensable with sleepiness and brain temperature change. Some scientists argue that stress is the expanding hypothesis of other hypotheses, such as brain cooling, and the evidence that supports the stress hypothesis will have similar effects on other hypotheses [8]. Yet, since all hypotheses could not eliminate the confounding factors, the important next step is to experimentally test which one is contributing the most to yawning.

6. FUTURE DIRECTION

The booming of multiple hypotheses in this area makes it an active research area. However, despite the great efforts made by other researchers, some theories become outdated and new theories emerge. Additionally, new evidence are showing promise in new theories. It's not hard to see that among all four hypotheses mentioned in this review, the stress hypothesis needs more direct evidence. However, this is not to say that the stress hypothesis is less convincing than the other three, but more explorations should be done.

Given the difficulty of experimentally manipulating an individual's stress level, it might not be feasible to conduct a controlled in-lab study. However, one possible solution is to conduct a survey on pedestrians, asking themselves evaluate and calculate the numbers of yawning they did in one day with different stress levels at different time periods. The experiment should involve the correct method of statistics to produce highly credible data. Another solution is to examine the influences of stress-controlled drugs on yawning in participants who have already prescribed these drugs. However, the validity of this study might be limited by the study population and might be difficult to generalize to populations that don't need to take stress-reduction drugs.

Besides the explorative approach to the stress hypothesis, more experiments should also be done in the other three fields. For instance, the fever mystery needs further exploration to prove the thermoregulation theory. More explanations are required based on actual experiments rather than verbal speculations.

7. CONCLUSIONS

Yawning is a neurophysiologically related behavior that is widely observed in vertebrates [4]. The experiments in other vertebrates provided indirect evidence for the functions of yawning. The functions of spontaneous are evaluated in the review. As previously shown, the circadian hypothesis demonstrates that yawning is a behavior that reflects the circadian rhythm, the oxygenation theory believes yawning is an anticipant of airway collapse, while the brain cooling hypothesis indicates yawning is contributed to decreasing the temperature of the brain [9]; [11]; [10]. However, they all have flaws and drawbacks. In contrast, a novel hypothesis that yawning functioned as a stress releasor seems more convincing but lacks evidence to support it. On the whole, the stress hypothesis shows high and strong potential, and may possibly guide the future development of medicine related to yawn-related disorders.

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