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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.

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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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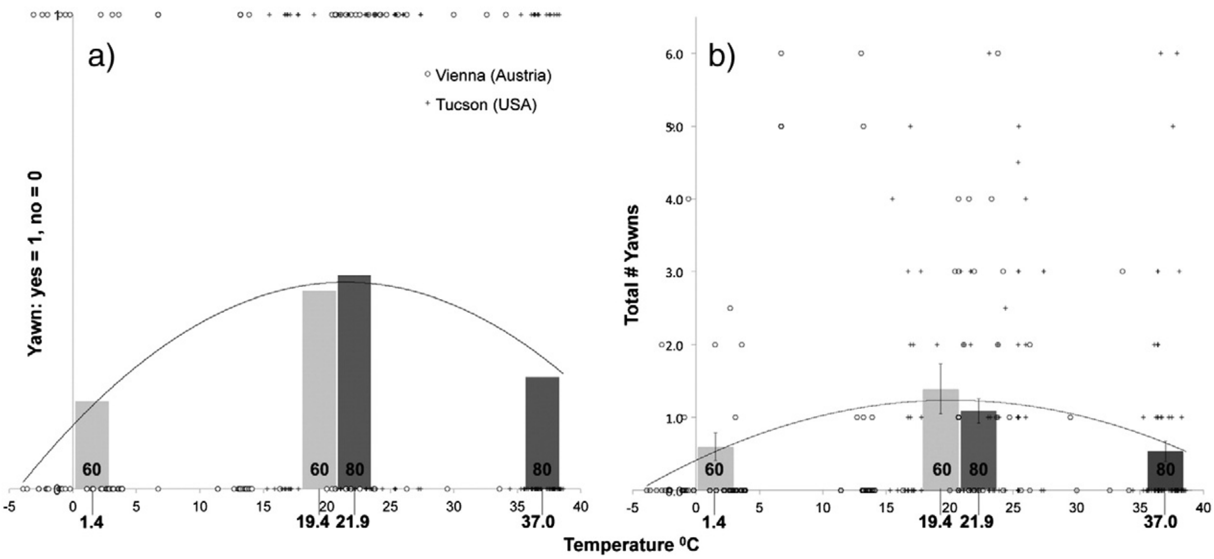

Fig. 1. (a) The proportion of participants reporting yawning, and (b) the mean ± s.e.m. frequency of reported yawns in the two seasonal conditions in Vienna, Austria (light gray bars), as well as the conditions of an earlier study in Tucson, Arizona USA (dark gray bars). Average temperatures and sample 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 countercurrent 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 counterproductive, 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.

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.

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 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