5-10-2014

A Thermal Window for Yawning in Humans: Yawning as a Brain Cooling Mechanism

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A thermal window for yawning in humans: Yawning as a brain cooling mechanism

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HIGHLIGHTS

- The thermoregulatory theory of yawning posits that yawns function in brain cooling.
- Yawning is constrained to an optimal thermal zone of ambient temperature.
- This theory explains basic features of both spontaneous and contagious yawning.
- Applications include improved treatment of patients with thermoregulatory problems.

ARTICLE INFO

ABSTRACT

The thermoregulatory theory of yawning posits that yawns function to cool the brain in part due to counter-current heat exchange with the deep inhalation of ambient air. Consequently, yawning should be constrained to an optimal thermal zone or range of temperature, i.e., a thermal window, in which we should expect a lower frequency at extreme temperatures. Previous research shows that yawn frequency diminishes as ambient temperatures rise and approach body temperature, but a lower bound to the thermal window has not been demonstrated. To test this, a total of 120 pedestrians were sampled for susceptibly to self-reported yawn contagion during distinct temperature ranges and seasons (winter: 1.4 °C, n = 60; summer: 19.4 °C, n = 60). As predicted, the proportion of pedestrians reporting yawning was significantly lower during winter than in summer (18.3% vs. 41.7%), with temperature being the only significant predictor of these differences across seasons. The underlying mechanism for yawning in humans, both spontaneous and contagious, appears to be involved in brain thermoregulation.

1. Introduction

Yawning occurs with an average duration of 4 to 7 s, and consists of three distinct phases: an active gaping of the jaw with inspiration, a brief period of acme corresponding with apnea and peak muscle contraction, and a passive closure of the jaw with shorter expiration [1]. In humans [2], as well as a handful of other social vertebrates [3–7], yawning can be categorized into two basic forms: spontaneous and contagious. Both forms include similar motor action patterns, but spontaneous yawns seem to be triggered by physiological mechanisms of homeostasis and arousal since they reliably occur during distinct behavioral contexts [8,9] and follow a consistent circadian pattern [10]. In contrast, contagious yawns are elicited simply by sensing or even thinking about the action in others [11]. Unlike its spontaneous form, which appears evolutionarily older by its observed presence in all classes of vertebrates [12] and early onset in uterine development [13], contagious yawning appears to be a more recently derived behavior as evidenced by its presence in relatively few highly social species [2–7] and delayed ontogeny [14–18]. Research investigating contagious yawning has emphasized the influence of interpersonal and emotional-cognitive variables on its expression [4,5,19–28], but there have been few attempts to combine theoretical frameworks when explaining both contagious and spontaneous effects. Due to the potential multifunctionality of yawning across species [12,29], however, recent reports on social primates have highlighted potentially important differences in yawn morphology or intensity [5,30,31].

Although it is commonly believed that yawns serve a respiratory function, experimental procedures have shown yawn frequency is independent of brain/blood levels of O_2 and CO_2 [32]. A more recent theory, which posits that the motor action of yawning functions as a brain

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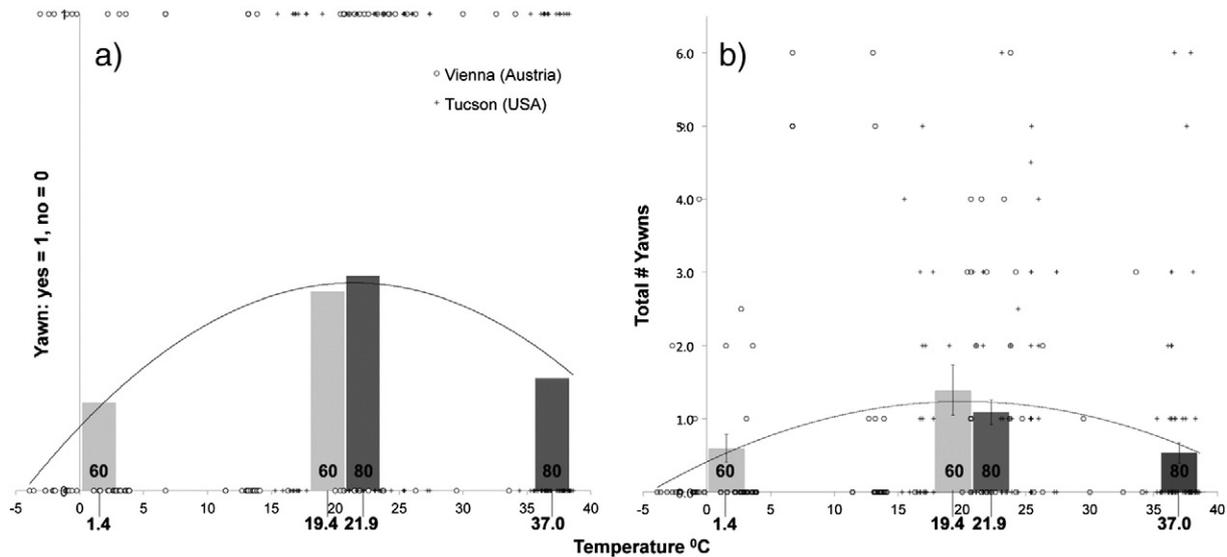
Fig. 1. (a) The proportion of participants reporting yawning, and (b) the mean ± s.e.m. frequency of reported yawns in the two seasonal conditions in Vienna, Austria (light gray bars), as well as the conditions of an earlier study in Tucson, Arizona USA (dark gray bars). Average temperatures and sample sizes for each are in bold. The best-fit lines demonstrate a non-linear relationship, with (a) probability of yawning and (b) yawn frequency dropping at extreme ambient temperatures.

cooling mechanism [33,34], has received growing empirical support [reviewed by 35]. For example, research on both rats and humans shows that yawning is preceded by intermittent rises in brain temperature and localized mild hyperthermia and then followed by equivalent decreases in temperature immediately thereafter [36,37]. While various critiques have been proposed regarding the thermoregulatory theory [38–42], no study has found evidence contrary to its main predictions and all current arguments remain untenable [35,43].

According to the thermoregulatory theory, the cooling effects of yawns occur through thermoregulatory mechanisms of counter-current heat exchange, evaporative cooling and enhanced cerebral blood flow [44]. Consequently, the effectiveness of yawning is dependent on the ambient air temperature, and the expression of this behavior should be constrained to an optimal thermal zone or range of temperature, i.e., a thermal window. In particular, this theory posits that yawns should (1) increase in frequency with initial rises in ambient temperature, as this stimulates thermoregulatory mechanisms to control temperatures within a normal range, (2) decrease as ambient temperatures draw near or exceed body temperature, since taking a deep inhalation of air above one's body temperature would be counter-productive, and likewise (3) diminish when temperatures fall below a certain point, because thermoregulatory cooling responses are no longer necessary and countercurrent heat exchange could result in deviations below optimal thermal homeostasis. Since both spontaneous and contagious yawns are indistinguishable, aside from different triggers, the predictions of the thermal window hypothesis should apply to both forms.

Experimental and observational research reports of spontaneous yawning in non-human primates [9,45], birds [46,47], and rats [48] have confirmed the first two predictions of this model. Additionally, it

was recently discovered that self-reported contagious yawning frequency in humans varies with seasonal climate variation [49]. In particular, two independent groups of pedestrians were sampled in an arid desert climate (Tucson, AZ, USA): the first in summer (37 °C) and the other during 'winter' (22 °C). Contagious yawning frequency was significantly lower during the hot summer climate (24% vs. 45%), with temperature being the only significant factor contributing to this response after controlling for other variables, such as humidity, sleep and time spent outside.

Here we tested the lower bound of the thermal window hypothesis by investigating the frequency of self-reported contagious yawning in a climate with a colder winter season (Vienna, Austria). In this case the summer condition provided temperatures equivalent to those in winter months of Tucson, while the winter condition included temperatures at and slightly below freezing.

2. Methods

2.1. Participants

Participants were 120 random pedestrians recruited in and around the city of Vienna, Austria (Lat.: 48.21; Lon.: 16.37). The experiments were conducted during two distinct time frames: December 2012–March 2013 (winter; average temperature: 1.4 °C) and June 2013–October 2013 (summer; average temperature: 19.4 °C). In total, per season we recruited 60 participants (winter: 25 males, 35 females; summer: 23 males, 37 females). Participants were all over 18 years of

Table 1
Descriptive statistics: mean and s.d. for each variable between and across conditions. Independent t-test and Chi² comparisons are between winter and summer conditions.

	Total	Winter	Summer	Test statistic	p
Sex (m:f)	48:72	25:35	23:37	$Chi^2 = 0.04$	0.852
Age (year)	28.6 ± 7.3	28.2 ± 7.3	29.0 ± 7.3	$t = -0.57$	0.567
Temp. (°C)	10.4 ± 10.1	1.4 ± 2.7	19.4 ± 5.9	$t = -21.42$	<0.001
Humidity (%)	54.8 ± 15.4	62.5 ± 16.0	47.0 ± 10.0	$t = 6.35$	<0.001
Time (min)[a]	63.8 ± 83.0	69.0 ± 74.6	59.8 ± 89.5	$t = 0.55$	0.586
Sleep (h)	7.1 ± 1.5	7.2 ± 1.5	7.1 ± 1.4	$t = 0.44$	0.661

[a] Time represents the time spent outside prior to participating.

Table 2
Best-fitting models (GLMMs) showing the factors influencing a) whether an individual reported yawning (binomial distribution, logit link function) ($n = 120$) and b) how often they yawned ($n = 120$). Original models included sex, season (winter or summer), age, temperature, humidity, time spent outside and hours of sleep and all 2-way interactions between these variables.

Variable denom. df		Beta ± s.e.m.	F	p
a) Dependent variable is yawn (y/n)				
Temperature	61	0.078 ± 0.02	13.09	0.001
b) Dependent variable is number of yawns				
Temperature	116	0.113 ± 0.04	7.25	0.008
Age	116	−0.053 ± 0.03	4.09	0.045
Winter or summer	116	1.186 ± 0.84	1.98	0.162

age and gave verbal and written consent to participate in this study (see ESM). The Ethics Committee of the University of Vienna approved this research.

2.2. Procedure

The procedure was similar to [49]: an experimenter approached pedestrians in public places and asked them to participate in a survey about contagious yawning. The participants then were instructed to carefully look through a series of 18 images of people yawning, after which they took a small survey self-reporting on whether and how often they had yawned during the experiment [for validity in this approach, see 50] and if not whether they had the urge to do so, how long they had been outside before participating in the study, how long they slept the night before, and how old they were. The last item was included to replicate a recent effect of age-related declines in contagious yawning [51]. To further trigger contagious yawns, additional questions were included for participants to report on their yawning behavior outside of the study (see ESM).

While the participants were taking the survey, an experimenter recorded the relative humidity (%) and ambient air temperature (°C) using a digital thermometer/hygrometer (TFA®) that was placed in the shade. Experimenters avoided directing their attention towards the participants during the experiment, since research suggests that people are less likely to yawn when they are being observed [52]. To avoid potential effects of circadian rhythms, all surveys were conducted between 13:00 h and 15:00 h [49].

2.3. Analysis

We compared variables across season using independent t-tests, Mann–Whitney U tests (non-normally distributed scale data), or Chi-square tests with Yates correction (binomial data). To assess the influence of several variables on reported yawning in parallel, we ran General Linear Mixed Models (GLMMs). If our response variable was binomial (yawn: yes/no) we ran GLMMs with a binomial distribution and logit link function. The sex of the participant was entered as a fixed factor and age, temperature, humidity, time spent outside and hours of sleep as fixed covariates. In addition, we included all 2-way interactions of these variables. To achieve the best models we used a backward stepwise approach, and our model choices were based on comparisons of the corrected Akaike Information Criteria (cAIC). For reasons of clarity, here we present only the best fitting models. All analyses were performed in IBM SPSS Statistics v.20 for Mac OS, with α set to 0.05. All reported p-values are 2-tailed.

3. Results

Of the 120 participants, 36 (30.0%) reported yawning during the experiment. As predicted, there was a significant difference in self-reported yawn contagion between the two seasons, with only 11 out of 60 (18.3%) participants in winter reporting yawning, and 25 out of 60 (41.7%) participants in summer reporting yawning ($Chi^2 = 6.71$, $p = 0.010$) (Fig. 1a). Further analyses showed that participants also reported more total yawns during the summer (Mann–Whitney U = 2203, $n = 120$, $p = 0.009$) (Fig. 1b).

As several variables differed between the two seasons (Table 1), we ran GLMMs to assess which variables best predicted self-reported yawning. The best fitting model revealed that temperature was the only significant predictor, with an increased likelihood to report a yawn at higher temperatures (Table 2a); i.e., none of the other variables (sex, season, age, humidity, time spent outside and hours of sleep the night before) had a significant effect on the likelihood of reporting a yawn, and were therefore excluded from the best fitting model (Table 2a).

Similarly, we found that temperature was a significant predictor of reported yawn frequency (Table 2b), with a greater number of yawns

being reported at higher temperatures. Consistent with previous research [51], age also had a significantly negative effect on reported yawn frequency. Season was also included in the best fitting model, albeit as a non-significant effect. None of the other variables had a significant effect on the reported yawn frequency and were therefore excluded from the best fitting model (Table 2b).

4. Discussion

Overall, these results show that significantly fewer pedestrians reported contagious yawning during the cold winter (−4 to 7 °C), and that, similar to effects observed in an arid desert climate [49], temperature was the only significant predictor of this response when controlling for other variables. As predicted by the thermal window hypothesis, reports of yawning were constrained to an optimal thermal zone or range of ambient temperature (Fig. 1). Importantly, changes in daylight across the seasons cannot account for these results. First, a particular time frame was chosen for both studies (between 1 and 3 pm) whereby contagious yawning frequencies remain unchanged [53]. Second, the proportion of people that reported yawning in the summer in Vienna, Austria (current study) was comparable to that of the winter in Tucson, Arizona, USA [49], whereas there is a large difference in daylight hours between these samples (summer in Vienna: ± 16 h vs. winter in Tucson: ± 10 h). Lastly, an inverse seasonal pattern emerged between the two study locations; i.e., whereas in Tucson there was a high frequency of reported yawning in winter, and a low frequency of reported yawning in summer, in Vienna there was a high frequency of reported yawning in summer, and a low frequency of reported yawning in winter. Thus, it cannot be generalized that people yawn more or less in winter vs. summer, nor with greater or fewer hours of daylight. Instead, the ambient air temperature accompanying the season appears to determine reported yawn frequency.

This report adds to accumulating research suggesting that the underlying mechanism for yawning, both spontaneous and contagious, is involved in brain thermoregulation. The thermoregulatory theory provides clear predictions for both the primitive and derived features of this behavior. That is, the thermoregulatory benefits resulting from yawning provide the mechanism by which arousal or state change can be achieved [8,10], while the spreading of this behavior, i.e., yawn contagion, would therefore coordinate arousal in a group and enhance overall group vigilance [33]. In addition to enhancing the basic understanding of why we yawn, applications from this research include improved treatment and diagnosis of patients with thermoregulatory problems [34,37,54,55].

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.physbeh.2014.03.032.

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