Evolutionary Psychology

www.epjournal.net – 2007. 5(1): 92-101

Original Article

Yawning as a Brain Cooling Mechanism: Nasal Breathing and Forehead Cooling Diminish the Incidence of Contagious Yawning

Andrew C. Gallup, Department of Psychology, State University of New York at Albany, Albany, NY 12222, USA.

Gordon G. Gallup Jr., Department of Psychology, State University of New York at Albany. Email: gallup@albany.edu (Corresponding author)

Abstract: We conducted two experiments that implicate yawning as a thermoregulatory mechanism. The first experiment demonstrates that different patterns of breathing influence susceptibility to contagious yawning. When participants were not directed how to breathe or were instructed to breathe orally (inhaling and exhaling through their mouth), the incidence of contagious yawning in response to seeing videotapes of people yawning was about 48%. When instructed to breathe nasally (inhaling and exhaling through their nose), no participants exhibited contagious yawning. In a second experiment, applying temperature packs to the forehead also influenced the incidence of contagious yawning. When participants held a warm pack (46^0C) or a pack at room temperature to their forehead while watching people yawn, contagious yawning occurred 41% of the time. When participants held a cold pack (4^0C) to their forehead, contagious yawning dropped to 9%. These findings suggest that yawning has an adaptive/functional component that it is not merely the derivative of selection for other forms of behavior.

Keywords: yawning, contagious yawning, nasal breathing, forehead cooling, brain temperature, thermoregulation, information processing, group vigilance.

Introduction

Yawning is characterized by gaping of the mouth accompanied by a long inspiration followed by a shorter expiration. In humans, yawning begins in utero by 20 weeks gestation (Sherer, Smith, and Abramowicz, 1991) and continues throughout life. People typically close their eyes at the peak of a yawn, and a single yawn can last for as long as 10 seconds (Daquin, Micallef, and Blin, 2001). Yawning is commonly accompanied by stretching and occurs most frequently before sleep and after waking (Provine, Hamernik, and Curchack, 1987). Yawning has long been associated with boredom and sleep. Under laboratory conditions subjects yawn more frequently after watching uninteresting color patterns than music videos (Provine and Hamernik, 1986). Yawning is widespread and has been recorded in many vertebrates (Baenninger, 1987). In some primates there is a special category of yawning that functions as a threat display (Hinde and Tinbergen, 1958; Tinbergen, 1952). Display yawns expose canine teeth, and unlike normal yawns the yawner keeps their eyes open during the yawning episode to monitor the effect of the yawn on the target subject.

Yawning is under the central control of several neurotransmitters and neuropeptides including dopamine, excitatory amino acids, acetylcholine, serotonin, nitric oxide, adrenocorticotropic hormone-related peptides and oxytocin (Argiolas and Melis, 1998). Yawning can be drug-induced, and drugs are especially effective when injections are made into the hypothalamus (Dourish and Cooper, 1990). Apomorphine injections have been reported to produce drug-induced yawning along with penile erection in male mice (Melis, Argiolas, and Gessa, 1987).

There have been many attempts to identify the function(s) of yawning in humans (Smith, 1999). However, the adaptive/functional/biological significance of yawning has yet to be established (Provine, 2005). It has long been thought (and is still commonly misconstrued) that the function of a yawn is to increase O2 levels in the blood. However, breathing increased levels of oxygen or carbon dioxide do not affect yawning (Provine, Tate, and Geldmacher, 1987).

Yawning is contagious. Seeing, hearing, thinking or reading about yawning can trigger yawns, and attempts to shield a yawn do not stop its contagion (Provine, 2005). Under laboratory conditions, slightly less than half of college students yawn contagiously, and individual differences in susceptibility to contagious yawning have been shown to be related to differences in processing information about oneself (Platek, Critton, Myers, and Gallup, 2003). Witnessing people yawn activates parts of the brain also associated with self-processing (Platek, Mohamed, and Gallup, 2005).

Here we investigate the physiological significance of yawning in humans, specifically whether yawning may function as a thermoregulatory mechanism. We propose that yawning serves to keep the brain in thermal homeostasis, and that yawning serves to maintain optimal mental efficiency. We believe that yawning serves as a compensatory cooling mechanism when regulatory mechanisms fail to operate favorably. In order to test this hypothesis, we conducted two separate experiments designed to indirectly manipulate brain temperature. Based on evidence supporting the selective brain cooling model (du Boulay, Lawton, and Wallis, 2000; Mariak, White, Lewko, Lyson, and Piekarski**,** 1999; Zenker and Kubik, 1996; Falk, 1990; Cabanac, 1986; Cabanac and Caputa, 1979), we choose to manipulate breathing conditions and forehead temperature by noninvasive means. Nasal breathing (du Boulay, Lawton, and Wallis, 2000; Mariak et al., 1999) and forehead cooling (Zenker and Kubik, 1996; Cabanac, 1986) have been shown to be involved in the thermoregulation (cooling) of the brain.

Contagious yawning was used as a proxy for yawning in both these experiments for two reasons. Contagious yawning is indistinguishable from spontaneous yawning aside from the fact that the triggers differ, and contagious yawning can be manipulated under laboratory conditions (e.g., Platek et al., 2003).

Experiment 1: Breathing Manipulation

The first experiment investigated whether different methods of breathing would affect the occurrence of contagious yawning, and was approved by the local Institutional Review Board. Breathing was the focus of this experiment because of its influence on brain temperature (du Boulay, Lawton and Wallis, 2000; Mariak et al, 1999).

Methods

Participants

Participants were 44 undergraduate students at the University of Albany. Twenty-seven participants were male and 17 were female, and all were eighteen to twenty-five years of age.

Procedure

Each participant signed a consent form, and was asked to step into a room and sit by themselves in front of a computer screen. Each participant was then instructed to either inhale and exhale strictly orally, strictly nasally, strictly orally while wearing a nose plug, or allowed to breathe normally (i.e., not instructed how to breathe) during the experiment. Eleven participants were randomly assigned to each of the four breathing conditions.

Participants were told to breathe in the manner instructed for a period of two minutes prior to and while watching a brief video tape lasting two minutes and fifty seconds. This same video was used in a previous contagious yawning study by Platek et al. (2003). The video consisted of 24 7-s digital videos of eight volunteers (four male, four female), each depicting three separate conditions (neutral, laughing or yawning). These videos were presented in random order on the computer screen to each participant using Microsoft Media Player.

Each participant was observed through a one-way mirror by a researcher who recorded their yawns. At the conclusion of the video presentation, participants were asked whether they had yawned during the experiment. Two of the participants (one in the oral group and one in the normal breathing group) who did not show detectable signs of a yawn, each reported yawning once. These self-reported instances of yawning were included in the data set.

Results

Figure 1 shows the distribution of yawning across all four groups. There were no yawns in the nasal breathing group. In all other groups, at least 45% of viewers yawned at least once. In the strictly oral breathing group (not the nose plug condition), 54% of viewers yawned at least once.

There were no significant effects of gender on yawning. Of the 16 yawners (9 male, seven female), six yawned several times (two male, four female). Multiple yawning occurred most frequently in the two oral breathing conditions. The average number of yawns per group ranged from three yawns per person in the oral group to 1.2 yawns per person in the normal breathing group. Frequency of yawns between groups was significantly different, $\chi^2(3) = 20.45$, $p<.001$. A comparison of the number of people yawning in the oral and nasal breathing groups also differed significantly, $\chi^2(1) = 6.00$,

$p<.02$. Using a binomial test based on the frequency of contagious yawning (41.5%) reported by Platek et al. (2003), the absence of yawning in the nasal breathing group was significant ($p = .0027$).

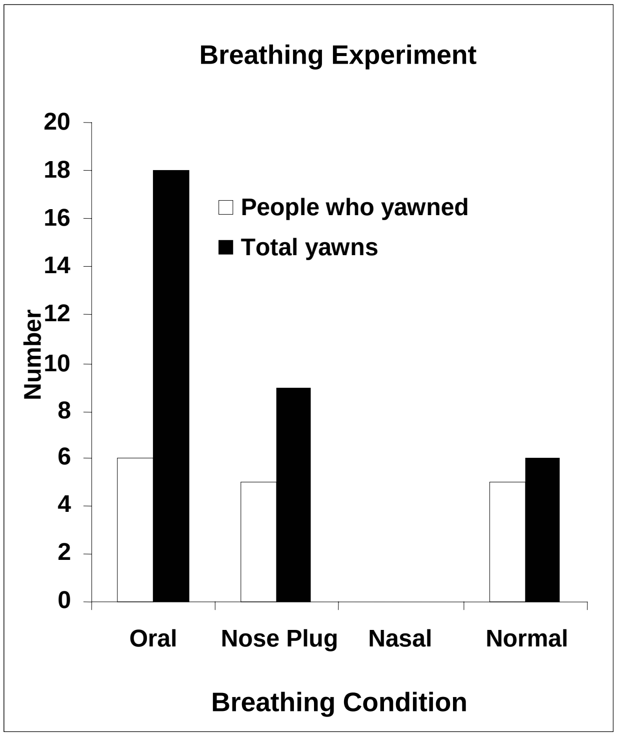

Figure 1: Number of people out of eleven in each group who yawned and total number of yawns as a function of breathing condition.

Experiment 2: Forehead Temperature Manipulation

The second experiment investigated whether forehead cooling had an impact on the occurrence of contagious yawning. Forehead temperature was the focus of this experiment because of its influence on brain temperature (Zenker and Kubik, 1996).

Participants

Participants consisted of an additional sample of 33 undergraduate students at the University of Albany. Twenty participants were female and 13 were male, and all were eighteen to twenty-five years of age.

Procedure

After each participant signed a consent form, they were asked to step into the same room used in the previous experiment and were seated in front of the same computer screen. Each participant was then either instructed to hold a warm pack, a cold pack, or a pack at room temperature to their forehead during this experiment, which lasted for the same length of time as the previous experiment (4 min, 50sec). Eleven participants were randomly assigned to each condition.

Each pack consisted of a hand towel folded over a few times and placed into a Ziploc plastic bag. To influence the temperature of the hot and cold packs, the hand towel was soaked in either warm water (46 ^{o}C) or cold water (4 ^{o}C) before being placed into the plastic bag. Temperature of the water and packs was monitored using a digital thermometer. The hot and cold packs were all within one degree Celsius of the intended temperature for every participant at the beginning of the testing procedure. The room temperature condition was achieved by placing a separate, dry towel into the plastic bag.

Participants were instructed to hold the pack to their forehead for a period of two minutes prior to the video, and to continue holding the pack to their forehead for the duration of the video. The same video from the first study was shown to the participants on a computer screen using Windows Media Player.

Each participant was observed through a one-way mirror by a researcher who recorded the incidence of yawning. Two of the participants (one in the cold pack group and one in the hot pack group) who did not show detectable signs of a yawn, each reported yawning once. These self-reported instances of yawning were included in subsequent analyses.

Results

Only one participant yawned in the cold pack group (see Figure 2), which was a self-reported but not independently verified instance. In the other two groups 41% of the participants yawned at least once. In the hot pack group, 36% of the participants yawned, while in the room temperature condition, 45% of the participants yawned. Eighteen yawns were recorded in the hot and room temperature groups while only one self-reported yawn was recorded in the cold condition.

There were no significant effects of gender on yawning. Of the 10 people who yawned, three yawned more than once (two male, one female). Figure 2 shows the distribution of yawning across all three groups. Of the people who yawned, the average number of yawns ranged from 2.25 per person in the warm pack group to one yawn per person in the cold pack group. The difference in number of yawns between groups was significant, $\chi^2(2) = 6.87$, $p<.05$. Again, using the data from Platek et al. (2003) on the occurrence of contagious yawning, a binomial test applied to the number of people yawning in the cold pack group was also significant, $p = .0199$.

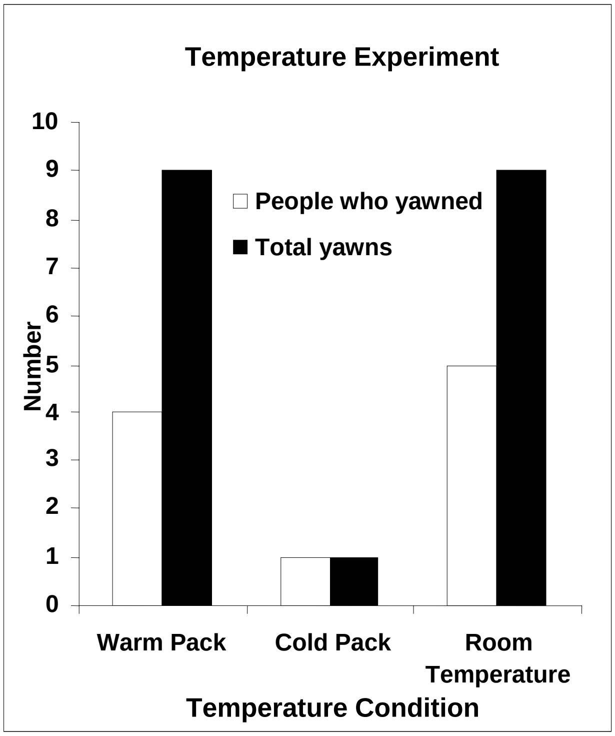

Figure 2: Number of people who yawned and the total number of yawns as a function of forehead temperature condition.

General Discussion

Different methods of breathing had a significant effect on the incidence of contagious yawning. Nasal breathing antagonized contagious yawning, while participants in the other breathing conditions yawned around 48% of the time. Manipulating forehead temperature also had a significant effect on the occurrence of contagious yawning. A cold pack held to the forehead greatly reduced contagious yawning, while warm and room temperature packs had no effect.

The two conditions thought to promote brain cooling (nasal breathing and forehead cooling), practically eliminated contagious yawning. Only one out of a total of 22 combined participants in the nasal breathing and forehead cooling conditions yawned, and that participant showed only one self-reported, but not independent verified instance of yawning. In the other conditions, 25 out of 55 participants yawned for a total of 51 yawns.

The manipulations involved in the breathing experiment are related to those done in a study by Provine (1986), where participants were instructed to think about yawning while clenching their teeth. Clenched teeth yawns were rated as abnormal and less satisfying, however clenching the teeth did not block yawns. Yawning still occurred as often as in baseline conditions and the duration of these yawns was not significantly different. This suggests that it was not simply the immobilization of the jaw in the nasal breathing group that eliminated yawning (even though the participants were not instructed to close their mouths, they were instructed to inhale and exhale nasally).

Based on evidence that clenching the teeth does not block yawning (Provine, 1986), we submit that it is the breathing manipulation (and the corresponding thermoregulation effects: see below) that alter the incidence in contagious yawning and not the difference between an opened or closed jaw.

Brain Cooling Model

Yawning has many physiological consequences that are concordant with those needed for the regulation of brain temperature. The constriction and relaxation of facial muscles during yawning increases facial blood flow and these changes alter cerebral blood flow (Zajonc, 1985). Yawning causes an overall increase in blood pressure (Arkenasy, 1996), arousal as measured by skin conductance (Greco and Baenninger, 1991), and heart rate (Heusner, 1946); all of which promote increased blood flow during the period immediately prior to yawning. Research by Cabanac and Brinnel (1985) shows that during hyperthermia (exercise-induced heat stress), blood flow is increased from the skin of the head into the cranial cavity, and this increase is essential for proper cooling of the brain. Similar physiological consequences occur during powerful stretching, and yawning is accompanied by stretching almost half the time (Provine, Hamernik, and Curchack, 1987). This increase in blood flow and cerebral blood flow (as a result of yawning) function like a radiator to produce alteration of temperature in the brain. Likewise, the gaping of the mouth and deep inhalation of cool air taken into the lungs during a yawn can alter the temperature of the blood in the brain through convection.

Thermoregulation has been strongly linked to structures of the hypothalamus (Cooper, 2002). Some recent research using tissue slices pinpoints the complex circuits within the hypothalamus serving thermoregulation (Boulant, 1996). Interestingly, yawning also appears to be regulated by the hypothalamus. Yawning is under the control of many neurotransmitter and neuropeptides, and the interaction of these substances in the nucleus of the hypothalamus can facilitate or inhibit yawning respectively (Argiolas and Melis, 1998). Dopamine is a common neurotransmitter that is released by the hypothalamus. When injected into the brain, dopamine agonists (compounds that activate dopamine receptors) not only produce yawning (Collins, Witkin, Newman, Svensson, Cao, Grundt, and Woods, 2005), but have also been shown to increase heat production (Yamawaki, Lai, and Horita, 1983; Lin, 1979).

Acute dopamine/norepinephrine reuptake inhibition has been shown to increase both brain and core temperature in rats (Hasegawa, Meeusen, Sarre, Diltoer, Piacentini, and Michotte, 2005). Prolonged sleep deprivation in rats also produces increases in brain temperature (Everson, Smith, and Sokoloff, 1994). Interestingly, yawning is ordinarily associated with being sleepy or tired, and a common symptom on many sleep deprivation checklists is excessive yawning.

The fact that nasal breathing antagonized yawning is consistent with the thermoregulatory hypothesis. Nasal breathing has been identified as one of the three putative mechanisms involved in cooling the brain. The vertebral venous plexus, which is located in the brainstem, is cooled by the vertebral artery as a result of nasal breathing (du Boulay, Lawton, and Wallis, 2000). Nasal breathing also cools other parts of the brain, including the frontal cortex (Mariak et al., 1999). Nasal mucosal blood flow decreases in response to skin cooling, increases in response to skin warming, and it rises in response to increases in core temperature (McIntosh, Zajonc, Vig, and Emerick, 1997).

We suggest that the cerebral cooling stimulated by nasal breathing was strong enough to inhibit mechanisms that would normally trigger yawning.

Cooling the forehead simulates a combination of the other two mechanisms thought to cool the brain, one being cooling of venous blood by the skin which in turn cools the arterial (carotid) blood supply to the brain. The other major brain cooling mechanism is the dissipation of heat through facial emissary veins (Zenker and Kubik, 1996; Cabanac, 1986; Cabanac and Brinnel, 1985), or heat loss through the skull. The density of sweat glands on the forehead is three times that of the rest of the body (Cabanac, 1986) and under normal conditions, blood from the face and forehead would be cooled by evaporation of sweat from the face and scalp.

Predictions of the Model

On the basis of this evidence we propose that yawning has a thermoregulatory function, and that yawning evolved to promote/maintain mental efficiency by keeping brain temperature in homeostasis. There are several other ways to test this model. For instance, we predict that yawning should be influenced by variation in ambient temperature. We predict that as ambient temperatures approach body temperature, yawning should diminish, and once temperature exceeds body temperature yawning should stop. If yawning functions to regulate brain temperature, yawning above $37^{o}C$ would warm the brain and would be counterproductive unless the individual is in a hypothermic state. Conversely, when ambient temperature drops below a certain point, perhaps $-10^{o}C$, yawning could produce a thermal shock by sending a wave of unusually cold blood to the brain. It follows that when people develop a fever, yawning should stop. That is, when body temperatures exceed normal values, it may simulate conditions ordinarily associated with an increase in ambient temperature above $37^{o}C$ and activate mechanisms that inhibit yawning. This may be the reason the application of the warm pack to the forehead in Experiment 2 failed to stimulate an increase in yawning.

We also predict yawning to increase when people are engaged in difficult mental tasks. Increased cortical metabolic activity associated with higher information processing loads would increase brain temperature and trigger compensatory yawning. It has been noted that yawning occurs frequently in transition periods from inactivity to activity and vice versa (Baenninger, Binkley, and Baenninger, 1996; Provine, Hamernik, and Curchack, 1987), which is consistent with the idea that yawning plays a role in mental efficiency. It has also been argued that the contraction of facial muscles during a yawn forces blood through cerebral blood vessels to the brain, which may function to increase alertness (Barbizet, 1958; Heusner, 1946).

According to our hypothesis, rather than promoting sleep, yawning should antagonize sleep. It has been widely believed that yawning in the presence of others is disrespectful and a sign of boredom (e.g., witness the fact that many people cover their mouths when they yawn). However, according to our account yawning more accurately reflects a mechanism that maintains attention. Likewise, when someone yawns in a group setting as evidence for diminished mental processing efficiency, contagious yawning may have evolved to promote the maintenance of vigilance.

Acknowledgment: The authors thank Jessica Wess for help reviewing the literature.

Received 8 September 2006; Revision received 16 January 2007; Accepted 17 January 2007.

References

Argiolas, A., and Melis, M.R. (1998). The neuropharmacology of yawning. *European Journal of Pharmacology, 343,* 1-16.

Arkenasy, J.J. (1996). Inhibition of muscle sympathetic nerve activity during yawning. *Clinical Autonomy Research*, *6*, 237-39.

Baenninger, R. (1987). Some comparative aspects of yawning in *Betta splendens*, *Homo sapiens, Panthera leo*, and *Papio sphinx*. *Journal of Comparative Psychology*, *101*, 349-354.

Baenninger, R., Binkley, S., and Baenninger, M. (1996). Field observations of yawning and activity in humans. *Physiology and Behavior*, *59,* 421-425.

Barbizet, J. (1958). Yawning. *Journal of Neurology, Neurosurgery, and Psychiatry, 21*, 203-209.

Boulant, J.A. (1996). Hypothalamic neurons regulating body temperature. In Fregly, M. J. and Blatteis, C. M., (Vol. Eds.), *Handbook of Physiology, Section 4, Vols. 1-2, Environmental Physiology. (*pp. 105-126). Oxford, Oxford University Press.

Cabanac, M. (1986). Keeping a cool head. *News in Physiological Sciences, American Physiological Society, 1*, 41-44.

Cabanac, M., and Brinnel, H. (1985). Blood flow in the emissary veins of the head during hyperthermia. *European Journal of Applied Physiology, 54,* 172-176.

Cabanac, M., and Caputa, M. (1979). Natural selective cooling of the human brain: Evidence of its occurrence and magnitude. *Journal of Physiology, 286*, 255-264.

Collins, G.T., Witkin, J.M., Newman, A.H., Svensson, K.A., Grundt, P., Cao, J., and Woods, J.H. (2005). Dopamine agonist-induced yawning in rats: A dopamine receptor-mediated behavior. *Journal of Pharmacology and Experimental Therapeutics, 314*, 310-319.

Cooper, K.E. (2002). Molecular biology of thermoregulation: Some historical perspectives on thermoregulation. *Journal of Applied Physiology, 92,* 1717-1724.

Daquin, G., Micallef, J., and Blin, O. (2001). Yawning. *Sleep Medicine Review, 5,* 299-312.

Dourish, C.T., and Cooper, S.J. (1990). Neural basis for drug-induced yawning. *Neurobiology of Stereotyped Behavior,* 91-116. Oxford: Clarendon Press.

du Boulay, G., Lawton, M., and Wallis, A. (2000). Selective brain cooling in animals: Internal carotid's significance for sudden infant death syndrome. *Ambulatory Child Health, 6,* 36-38.

Everson, C.A., Smith, C.B., and Sokoloff, L. (1994). Effects of prolonged sleep deprivation on local rates of cerebral energy metabolism in freely moving rats. *Journal of Neuroscience*, *14,* 6769-6778.

Falk, D. (1990). Brain evolution in Homo: The "radiator" theory. *Behavioral and Brain Sciences, 13,* 333-381.

Greco, M., and Baenninger, R. (1991). Effects of yawning and related activities on skin conductance and heart rate. *Physiology and Behavior*, *50,* 1067- 1069.

Hasegawa, H., Meeusen, R., Sarre, S., Diltoer, M., Piacentini, M.F., and Michotte, Y. (2005). Acute dopamine/norepinephrine reuptake inhibition increases brain and core temperature in rats. *Journal of Applied Physiology, 99,* 1397-1401.

Heusner, A.P. 1946. Yawning and associated phenomena. *Physiological Review, 25,* 156-168.

Hinde, R.A., and Tinbergen, N. (1958). The comparative study of species specific behavior. In A. Roe and G. C. Simpson (Eds.), *Behavior and Evolution*, 251-268. New Haven, CT: Yale University Press.

Lin, M.T. (1979). Effects of dopaminergic antagonist and agonist on thermoregulation in rabbits. *Journal of Physiology, 293,* 217-228.

Mariak, Z., White, M.D., Lewko, J., Lyson, T., and Piekarski, P. (1999). Direct cooling of the human brain by heat loss from the upper respiratory tract. *Journal of Applied Physiology, 87,* 1609-1613.

McIntosh, D.N., Zajonc, R.B., Vig, P.S., and Emerick, S.W. (1997). Facial movement, breathing, temperature, and affect: Implications of the vascular theory of emotional efference. *Cognition and Emotion, 11,* 171-195.

Melis, M.R., Argiolas, A., and Gessa, G.L. (1987) Apomorphine-induced penile erection and yawning: Site of action in the brain. *Brain Research, 415,* 98-104.

Platek, S.M., Critton, S.R., Myers T E, and Gallup, Jr. G.G. (2003). Contagious yawning: the role of self-awareness and mental state attribution. *Cognitive Brain Research, 17,* 223-227.

Platek, S.M., Mohamed, F.B., and Gallup, Jr., G.G. (2005). Contagious yawning and the brain. *Cognitive Brain Research, 23*, 448-452.

Provine, R.R. (1986). Yawning as a stereotyped action pattern and releasing stimulus. *Ethology*, *72,* 109-122.

Provine, R.R**.** (2005). Yawning. *American Scientist, 93,* 532-539.

Provine, R.R., and Hamernik, H. B. (1986). Yawning: Effects of stimulus interest. *Bulletin of the Psychonomic Society, 24,* 437-438.

Provine, R.R., Hamernik, H.B., and Curchack, B.B. (1987). Yawning: Relation to sleeping and stretching in humans. *Ethology, 76,* 152-160.

Provine, R.R., Tate, B.C., and Geldmacher, L.L. (1987). Yawning: No effect of 3-5% CO2, 100% O2, and exercise. *Behavioral Neural Biology, 48,* 382-393.

Sherer, D.M., Smith, S.A., and Abramowicz, J.S. (1991). Fetal yawning in utero at 20 weeks gestation. *Journal of Ultrasound Medicine, 10,* 68.

Smith, E.O. (1999). Yawning: An evolutionary perspective. *Human Evolution, 14,* 191-98.

Tinbergen, N. (1952). Derived activities: Their causation, biological significance, origin, and emancipation during evolution. *Quarterly Review of Biology*, *27,* 1-32.

Yamawaki, S., Lai, H., and Horita, A. (1983). Dopaminergic and serotonergic mechanisms of thermoregulation: Mediation of thermal effects of apomorphine and dopamine. *Journal of Pharmacology and Experimental Therapeutics, 227,* 383-388.

Zajonc, R.B. (1985). Emotion and Facial Efference: A Theory Reclaimed. *Science*, *288,* 15-21.

Zenker, W., and Kubik, S. (1996). Brain cooling in humans – anatomical considerations. *Anatomy & Embryology (Berl)*, *193,* 1-13.