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Facial Movement, Breathing, Temperature, and Affect: Implications of the Vascular Theory of Emotional Efference

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The vascular theory of emotional efference (VTEE) states that facial action can alter the volume of air inhaled though the nose, which in turn influences brain temperature and affective states. Cooling enhances positive affect, whereas warming depresses it. Three studies assessed this hypothesised series of effects. Study 1 found that when subjects engaged facial muscles in a manner analogous to a negative emotional expression, the volume of ambient air inhaled through the nose decreased, forehead temperature (a measure of brain temperature) increased, and participants reported feeling more negative affect. Study 2 established that prevention of nasal breathing generated negative affect. Study 3 indicated that forehead temperature increased when nasal breathing was prevented, without forehead muscle movement. Further, facial movement and prevention of nasal inhalation had no effects on arm temperature, showing that facial movement has only locally specific temperature effects. The hypotheses generated from VTEE were thus generally supported, and suggest a means by which facial action can cause changes in affective state in the absence of cognitive appraisal.

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INTRODUCTION

The study of emotion easily traces roots to James' (1890/1950) *The principles of psychology*. James was concerned with the *processes* responsible for emotions (Mandler, 1990), and suggested that physiological changes are fundamental causes of subjective emotional experience. Over 100 years later, psychologists continue to delineate possible physical influences on the process of emotional experience.

A number of researchers have found diverse physical changes related to emotion (see Cacioppo, Klein, Berntson, & Hatfield, 1993, for discussion). Muscle tension, electrodermal response, and blood pressure are common psychophysiological measures of emotional response, although they primarily measure only the arousal component of emotional experience. Heart rate has been found to discriminate hedonic polarity via differential increases (Ekman, Levenson, & Friesen, 1983; Winton, Pulls, & Krauss, 1984). Lateralisation of brain activity also seems to vary with affective polarity of stimuli (Ahern & Schwartz, 1985; Davidson, 1983, 1984). Moreover, most people's subjective experiences suggest that emotions and physiological changes are closely associated. From this evidence, it seems clear that physical variations and emotional experience are related. What is less clear are the specific processes by which such changes are linked to feeling state. When investigating underlying processes of emotional experiences, it is important to explore how specific physical changes are related to affective changes, and why.

Working in this vein, Zajonc (1985) and colleagues (Berridge & Zajonc, 1991; McIntosh, Zajonc, Vig, & Emerick, 1991; Winkielman, McIntosh, Zajonc, Emerick, Vig, & Denney, 1993; Zajonc & McIntosh, 1992; Zajonc, Murphy, & Inglehart, 1989; Zajonc, Murphy, & McIntosh, 1993) have advanced the vascular theory of emotional efference (VTEE). This theory proposes a specific link between physical changes and affective experience. It indicates what changes (brain temperature), how it changes (facial action and breathing patterns), and what consequences the changes have (cooling is felt as positive, heating as negative). The studies reported here add to the discourse on physiological processes and subjective affective experience by examining some of the causal relations hypothesised by VTEE.

The Vascular Theory of Emotional Efference

VTEE begins with the recognition that because the metabolic activity of the brain produces considerable heat, the brain requires continuous cooling. VTEE assumes the cooling of the brain essential to the maintenance of normal functions is hedonically positive. More specifically, impeded cooling is felt as discomfort, whereas facilitated cooling is felt as pleasurable. Neurochemical brain processes are temperature-sensitive; thus, brain-cooling might have subjectively felt effects mediated by temperature-dependent changes in the release and synthesis of emotion-related neurochemicals (e.g. endorphins, serotonin, and dopamine).

VTEE argues that one of the physiological processes closely associated with affective valence is thermoregulation of the arterial blood that enters the hypothalamus. This regulation is done in part via the cavernous sinus, a venous formation enveloping the internal carotid just before the latter enters the brain. Because of this configuration, the temperature of blood in the cavernous sinus can influence the temperature of blood entering the brain. The cavernous sinus not only receives blood from facial veins, but also its veins are air-cooled in the course of normal nasal breathing (Kluger & D'Alecy, 1975). This arrangement creates the possibility that changes in nasal breathing will have affective consequences.

VTEE postulates that facial actions influence breathing patterns, which influence changes in brain temperature, which in turn influence affective state. For VTEE to be plausible, manipulating factors that come earlier in this series should affect variables that come later. Zajonc et al. (1989) give evidence consistent with this series of effects. First, they evaluated the consequences of facial action similar to emotional expressions on temperature and affect. The pronunciation of the phoneme *ü* resembles the facial musculature action associated with negative emotions, whereas the pronunciation of the phonemes *e* (as in "cheese") and *ah* resemble facial musculature action associated with positive emotions. The effects of repeatedly voicing such phonemes on forehead temperature and affect were assessed. Uttering *ü* was associated with the greatest increase in forehead temperature, was liked least, and put subjects in a negative mood, and speaking the phonemes *e* and *ah* were associated with the greatest decreases in temperature, were liked best, and put subjects in the most positive moods. This suggests a causal influence of facial action on brain temperature (changes in forehead temperature at the site measured are highly correlated with changes in tympanic membrane temperature that have been shown to be good estimates of changes in brain temperature[1]

[1] Tympanic membrane temperature is typically used to estimate brain temperature in humans (see Baker, Stocking, & Meehan, 1972; Benzinger, 1969). However, this procedure can be intrusive, and damaging to the subject (e.g. Wallace, Marks, Adkins, & Mahaffey, 1974). Therefore, Zajonc et al. (1989) used points on the forehead that are on or near the frontopolar branch of the anterior cerebral artery. This artery issues from the internal carotid as the latter enters the brain. The distance of these arteries from the cavernous sinus is small, and thus changes here are likely to reflect changes in blood temperature caused by the passage of the internal carotid through the cavernous sinus. Although forehead temperature cannot be used to estimate absolute levels of brain temperature, it is a good estimate of changes in temperature (see, e.g. Germain et al., 1987; McCaffrey et al., 1975).

(see e.g. Germain, Jobin, & Cabanac, 1987; McCaffrey, McCook, & Wurster, 1975). It also demonstrates a causal role of facial action on affective judgements.

Zajonc et al. (1989) also explored whether nasal breathing can influence forehead temperature and affective state. They found that systematic temperature variations in air introduced into the nose are correlated with hedonic reactions to stimuli and changes in forehead temperature (see also Winkielman et al., 1993). This demonstrates the role of nasal breathing on changes in forehead temperature, and indicates that breathing can influence affective reactions to stimuli. From this work, there is evidence that facial actions do indeed influence forehead temperature and affect, and that nasal breathing is associated with forehead temperature and affect. Not established is whether facial action influences breathing patterns, and whether the breathing changes caused by facial actions can cause changes in temperature and affect. Evaluating these links is the purpose of the present studies.

Overview of the Present Studies

We seek to elaborate the earlier findings and further test predictions of VTEE. In the first study, we examine the initial link in the postulated chain of events: the effects of facial movement on breathing, as well as on forehead temperature and on affective reactions. Because the cavernous sinus is air cooled, and given that air that enters the nasal airways is generally lower in temperature than the body, decreases in the volume of air inhaled via the nose should reduce cooling. Thus, VTEE predicts that facial actions that decrease nasal air volume should be associated with temperature increases and negative affect.

The second study examines the effect of breathing on forehead temperature and affect by directly manipulating nasal and oral breathing while subjects are exposed to stimuli. If changes in nasal air volume cause changes in affect, varying nasal air volume should have affective consequences.

The influence of nasal breathing, separate from facial muscle movements, on forehead temperature is evaluated in the third study. If breathing changes are responsible for temperature changes, then manipulating breathing alone should cause changes in temperature.

STUDY 1

Study 1 replicated and extended the Zajonc et al. (1989) vowel-speaking study discussed earlier. In addition to repeating the tests of the effects of facial action on affect and forehead temperature, we have evaluated the influence of such movement on the volume of air inhaled via the nose and on arm temperature. Participants experienced three 4-minute trials during which they were alternately silent, or voiced one of three vowels designed to cause facial action matching emotional efference. VTEE predicts that during facial actions similar to those displayed during positive affect (saying *e*), forehead temperature will be lower, affect more positive, and nasal volume greater than during facial actions similar to those associated with more negative affect (voicing *ü*). Further, these changes in skin temperature should occur only on the forehead, where the frontopolar branch of the anterior cerebral artery comes close to the surface—that is, where changes in brain temperature can be assessed.

Method

Subjects

Participants were 13 men and 13 women from the paid subject pool of either the University of Michigan Department of Psychology or Dental School Respiration Laboratory, under the direction of Peter S. Vig. These individuals were telephoned, told the basic procedure of the study, and asked if they wanted to participate. Only those who had no prior surgery to the cranial-facial complex (except tooth extraction), were taking no drugs that influence the respiratory passages, were not experiencing any nasal congestion due to allergies or infection, and were not troubled by the prospect of having their head encased in a clear plastic bubble were scheduled for an appointment.

Measures

Nasal Volume. Breathing parameters were measured using the simultaneous nasal and oral respirometric technique (Keall & Vig, 1987). This respirometer includes a Plexiglas bubble that is placed over the subject's head. The bubble is hermetically sealed, using a series of neoprene and hard plastic rings around the subject's neck. The subject is supplied with as much air as desired through both a nose mask and a second opening into the bubble. Both inputs pass through bidirectional flow meters connected to differential air pressure transducers. The nose mask is specially fitted for each subject, and its position is easily adjusted to fit the subject. Soft rubber is applied to the mask to provide a flexible and airtight seal around the participant's nose. This procedure allows for precise and separate measurement of the volume of air inhaled via the nose and the mouth. Air volume data are both displayed on the computer monitor and stored for later analysis.

Temperature. In this and the following studies, brain temperature was indirectly estimated via changes in forehead temperature (see earlier, and Zajonc et al., 1989, 1993). Specifically, forehead temperature was measured at a point directly above each subject's pupils (while looking forward) and midway between the eyebrows and hairline. Only one side of the forehead was used because previous studies have found no lateralisation of temperature. This point is on or near the frontopolar branch of the anterior cerebral artery, which issues from the internal carotid as it enters the brain. As noted previously, change in forehead skin temperature here is used to indicate changes in brain temperature. Note that we do not know precisely where in the brain temperature change is most associated with forehead temperature change. Changes at this point of measurement may reflect both changes in blood temperature related to passage through the cavernous sinus, and changes in brain temperature of the structures through which the blood passes following the cavernous sinus. Thus, although we know that nasal air cooling can decrease hippocampal and cortical temperatures in dogs (Natale & D'Alecy, 1989) and hypothalamic temperature in rabbits (Kluger & D'Alecy, 1975), we cannot confirm from forehead temperature exactly what is being cooled in the present experimental procedures.

To assess general changes in overall skin temperature, temperature was measured on the under side of subject's left arms, approximately 5–6cm below the elbow.

Probes (Omega OL-709-PP) were attached to the subjects' foreheads and arms with 3M Micropore tape. Temperature was measured with an Omega thermistor thermometer (model 5831) with a 0.01°C. resolution.

Affect. After each trial, subjects answered on 7-point scales the following questions: How easy or difficult was it to say the vowel (1 = Difficult, 7 = Easy)? How pleasant or unpleasant was producing the vowel (1 = Unpleasant, 7 = Pleasant)? Did repeating the vowel put you in a good or bad mood (1 = Bad, 7 = Good)? How much do you like the vowel you just repeated (1 = Not At All, 7 = Very Much)?

Prodecure

Preparation. On entering the lab, participants were again asked the screening questions. After subjects were given basic instructions, they were fitted for a nose piece; collars, earphones, and temperature probes were attached.

After the equipment was connected, the subject was seated and sealed in the respirometer. Each was given time to adjust to breathing in the bubble. Once they were comfortable and had settled into a regular breathing pattern, the experimental procedure began.

Experimental Procedure. During three 4-minute trials, subjects breathed normally for 2 minutes. During the other 2 minutes, the subjects heard over earphones one of three vowels repeated 40 times. They had been instructed to repeat aloud the vowels as they heard them. Subjects were randomly assigned to two crossed conditions: Whether they repeated the vowels during the first or second 2 minutes of the session, and which of the six permutations of vowel order they experienced. Speaking these phonemes aloud moves the face in ways similar to emotional facial expressions. Repeating the phoneme *e* draws the corners of the lips back as in a smile. Speaking the phoneme *ü* constricts the nostrils, and pushes the mouth and brows forward, as in a scowl. When the phoneme *o* is spoken, the face is fairly relaxed. Thus, this procedure resulted in the subjects' repeatedly moving their faces in ways similar to emotion-related facial actions. During this time, breathing and temperature were measured.

After each trial, the subjects completed the vowel-rating questionnaire. The time between trials was approximately 2 minutes. On completion of all trials the participant was disconnected from the equipment, thanked, paid, and excused.

Results

VTEE predicts that the facial action resembling that associated with negative affect should cause the amount of air inhaled via the nose to be less than nasal air volume during facial action resembling that associated with positive affect. To test this, a 1-factor repeated-measures ANCOVA was run comparing nasal volume per breath during the speaking of each of the three vowels, controlling for nasal volume per breath during the 2-minutes of normal breathing associated with each vowel. Volume of air per breath inhaled via the nose is depicted in Fig. 1. As predicted, facial configuration made a difference in nasal volume [multivariate $F(2, 22) = 6.29$, $P < .01$]. Follow-up *t*-tests reveal that less air was inhaled through the nose while subjects were repeating *ü* than when they were repeating *o* [$t(25) = 2.54$, $P < .05$], or *e* [$t(25) = 3.10$, $P < .01$].

VTEE also predicts that forehead temperature should be higher during *ü* than during o and *e*, because the expression associated with *ü* restricts air flow and matches facial efference associated with negative affect. This was tested by comparing temperature change during each of the vowel sessions, controlling for temperature change during the 2-minutes of normal breathing associated with each vowel. As depicted in Fig. 2, temperature increased different amounts depending on the phoneme being spoken [$F(2, 22) = 7.2$, $P < .005$]. Follow-up *t*-tests indicate that temperature increased more while subjects were repeating *ü* than *o* [$t(25) = 3.97$, $P = .001$), or *e* [$t(25) = 3.25$, $P < .01$]. In contrast to predictions, however, forehead temperature did not

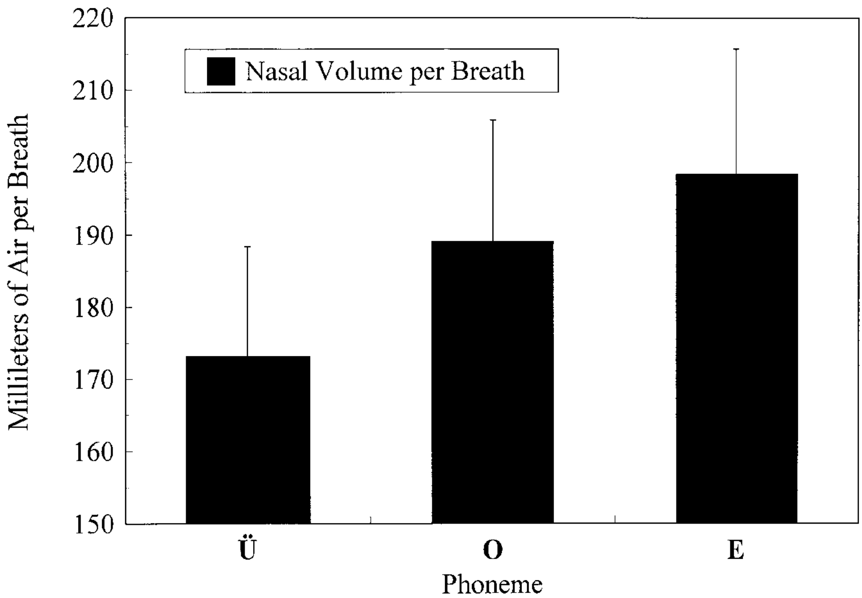

FIG. 1. Study 1: Effects of speaking phoneme on volume of air inhaled through the nose.

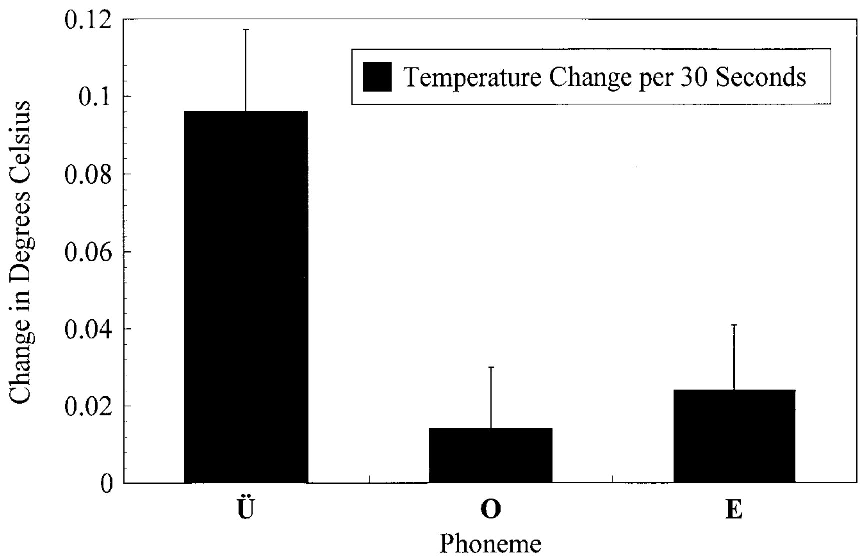

FIG. 2. Study 1: Effects of speaking phoneme on forehead temperature of change.

decrease when subjects were voicing *e*, the movements that match affectively positive facial efference. Although the increases during the *e* and *o* were not significantly greater than zero [*e*: $t(25) = 1.41$, $P > .10$]; *o*: $t(25) = 0.88$, $P > .30$], the findings are not wholly consistent with VTEE.

Are the skin temperature changes specific to the forehead, as would be predicted by VTEE? To test this, arm temperature measurements were taken simultaneously with forehead temperature. As with forehead temperature, an ANCOVA was done comparing change in arm temperature during the speaking of each vowel, controlling for the change in arm temperature during the silent part of the trial associated with each vowel. There was no effect on arm temperature [$F(2, 22) < 1$]; facial action did not cause changes in overall skin temperature. This is consistent with the reason for forehead temperature change postulated by VTEE (i.e. facial action changes breathing patterns, which influence brain cooling).

Finally, VTEE predicts that the different facial actions will have different subjective consequences. This was tested for each question asked of the subjects following each trial. Mean responses are displayed in Fig. 3; the differences among vowels were compared for each question in 1-factor repeated-measures ANOVAs. All differences were found to be significant. After repeatedly uttering the phonemes, subjects' reports of the type of

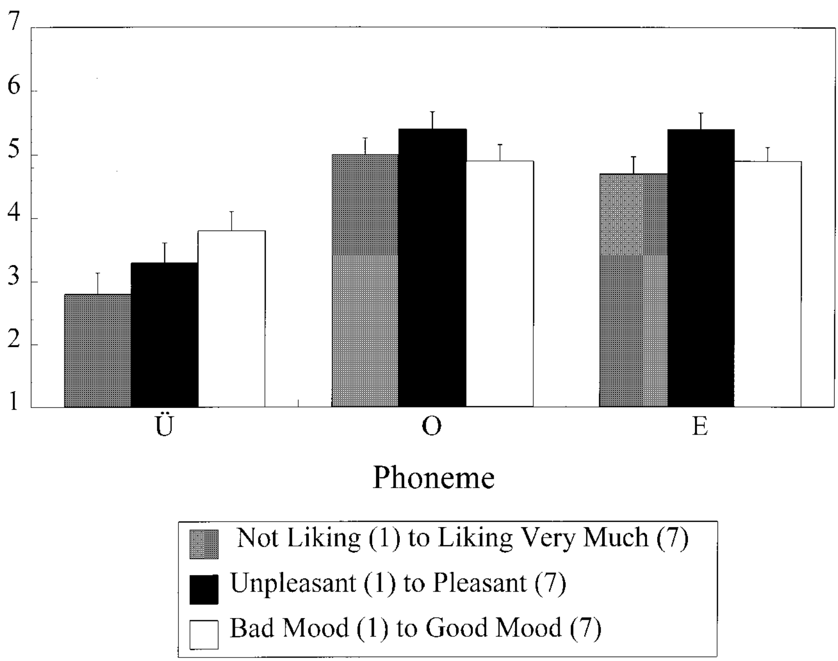

FIG. 3. Study 1: Effects of speaking phoneme on subjective state.

mood the vowel would put them in, [multivariate $F(2, 24) = 7.51$, $P < .01$], their *liking* for the vowel [multivariate $F(2, 24) = 22.72$, $P < .001$], and the *pleasantness* of the vowel [multivariate $F(2, 24) = 32.74$, $P < .001$], were all lower for *ü* than the other phonemes. However, when level of difficulty was included as a covariate, only the differences among vowels in mood remained significant [$F(2, 22) = 3.59$, $P < .05$].

Discussion

VTEE predicts that facial movement alters breathing, which changes temperature and therefore affect. This study demonstrates that facial movement similar to scowls decreases the amount of air inhaled via the nose, thus establishing the first link in the causal chain. According to VTEE, air serves to cool the brain. Indeed, forehead temperatures increased when subjects were scowling (and thus inhibiting air flow). These data replicate the findings of Zajonc et al. (1989) in that changes in facial configuration caused changes in forehead temperature. It is unclear to what to attribute the lack of temperature decreases associated with voicing *e* in the present study. It may be that temperature in the sealed plastic bubble increased in general during experimental trials, masking possible subtle decreases in temperature.

Skin temperature changes did not occur on the arm. This increases our confidence in the process postulated by VTEE.

Finally, these facial movements influenced participants' affective reaction to the vowels. The effect on mood remained even after the difficulty of speaking the vowel was controlled. Combined with the findings of Zajonc et al. (1989) that these effects occur even in subjects for whom the vowel is a natural part of their language, these data suggest that the effect is due to more than difficulty or novelty in speaking the phoneme.

Although facial action influences the volume of air inhaled via the nose, forehead temperature, and affect, that the latter three variables co-occur does not demonstrate that nasal breathing cools the brain or alters affective response. Facial action may influence each independently. For example, forehead temperature change may be due to heat from muscle action, and affect change may be due to self-perception processes (e.g. Laird, 1974; see McIntosh, 1996). Zajonc et al. (1989) demonstrated that manipulating air temperature influences temperature and affect, suggesting that nasal breathing has a causal role in temperature and affect changes. However, it is not yet clear that the changes in nasal air volume caused by facial action influence temperature and affect. The following studies were designed to evaluate whether such changes in nasal air volume, without changes in muscle activity also associated with facial action, influence forehead temperature and affect.

STUDY 2

If the changes in nasal air volume caused by facial action influence emotional responses, then preventing nasal breathing during exposure to stimuli should modify subjects' affective reactions to them. In this study, people's reactions to musical stimuli were compared under three conditions: natural breathing, exclusive oral breathing, and exclusive nasal breathing. Differences related to breathing condition will support the notion that breathing has a causal role in affective responses. We also hypothesised that changes in nasal air volume would influence temperature.

Method

Subjects

Eighteen men and 20 women from the paid subject pools of the University of Michigan Department of Psychology and Dental School Respiration Laboratory participated. Recruitment and preparation of subjects were identical to the previous study.

Stimuli

Music, which can effectively elicit both positive and negative reactions (e.g. Pignatiello, Camp, & Rasar, 1986), was used as a stimulus. Two-minute excerpts from two musical pieces were used. *Vogue*, performed by the popular vocalist Madonna, is a fast-paced, upbeat rock song; it tended to generate positive affect in pilot tests. The second piece was taken from Albinoni's *Adagio in G minor*; it is much slower and generally induced negative feelings in pilot testing. These stimuli were recorded on a Memorex dBS cassette tape and presented to the subject via foam padded earphones connected to a Panasonic (model no. RQ-413AS) cassette player.

Measures

Prior to the each trial, subjects indicated on a 10-point scale (0 = Not At All, 9 = Quite A Lot) the degree to which they currently felt each of the five valenced emotions used by Ekman et al. (1983): happiness, disgust, sadness, anger, and fear. These same scales were completed at the end of each trial. These emotions were combined to form an *affect* scale, with higher scores indicating more positive affect (happiness minus the sum of the negative emotions). The affect score at the beginning of each trial was subtracted from that of the end to give a score representing change in affect.

In addition, during each session, subjects watched a line on a computer screen move up a 10-point scale. They pushed a button to indicate when the line was congruent with how they were currently feeling; a computer recorded the position of the line when the button was pressed. The bottom of the scale was negative, the middle was neutral, and the top was positive. Ratings from the beginning of the trial were subtracted from ratings of the end of the trial to find changes in *feeling* state.

After each trial, subjects also indicated on the 10-point scale how much they liked the music or silence they heard during their time in the bubble.

Breathing and forehead temperature data were collected as before. Arm temperature was not measured.

Procedure

Subjects engaged in practice sessions until they were comfortable using the respirometer. All subjects then engaged in three 2-minute trials during which they repeatedly listened to *Vogue*, *Adagio*, or silence. One-third of the subjects were randomly assigned to experience each stimulus. In one of the trials, subjects breathed normally. In the other two, they were instructed to breathe exclusively through either their mouths or their noses. One experimenter monitored the nasal and oral air flow during the procedure to evaluate compliance with the request; all participants followed the instruction fully. Subjects were randomly assigned to piece of music (or silence), and order of breathing conditions, which was balanced among the six permutations. Time between trials was approximately two minutes.

Results

VTEE predicts that nasal breathing influences feeling state. Because exclusive oral breathing does not alter cavernous sinus temperature, it is theorised to reduce brain cooling, and it should therefore generate affect more negative than nasal breathing generates. Further, if the musical stimuli used above change affect due in part to changing breathing patterns, then these affect changes should be different when nasal breathing is blocked. These hypotheses were tested by comparing changes in the *affect* index, *feeling* state, and *liking* for the music.

A 3 (type of music, between subjects) × 3 (breathing condition, within-subjects) ANOVA was done comparing changes in the affect index. These scores are displayed in Table 1; changes in the specific emotions included in the index are presented in Table 2. Because VTEE predicts only overall changes in affective valence, only effect on the overall index was statistically tested. As predicted by VTEE, there is a significant main effect for breathing condition, with subjects' emotions becoming more negative with

TABLE 1
Study 2: Breathing Condition and Music Effects on Affect Change

	Breathing Condition							
Music	*Nasal*	(*SD*)	*Natural*	(*SD*)	*Oral*	(*SD*)	*Mean*	(*SD*)
Adagio	−.31	(2.25)	−.15	(1.95)	−.38	(1.26)	−.28	(1.00)
Silence	.82	(2.18)	.55	(2.91)	−2.00	(3.77)	−.21	(2.07)
Vogue	.25	(1.54)	1.25	(1.86)	−.58	(2.68)	.31	(1.55)
Mean	.22	(2.02)	.53	(2.27)	−.94	(2.71)		

Note: $N = 36$. Affect is the sum of four negative emotions subtracted from happiness. The scale for each emotion ranges from 0 (Not At All) to 9 (Quite A Lot). Mean changes in affect over the breathing sessions are shown here (post-trial minus pre-trial). Breathing Condition is a within-participants variable, with the mean of people's across-condition averages displayed in the rightmost column. Music is a between-participants variable, with the mean across people displayed in the bottom row.

time when they breathed only through their mouths [multivariate $F(2, 32) = 4.07$, $P < .05$]. Note using Table 2 that, with the exception of sadness, the specific emotions all follow this pattern. There was no music by breathing condition interaction, however [multivariate $F(4, 62) = 1.46$, $P > .20$]. Breathing through the mouth appears to make people's affect more negative regardless of the music to which they are listening.

The same ANOVA was performed examining changes in feeling state. Changes in overall feeling state are shown in Table 3. In this case, music did have a marginal influence on feelings [$F(2, 27) = 2.95$, $P < .10$], with *Vogue* causing a move towards the positive and *Adagio* causing a move towards the negative. As predicted by VTEE, there was again a tendency for breathing condition to influence subjective experience, although the main effect for breathing was only marginally significant [multivariate $F(2, 26) = 2.80$, $P < .10$]. Note that during silence, oral-only breathing caused more negative ratings of feelings, whereas natural and nasal breathing cause more positive ratings. Further, the positive effect of *Vogue* appears enhanced when individuals breath exclusively through their nose. However, the music by breathing condition interaction is only marginally significant [multivariate $F(4, 54) = 2.1$, $P < .10$]. The pattern of findings using the single-item feeling level measure is consistent with VTEE.

A third measure of the subjective influence of the music and of breathing condition is in how well the subjects reported liking the music or silence. As earlier, a 3 × 3 ANOVA was used to compare liking scores among the conditions. These ratings are displayed in Table 4. There was a main effect for music [$F(2, 31) = 4.08$, $P < .05$]. Follow-up comparisons of mean liking using the Tukey-B method indicate that this is due to subjects liking silence less than *Vogue*. VTEE predicts that breathing patterns will influence

TABLE 2
Study 2: Breathing Condition and Music Effects on Individual Emotions

	Breathing Condition							
Music	*Nasal*	(*SD*)	*Natural*	(*SD*)	*Oral*	(*SD*)	*Mean*	(*SD*)
Adagio								
Sadness	.54	(.97)	.69	(.95)	.15	(.90)	.46	(.67)
Fear	−.77	(1.0)	.00	(.41)	.00	(.41)	−.26	(.31)
Anger	.23	(.83)	.07	(.28)	.08	(.49)	.13	(.40)
Disgust	−.23	(.44)	−.08	(.49)	.23	(1.0)	−.03	(.29)
Happiness	−.46	(.97)	−.08	(.29)	−.69	(.95)	−.41	(.61)
Silence								
Sadness	.45	(1.4)	−.27	(.90)	.00	(.77)	.06	(.59)
Fear	−.64	(1.0)	.09	(.70)	.45	(1.6)	−.03	(.78)
Anger	.00	(.00)	.18	(.75)	.73	(1.1)	.30	(.55)
Disgust	.18	(.40)	−.18	(.75)	.45	(1.1)	.15	(.40)
Happiness	.36	(1.4)	.55	(1.0)	−.82	(.75)	.03	(.43)
Vogue								
Sadness	.08	(.29)	−.42	(.79)	.25	(.87)	−.03	(.41)
Fear	−.17	(.58)	−.25	(.75)	.08	(1.1)	−.11	(.48)
Anger	.08	(.29)	−.08	(.67)	.08	(.29)	.03	(.36)
Disgust	.17	(.39)	−.17	(.58)	.08	(.29)	.03	(.17)
Happiness	.25	(.62)	.08	(1.5)	−.42	(1.6)	−.03	(.93)
Mean								
Sadness	.36	(.99)	.03	(1.0)	.14	(.83)		
Fear	−.53	(.91)	−.06	(.63)	.17	(1.1)		
Anger	.11	(.52)	.06	(.58)	.28	(.74)		
Disgust	.03	(.45)	−.14	(.59)	.25	(.87)		
Happiness	.03	(1.1)	.17	(1.2)	−.64	(1.2)		

Note: $N = 36$. The scale for each emotion ranges from 0 (Not At All) to 9 (Quite A Lot). Mean changes in reported emotion over the breathing trials are shown here (post-trial minus pre-trial). Breathing Condition is a within-participants variable, with the mean across-condition average displayed in the rightmost column. Music is a between-participants variable, with the mean across people displayed in the bottom row.

subjective state, and therefore liking of the stimuli presented. This was confirmed, as there was a main effect for breathing condition [multivariate $F(2, 30) = 3.29$, $P = .05$]. As expected, follow-up t-tests revealed that liking was higher during nasal breathing than during oral breathing [$t(34) = 2.71$, $P = .01$]; subjects liked the stimuli better when they were allowed to breath through their noses. There was no difference between nasal breathing and natural breathing [$t(33) = 1.0$, $P > .30$]. There was no music × breathing condition interaction [$F(4, 58) = 1.47$, $P > .20$].

VTEE postulates that one reason music can influence affect is by changing breathing patterns. If true, then there should be an effect of music on the volume of air inhaled via the nose. In a 3 (music) × 2

TABLE 3
Study 2: Breathing Condition and Music Effects on Feeling Change

	Breathing Condition							
Music	*Nasal*	(*SD*)	*Natural*	(*SD*)	*Oral*	(*SD*)	*Mean*	(*SD*)
Adagio	− .45	(.82)	− .73	(.65)	− .27	(.65)	− .48	(.48)
Silence	.40	(.70)	.20	(.92)	− .80	(.92)	− .07	(.66)
Vogue	.67	(1.6)	.33	(.71)	.33	(2.1)	.44	(1.3)
Mean	.17	(.91)	− .10	(.88)	− .27	(1.4)		

Note: $N = 30$. The feeling measure is a 10-point scale with higher scores indicating more positive feelings. Here, mean changes across trials (post-trial minus pre-trial) are shown. Breathing Condition is a within-participants variable, with the mean across-condition average displayed in the rightmost column. Music is a between-participants variable, with the mean across participants displayed in the bottom row.

TABLE 4
Study 2: Breathing Condition and Music Effects on Liking of Music

	Breathing Condition							
Music	*Nasal*	(*SD*)	*Natural*	(*SD*)	*Oral*	(*SD*)	*Mean*	(*SD*)
Adagio	5.50	(1.93)	5.17	(2.44)	5.33	(1.78)	5.33	(1.94)
Silence	4.00	(2.00)	4.00	(2.22)	2.83	(1.90)	3.61	(1.82)
Vogue	6.40	(2.72)	5.80	(3.05)	5.90	(2.33)	6.03	(2.48)
Mean	5.24	(2.36)	4.94	(2.59)	4.62	(2.36)		

Note: $N = 34$. Liking was measured on a 10-point scale ranging from 0 (Not At All) to 9 (Quite A Lot). Breathing Condition is a within-participants variable, with the mean of each person's across-condition average displayed in the rightmost column. Music is a between-participants variable, with the mean across participants displayed in the bottom row.

(breathing condition, excluding oral only because there is no nasal volume in that condition) ANOVA, nasal volume was evaluated. These means are displayed in Fig. 4. As predicted, there is a significant main effect of the music [$F(2, 34) = 4.28$, $P < 0.05$]. Follow-up comparisons using the Tukey-B criterion reveal the same pattern for nasal volume as found for liking: the difference between silence (M = 9291.92ml/minute) and *Vogue* (M = 12,162.01ml/minute) is the one that is significant (the mean for *Adagio* was in the middle: M = 10,439.52ml/minute). There was no main effect for breathing condition [$F(1, 34) < 1$], or music × breathing condition interaction [$F(2, 34) < 1$]. No differences in nasal volume were found between natural and nasal breathing.

Finally, VTEE predicts that changes in forehead temperature should follow these differences in breathing and affect. Temperature change over the course of the trails was evaluated in a 3 × 3 ANOVA, as

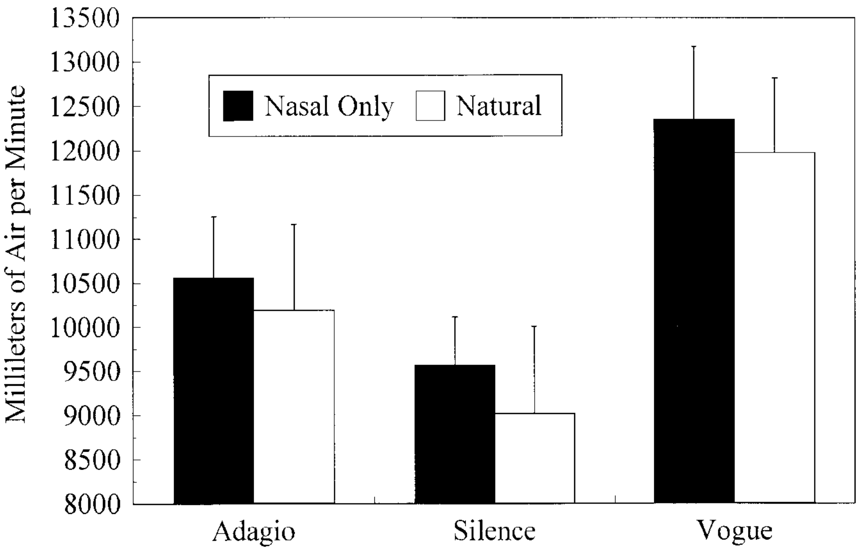

FIG. 4. Study 2: Effects of breathing condition and music on volume of air inhaled through the nose.

earlier. No significant effects were found: music [$F(2, 34) < 1$]; breathing condition [multivariate $F(2, 33) = 1.16$, $P > .30$]; music by breathing [$F(4, 64) < 1$]. The influence of the music and breathing changes in this study do not appear to have been strong enough to generate measurable change in forehead temperature. These findings do not support VTEE.

Discussion

This study tested whether manipulating subjects' breathing patterns while they listened to music would influence affective reactions to that music. Based on VTEE, we predicted that exclusive oral breathing would be associated with more negative affect, because it impairs cooling of the brain. This was confirmed; oral breathing generated negative affect in subjects while they listend to music. This lends support for the mechanism of affect change postulated by VTEE.

In addition, we hypothesised that nasal volume and forehead temperature change should follow the patterns of affect change. This was found to be true for nasal volume, adding to the evidence that nasal volume is related to changes in affect. However, there were no differences found in forehead temperature change. This is not consistent with VTEE. It may be that the changes in temperature generated in this study were not enough to be measured. Alternatively, although it is inconsistent with previous findings, it may be that the changes in affect caused by hindering nasal breathing are unrelated to temperature change. For example, oral-only breathing may dry the mouth and therefore be unpleasant, or exclusive oral breathing may be classically conditioned to the negative mood associated with an upper respiratory infection. The absence of a significant change in temperature in Study 2 suggests that the cooling effect is weak, is due to chance in the previous data, the method of assessing temperature change is not powerful, procedures used in this study masked such change, or some combination of these factors. Further work must continue to evaluate the effects of various breathing patterns on temperature with an eye toward unconfounding various possibilities. For example, indices of brain temperature change other than forehead temperature change would be useful. Study 3 tested again whether changing nasal air volume would influence temperature. It was done outside the plastic bubble; thus heat build-up inside the bubble could not mask changes in forehead temperature.

STUDY 3

If nasal breathing cools the brain, and thus the forehead, then prevention of nasal breathing should result in increases in forehead temperature. This effect should occur without the facial musculature action involving brow movement. To evaluate this hypothesis, subjects' temperatures were measured while they in turn breathed normally, squeezed their nostrils shut to prevent nasal breathing, and squeezed their thumbs to control for the effort of squeezing while breathing normally.

Method

Subjects

Sixteen students received class credit in introductory psychology for participation in this study.

Measures

One temperature probe was attached to subjects' foreheads, midway between the hairline and the brow, directly above the pupil. A second probe was attached to the inside of the subjects' nondominant arms, approximately 5cm below the elbow. A third probe was used to monitor air temperature. Temperature readings were taken at the beginning and at the end of the 1-minute trials. The dependent variables were the change in temperature at each location during each trial.

Procedure

Subjects had spent approximately 30 minutes in the lab prior to this study participating in an unrelated experiment. Temperature probes had been taped to subjects at the beginning of the session as part of a cover story for the earlier study.

Subjects followed instructions from an experimenter in the lab, but hidden behind a screen. Participants engaged in three separate 1-minute trials: they breathed normally, they used their nondominant hand to pinch their nostrils closed to prevent nasal breathing (they were instructed to breath through their mouths), and they squeezed the thumbs of their dominant hand with their nondominant hand. Participants rested for 30 seconds between trials. Participants were randomly assigned to one of the six possible permutations of the order of trials.

Results

A 3 (location of measurement) × 3 (condition) repeated-measures ANOVA was used to evaluate whether changes in nasal breathing influence forehead temperature, and only forehead temperature. If nasal breathing serves to cool the brain, then forehead temperature should increase when the nose is closed. To rule out alternative explanations, such as changes in room temperature or general skin temperature change due to the effort of squeezing, temperature should not increase under any other condition or at any other location. Mean temperature changes are displayed in Fig. 5. The main effect for condition was significant [$F(2, 14) = 5.62$, $P < .01$], and the main effect for location of measurement was marginally significant [$F(2, 14) = 3.04$, $P < .10$]. Importantly, the location × condition interaction was also significant [$F(4, 12) = 3.99$, $P < .05$]. Follow-up tests show that only on the forehead were the differences caused by breathing condition significant [forehead: $F(2, 14) = 14.65$, $P < .001$; arm: $F(2, 14) < 1$; room: $F(2, 14) = 2.06$, $P > .15$]. These findings support the notion that changes in nasal breathing alter forehead temperature.

Discussion

Previous studies demonstrated that facial action influences the volume of air inhaled via the nose and forehead temperature. It was not clear in these studies, however, whether it was the changes in air inhalation or the direct heat from the muscle movement that influenced forehead temperature. By comparing forehead temperature during normal breathing and mouth-only breathing, the present study shows that changes in nasal air volume independent of facial musculature action cause changes in forehead temperature.

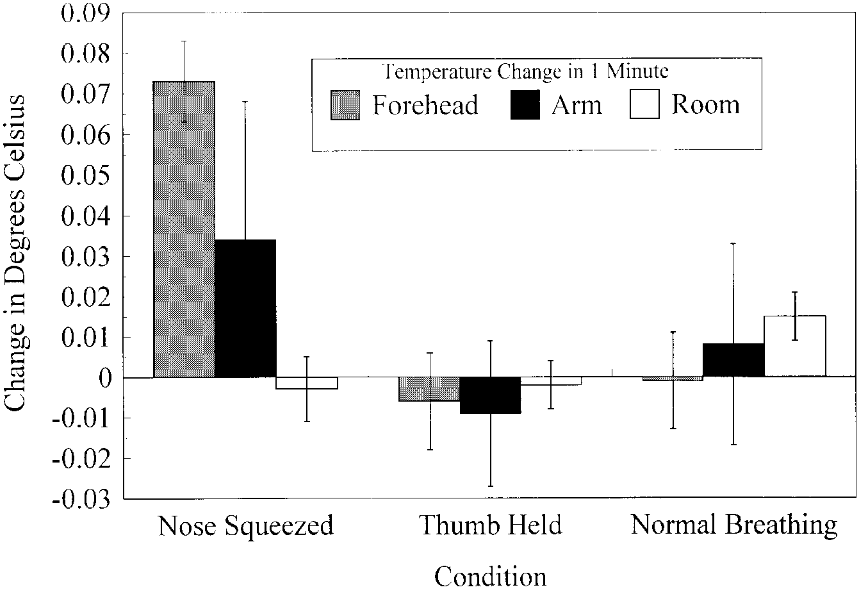

FIG. 5. Study 3: Effects of breathing condition on forehead temperature change.

GENERAL DISCUSSION

The vascular theory of emotional efference (VTEE) makes specific predictions about the relations among facial action, nasal air volume, temperature, and affect. A primary mechanism of brain-cooling discussed by Zajonc (1985; Zajonc & McIntosh, 1992; Zajonc et al., 1989, 1993) is the intake of air via the nose causing cooling of the cavernous sinus. This is held to cool brain temperature, which in turn is associated with affective state. Facial action is postulated to influence nasal breathing.

On the whole, findings were consistent with VTEE's predictions. Study 1 tested the causal role of facial efference on feeling state, temperature, and nasal breathing. Specifically, VTEE predicts that facial movement will influence nasal breathing, which will change brain temperature and influence affect. In this study, we manipulated facial action by having subjects repeatedly vocalise phonemes, the pronouncing of which match positive, neutral, or negative emotional facial patterns. As predicted, uttering a phoneme that resembles a negative expression resulted in less inhalation of air through the nose, higher forehead temperatures, and more negative affect than facial actions matching affectively positive or neutral expressions. One important implication of these data combined with that of Zajonc et al. (1989) is the suggestion that one way affect can be influenced by noncognitive means is via changes in breathing patterns caused by changes in facial movement.

Specifically relevant to these implications is work on the "facial feedback hypothesis" (see e.g. Laird, 1974; Tomkins, 1962)—the idea that facial action can alter subjective emotional experience (see McIntosh, in press, for a review). Much work has demonstrated an association between affect and facial expression, and in recent years, data supporting a causal influence of facial efference on subjective experience (e.g. Strack, Martin, & Stepper, 1988), and physiological change (e.g. Levenson, Ekman, & Friesen, 1990; cf. Zajonc & McIntosh, 1992) have emerged. Similarly, the present Studies 1 and 2 and findings from Zajonc et al. (1989) also show effects on subjective experience, and provide some support for associated temperature change. With support for the feedback hypothesis growing, research is turning toward determining the mechanisms by which facial action causes these changes (Ekman, 1992; McIntosh, in press).

VTEE proposes one mechanism by which facial action can cause changes in affect. Indeed, several findings in the literature that show broad effects on the valence of emotional experience are consistent with VTEE (e.g. Strack et al., 1988). Other studies find emotional changes not predicted by VTEE. For example, neither within-valence subjective effects of facial action (e.g. Duclos et al., 1989) nor asymmetry in brain electrical activity associated with smiles that include orbicularis oculi muscle activation ("Duchenne smiles", e.g. Ekman, 1992, p. 36), but not other smiles, (Ekman, Davidson, & Friesen, 1990) are predicted by VTEE. However, data on the effects of nasal air flow, temperature of air inhaled, and associated forehead temperature are not predicted by alternative theories. Additionally, findings from studies on VTEE suggest that smile-like actions without orbicularis oculi activation (nonDuchenne smiles) have subjective effects; these data are inconsistent with an exclusive interpretation of the theorised mechanisms that predicted differences between Duchenne and nonDuchenne smiles (e.g. Ekman, 1992; Ekman et al., 1990). The most sensible way to reconcile these and other contrasting findings is to assume that there are multiple ways in which facial action can alter emotion-related phenomena (McIntosh, in press). VTEE does not claim to be the exclusive way in which facial action can change affect. There is no reason to assume that facial efference influences emotional state via only one route; in fact, the accumulating data suggest that more than one mechanism is at work. A full understanding of the facial feedback phenomenon requires that multiple mechanisms be explored. It would be helpful for future work to examine directly the relative contributions of the various theorised routes, and the ways in which they may interact in influencing subjective and physiological changes.

To test the causal role of nasal breathing in subjective experience, Study 2 evaluated the effects of blocking nasal breathing on affective reactions to music. As predicted, exclusive oral breathing generated affect more negative than that generated during either natural breathing or exclusive nasal breathing. Unlike in previous studies, however, forehead temperature was not influenced by this manipulation.

Study 3 was done to evaluate specifically the sufficiency of blocking nasal breathing for causing forehead temperature change. It was found that simply blocking nasal breathing increased forehead temperature. This supports the proposed mechanism indicated by VTEE.

In addition to finding the relations postulated by VTEE, these studies failed to find evidence that would be consistent with two alternative explanations for the relations. First, Studies 1 and 3 tested arm temperature along with forehead temperature. There were no effects of facial movement or breathing changes on arm temperature. This rules out the possibility that we found temperature change due to general increases in skin temperature associated with affective change. Note that it does not rule out that skin temperature can change in association with emotional experience, or that there are specific other locations that change along with forehead temperature.

Second, Study 3 evaluated whether temperature change on the forehead can be caused solely by changes in breathing, or if muscle movement is required. Consistent with the predictions of VTEE, forehead temperature increased when nasal breathing is blocked, even when there is no muscle movement. This suggests that there is an effect of nasal breathing on forehead temperature even with no muscle movement. This may not be surprising, as Anbar (1994) notes that skin temperature relates primarily to the blood below the skin's surface.

The lack of evidence for these two alternative explanations for forehead change do not, however, rule out the possibility that forehead temperature is changing for reasons other than those postulated by VTEE. Other possibilities also rely—like VTEE—on changes relating to blood. For example, it may be vasodilation and constriction that alters forehead temperature in these situations, or other changes in local blood flow. Local blood flow may be altered in the service of one or more of the three functions of blood supply: (1) heat transfer; (2) transport of materials such as nutrients, oxygen, hormones, etc.; and (3) maintenance of osmotic pressure and electrolyte composition of the extracellular fluid (Anbar, 1994). If facial movement, introduction of temperature-modified air, and nose-holding alter these needs in the forehead area, then blood flow might well be changed, and temperature altered, as found in Studies 1 and 3 and Zajonc et al. (1989). Thus, there may well be some as-yet unknown reason for these procedures to alter forehead skin temperature; nonetheless, VTEE appears to provide the only single reason for these changes—that is, changes in nasal inhalation alter blood temperature in the brain. It would be helpful in understanding this phenomenon if future work explored a variety of reasons for the forehead skin temperature to change in these situations.

A finding not consistent with VTEE was the lack of forehead-cooling during Study 1. Although the temperature increases under conditions in which VTEE would predict decreases were not significant, that they are consistent, and that no decreases were found, provides no support for VTEE. One possible reason for the lack of temperature decreases is the steady increase in temperature in the respirometer bubble. Future work using this method should measure ambient bubble temperature in order to control for environmental effects. Another possibility is based on the fact that the brain is itself a heat generator. Brain-cooling must always be occurring for the temperature to remain constant. Manipulations that attempt to achieve a decrease in temperature from normal, then, must cause increased cooling, whereas those that seek to increase temperature must simply hinder the cooling that is already present. It is not impossible to achieve this cooling. Decreases in temperature were found by Zajonc et al. (1989), both when subjects were repeating "positive-affect" phonemes and when cool air was introduced into the nose. At least, then, we know that facial movements and breathing changes can change temperature, often causing increases, sometimes causing decreases.

Another concern is that the effects found were not large. However, VTEE does not claim that alterations in breathing and temperature caused by facial action are the sole determinants of affective state. Other factors (e.g. the meaning of the situation to the individual) certainly influence emotional experience. Although we do not know whether affective changes caused by these other processes necessarily alter breathing or temperature, some data indicate that breathing (Study 2) and forehead temperature (McIntosh et al., 1991; see also Zajonc et al., 1993) change in association with emotional stimuli. VTEE does not require, however, that these changes occur for each shift in affect. It is also important to note that VTEE does not claim that the face or breathing must change in order for emotions to change. For example, the process postulated by VTEE suggests that breathing or temperature changes caused by events other than facial action should alter affect (e.g. Study 2 shows that cessation of nasal breathing without facial action changes affect, Study 3 demonstrates that holding one's nose changes temperature, and Study 5 of Zajonc et al., 1989, indicates that breathing temperature-modified air alters forehead temperature and affective experience). In short, VTEE is only one of many parts of the explanation for how facial action can cause emotional responses, and how emotions in general are caused by, and influence, subjective and physiological changes.

Nonetheless, it seems clear that the basic relations postulated by VTEE exist. Results from these and previous studies are mutually supporting of

VTEE, and present a picture that is coherent and consistent with VTEE. Facial action influences breathing, temperature, and affect. Manipulation of breathing causes changes in affect and forehead temperature. It is notable that even minor and short-lived variations in air inhalation (e.g. those caused by speaking vowels, and exclusive oral breathing for 1 minute) resulted in such changes. Although these data combined with the previous work provide evidence supporting the mechanism of affective change specified in VTEE, they cannot prove that mouth breathing and breathing hot air are not merely uncomfortable in the way general aversive stimuli are uncomfortable, and, that breathing cooled air is pleasant in the same way innately pleasurable stimuli are pleasant. However, the continued findings of associations and causal effects predicted by VTEE render the theorised mechanism more plausible. The effects of emotion-related facial movement on breathing, of breathing on forehead temperature (see Zajonc et al., 1993, for further review and discussion of previous data), and the findings of Berridge and Zajonc (1991) that hypothalamic cooling in rats causes the same behaviours as pleasurable electrical stimulation all are nonobvious links that are tied together by VTEE. By further establishing the plausibility of VTEE, it is hoped that the present study will spur more investigation of the phenomenon. Additional work using other measures of brain temperature change, examining the efficacy of breathing on brain-cooling, and evaluating temperature effects on neurochemical activity, for example, is needed to solidify our understanding of this phenomenon. Further, future work should evaluate factors that influence these relations (e.g. individual differences) and explore their implications.

CONCLUSION

There are many factors that influence an individual's affective state. VTEE suggests that one is brain temperature—a variable that can be modified via facial movement and associated changes in nasal breathing. The present studies support this notion by demonstrating the theoretically predicted relations among facial action, nasal breathing, forehead temperature, and affect, and go beyond previous work by demonstrating for the first time that facial action alters breathing in the predicted ways, and providing evidence inconsistent with some alternative explanations. Further exploration of this phenomenon will move us closer to understanding the processes of emotion, and the relation between emotion and physiological changes.

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