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Unilateral Nostril Breathing Influences Lateralized Cognitive Performance

RICHARD A. BLOCK, DAVID P. ARNOTT, BARBARA QUIGLEY, AND WESLEY C. LYNCH

Montana State University

Relative nostril efficiency (nasal cycle) is related to hemispheric EEG differences and performance on cognitive tasks. We investigated how unilateral forced nostril breathing influences spatial and verbal performance. Right-handed males and females performed both tasks under either left-nostril, right-nostril, or free-breathing conditions. Unilateral breathing affects performance differently in males and females. It influences male performance ipsilaterally on both tasks: Their spatial performance is better during right-nostril breathing, and their verbal performance is better during left-nostril breathing. Unilateral breathing influences female performance contralaterally, but only on the spatial task: Their spatial performance is better during left-nostril breathing. These differences within and between sexes may exist because unilateral nostril breathing differentially activates the two hemispheres and thereby facilitates performance, or because attempts of the brain to control the nasal cycle unilaterally interfere with performance. © 1989 Academic Press, Inc.

There are various physiological, behavioral, and cognitive rhythms with a period of approximately 90–100 min, varying from about 80 min to about 120 min. Some cognitive variables that show this kind of ultradian rhythm are visual detection errors, fantasy production, response latency, and spatial and verbal performance (see Kripke, 1974, 1982; and Rossi, 1986, for reviews). Kripke and Sonnenschein (1978), for example, reported an approximately 90-min daydreaming cycle. Klein and Armitage (1979) found that performance on both spatial and verbal tasks followed approximately 96-min cycles and that when performance on one kind of task was best, performance on the other kind of task was worst. Their findings suggest that there are "oscillations in the relative activation or efficiency of the two cerebral hemispheres, which are specialized for the

Correspondence and reprint requests should be sent to Richard A. Block, Department of Psychology, Montana State University, Bozeman, MT 59717. We thank Ray Klein, Larry Fisher, and an anonymous reviewer for helpful comments on the manuscript.

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performance of verbal and spatial tasks" (Klein & Armitage, 1979, p. 1327).

Although sleep research reveals ultradian rhythms most extensively and clearly (see Bakan, 1978–1979), ultradian rhythms of hemispheric activation also occur while a person is awake. For example, there are 70- to 110-min cycles in EEG delta (Kripke, 1972) and alpha (Kripke & Sonnenschein, 1978) activity.

Several studies have investigated ultradian rhythms in relative nostril efficiency (henceforth called the *nasal cycle*) and effects of unilateral forced nostril breathing (see Rossi, 1986, for a review). Kayser first discovered a nasal cycle in 1895. Heetderks (1927) reported that the nasal cycle ranges between 25 min and 4 hr, and that it averages about 2.5 hr. The autonomic nervous system probably regulates the cycle (Keuning, 1968; Stoksted,1952, 1953). In this account, increased parasympathetic activation of a nostril causes the mucous membranes of that nostril to become engorged with blood. As a result, airflow decreases in it, and the other nostril becomes more open. Although several additional studies have also explored the physiological regulation of the nasal cycle (see Rossi, 1986), the specific brain areas that regulate it, as well as the specific areas that are influenced by it, remain somewhat elusive. Eccles and Lee (1981), however, found that stimulating the hypothalmus or mesencephalon in cats causes nasal vasoconstriction—hence, more free airflow—which is greater on the ipsilateral side than on the contralateral side.

Recent research on the nasal cycle supports three general conclusions: (1) Changes in hemispheric EEG differences are correlated with the nasal cycle; (2) Relative performance on spatial and verbal tasks is related to nostril dominance in free-breathing subjects; and (3) At least theoretically, unilateral forced nostril breathing may differentially affect the ipsilateral and contralateral cerebral hemispheres, thereby changing relative EEG activity and influencing relative spatial and verbal performance. Consider, now, the evidence supporting these three conclusions.

Werntz, Bickford, Bloom, and Shannahoff-Khalsa (1983) reported that when there is predominant air intake through either nostril, there is greater integrated EEG amplitude over the contralateral hemisphere; and when the predominant air intake subsequently shifts to the other nostril, there is a corresponding shift in integrated EEG amplitude. The results of a subsequent experiment by Werntz, Bickford, and Shannahoff-Khalsa (1987) revealed that alteration of the nasal cycle by unilateral nostril breathing can produce changes in the relative hemispheric distribution of EEG activity, such that the hemisphere contralateral to the previously congested (and now dominant) nostril shows relatively greater integrated EEG amplitude.

Klein, Pilon, Prosser, and Shannahoff-Khalsa (1986) recently reported that there is a slight, but significant, correlation between the dominant nostril and the relative cognitive performance of free-breathing subjects. According to Klein et al., "the direction of this significant relationship is consistent with the claim that right nostril dominance is associated with better verbal performance and left nostril dominance is associated with better spatial performance" (p. 133). A more detailed analysis of their findings reveals that spatial performance was slightly better when the left nostril was dominant than when the right nostril was dominant. However, the correlation between free-breathing nostril dominance and verbal performance was not significant. In addition, they found no effect of unilateral forced nostril breathing on either spatial or verbal performance.

The present study investigates whether unilateral forced nostril breathing influences spatial and verbal performance.[1] Although Klein et al. (1986) reported no significant influence, the findings of Werntz et al. (1983, 1987) and Klein et al. leave open the possibilities that left-nostril breathing enhances spatial performance and that right-nostril breathing enhances verbal performance. We also used a free-breathing control condition in order to ascertain whether unilateral nostril breathing might facilitate or impair performance of either task.

Previous studies of the nasal cycle and unilateral nostril breathing have not reported any sex differences, so we did not expect to find any. However, a number of researchers conclude that the typical male brain is more highly lateralized in function than is the typical female brain (for recent reviews, see Halpern, 1986; Springer & Deutsch, 1985). For example, Lansdell (1962) and McGlone (1978) compared spatial and verbal performance following unilateral brain damage, and both concluded that these abilities are more highly lateralized in males (who showed relatively greater left-hemisphere language deficits) than they are in females. Although a few other findings are somewhat equivocal and the issue remains unresolved, these findings suggest that unilateral nostril breathing might influence the performance of males to a greater extent than that of females. As a measure of the potential sensitivity of our particular spatial and verbal tasks to possible influences of unilateral nostril breathing, the present study also attempts to replicate the typical findings that males tend to perform slightly better on spatial tasks than do females, and that females perform slightly better on verbal tasks (for a meta-analytic review, see Hyde, 1981).

[1] After we had completed this study, Rossi's (1986) review chapter was published. In it, one of his questions for future research is: "Will the selective activation of the cerebral hemispheres by forced uninostril breathing have measurable effects on the types of . . . cognition associated with each cerebral hemisphere?" (p. 124). This is exactly the focus of our study, and Klein et al.'s (1986) recent study also investigated it.

METHOD

Subjects and design. Introductory psychology students composed an initial pool of potential participants. The actual participants were 30 male and 30 female right-handed students who volunteered in exchange for course credit.

The design was a 2 × 2 × 2 factorial, with two between-subjects variables (nostril condition and sex) and one within-subjects variable (task). We randomly assigned 10 males and 10 females to a left-nostril (open) condition and the same numbers to a right-nostril (open) condition. Another 10 participants of each sex served in an offset satellite control condition with no restrictions on breathing. The order of task administration (i.e., whether the spatial or the verbal task was performed first) was block randomized, as was the order of conditions across groups of subjects.

Materials. The spatial task was Vandenberg and Kuse's (1978) paper-and-pencil adaptation of Shepard and Metzler's (1971) mental-rotation task. Each item requires subjects to compare a three-dimensional block design with four highly similar structures. Two of the four structures have the same geometric configuration as the original but are rotated in space, sometimes as much as 180°. The task is to identify these two structures. Performance on this task mainly involves abilities linked more closely with the right hemisphere than with the left. This spatial task contains 20 items, each with two correct answers.

The verbal task was a consonant–vowel matching task designed for this experiment. On each item, subjects see a 5- or 6-letter word and 4 alternative words with the same number of letters. The task is to identify the alternative with the same vowel–consonant sequence as the given word. (For example, given the word PICNIC and the alternatives GOVERN, HINDER, MOSTLY, and SOLACE, the correct answer is HINDER.) Performance on this task mainly involves abilities linked more closely with the left hemisphere than with the right—both verbal (letter recognition, consonant and vowel distinction) and linear sequencing. This verbal task contains 20 items, each with one correct answer.

Procedure. Participants served in mixed-sex groups of about four to six subjects, all in the same experimental (or control) condition. When they arrived, the experimenter seated them in a waiting room and asked them to fill out a participation form. The experimenter watched each subject's handwriting to ensure that all subjects were right-handed. The experimenter dismissed any left-handed writer.

Then the experimenter seated subjects in the experimental room and gave them instructions. Subjects in the two unilateral nostril conditions were asked to block one nostril with cotton, to hold their left index finger over the plugged nostril, and to breathe only through the other nostril. The experimenter gave subjects tissues to clear their nostrils and told them to insert the cotton plug in either their left or their right nostril (depending on the condition). Subjects were told to close their eyes, to relax, and to try not to breathe through the mouth during this 5-min period. They were encouraged to clear their unplugged nostril with tissue as often as they felt necessary.

Free-breathing (control) subjects received modified instructions which did not mention breathing. Instead, they sat quietly for 5 min with their eyes closed.

At the end of 5 min, the experimenter asked experimental subjects to continue to hold the left index finger over the plugged nostril and to breathe only through their unplugged nostril while they performed two cognitive tasks. All subjects had 2 min to read the instructions and sample items for each task and 2.5 min to work on each task.

RESULTS

We first calculated each subject's total number of correct answers on each task. On the spatial task, there are two correct answers per item, and we awarded one point for each of them. The verbal task has only one correct answer per item. No subject completed the spatial task, and only one subject completed the verbal task; so each subject's score on a task primarily reflects the rate at which he or she performed the task.

We tested these multivariate data for assumptions of normality, linearity, and muticollinearity. The assumptions were satisfied following the deletion of a single multivariate outlier. We then performed a 2 × 2 × 2 multivariate analysis of variance on the data from the two experimental (nostril) conditions, excluding the control (free-breathing) condition.

We also repeated all analyses using a Z-score measure like the one used by Klein et al. (1986). Specifically, we obtained a Z score for each subject separately for each task. We subtracted the overall mean score on that task from the subject's score, then divided by the standard deviation. These analyses change none of our conclusions, because all significant Fs and ts in the raw-score analyses remain significant, and all nonsignificant Fs and ts in the raw-score analyses remain nonsignificant.[2] In what follows, we report the statistics on the raw scores.

Table 1 shows the overall spatial and verbal performance of males and females, collapsed across the two nostril conditions and expressed both in terms of mean raw-scores and mean Z-scores. Table 2 shows the mean spatial and verbal performance of males and females in the two nostril conditions as well as in the free-breathing control condition, expressed both in terms of mean raw-scores and mean Z-scores.

The data shown in Table 1 reveal a substantial multivariate effect of sex, $F(2, 53) = 15.5$, $p < .001$. Meta-analyses of sex differences in cognitive performance commonly use d as a measure of effect size—that is, the difference between the two means divided by the average of the two standard deviations. Using this measure, males scored nearly a standard deviation higher than females on our spatial task ($d = .91$); and females scored more than a standard deviation higher than males

TABLE 1
MEAN RAW SCORE AND Z SCORE IN EXPERIMENTAL CONDITIONS[a]

	Raw score		Z score	
Sex	Spatial(S)	Verbal(V)	Z(S)	Z(V)
Male	10.2 ± 2.7	10.9 ± 3.0	.42	−.55
Female	7.8 ± 2.5	15.1 ± 3.4	−.42	.55

[a] These data are collapsed across subjects in the two nostril conditions. The total possible score is 40 on the spatial task and 20 on the verbal task. Each raw-score mean is shown with its *SE*.

[2] The only exception is the theoretically meaningless multivariate effect of task, $F(1, 36) = 43.8$, $p < .001$, which is statistically removed when we standardize performance on each task.

TABLE 2
MEAN RAW SCORE AND Z SCORE IN EACH CONDITION[a]

Condition	Raw score: Spatial(S)	Raw score: Verbal(V)	Z score: Z(S)	Z score: Z(V)
Male				
Left nostril	8.9 ± 2.8	12.6 ± 2.6	−.05	−.29
Right nostril	11.4 ± 2.0	9.3 ± 2.4	.83	−1.24
Free breathing	10.6 ± 3.1	14.6 ± 2.6	.55	.28
Female				
Left nostril	8.9 ± 2.6	14.9 ± 3.9	−.05	.37
Right nostril	6.7 ± 1.8	15.0 ± 2.6	−.82	.40
Free breathing	7.7 ± 2.4	15.3 ± 3.1	−.47	.48

[a] The total possible score is 40 on the spatial task and 20 on the verbal task. Each raw-score mean is shown with its *SE*.

on our verbal task (d = 1.30).[3] Both absolutely and comparatively, these effects are large: Cohen (1977) considers a value of .80 to be large, and Hyde's (1981) meta-analysis found median effect sizes (ds) in the literature of about .43 for spatial performance and .24 for verbal performance. Others (e.g., Sanders, Cohen, & Soares, 1986) have also concluded that the spatial task we used produces a relatively clear and consistent sex difference in which males score about a standard deviation higher than females.

On the basis of the findings of Werntz et al. (1983, 1987), the primary hypothesis of interest predicts an interaction between nostril condition and task performance—that is, that spatial performance would be relatively better in the left-nostril condition and verbal performance would be relatively better in the right-nostril condition. The observed interaction of nostril condition and task is in the opposite direction from that predicted, but it is not significantly so, $F(1, 36) = 2.12$. The main effect of nostril condition is also not significant, $F(1, 36) = 1.53$.

A 2 × 3 × 2 (Sex × Nostril Condition × Task) multivariate analysis reveals that males and females reacted to the experimental conditions in opposite ways, $F(1, 36) = 11.4$, $p < .002$. These data are shown in Table 2. Apparently combining the scores of males and females eliminated the interaction of nostril condition and task.

We then made a planned comparison involving the four experimental conditions in order to test the main hypothesis of interest, and we made it separately for males and for females. We also did four planned t tests, one for each combination of task and sex, specifically to determine

[3] As Table 1 shows, the mean sex differences in our Z-score analyses are only slightly discrepant from these estimates—.84 for the spatial task and 1.10 on the verbal task.

whether unilateral nostril breathing condition influenced performance. The comparison involving males is significant, $t(36) = 3.42$, $p < .002$. As shown in the upper half of Table 2, male spatial scores are higher in the right-nostril than in the left-nostril condition, $t(16) = 2.31$, $p < .05$, and their verbal scores are higher in the left-nostril than in the right-nostril condition, $t(16) = 2.92$, $p < .01$. The comparison involving females reveals only a marginal effect, $t(36) = 1.35$, $p < .20$. As shown in the lower half of Table 2, female spatial scores are higher in the left-nostril than in the right-nostril condition, $t(16) = 2.19$, $p < .05$, but their verbal scores do not differ between the two conditions, $t(16) = .07$.

Finally, for both sexes spatial performance in the free-breathing control condition fell between that on the two nostril conditions, and verbal performance in the free-breathing condition was roughly equivalent to that in the better nostril condition.

DISCUSSION

Our findings reveal that unilateral forced nostril breathing influences spatial and verbal performance differently in males and females. Males perform better on a spatial task during right-nostril breathing than they do during left-nostril breathing, and they perform better on a verbal task during left-nostril breathing than they do during right-nostril breathing. Females show nearly the opposite: They perform better on a spatial task during left-nostril breathing than they do during right-nostril breathing, but unilateral breathing does not influence their verbal performance. If we assume that spatial processing is closely linked to relative right-hemisphere activation and that verbal processing is closely linked to relative left-hemisphere activation, our findings suggest that unilateral nostril breathing influences hemispheric dominance ipsilaterally in males. Unilateral breathing apparently influences spatial, but not verbal, processing in females, and it does so in a contralateral manner.

On the basis of the conclusions of Werntz et al. (1983, 1987) and Klein et al. (1986), we did not predict these effects. We predicted that performance of all subjects on the spatial task would be better in the left-nostril condition than in the right-nostril condition, and vice versa for verbal performance (i.e., contralateral effects). This is clearly not the case.

There are several possible reasons why Werntz et al.'s (1983, 1987) reported contralateral effects are problematic. First, olfaction is unique among sensory systems for several reasons. One reason is that its primary afferent cortical connections are ipsilateral, although there is a minor pathway from one olfactory bulb to the other via the anterior commissure (Carpenter, 1978).

Second, when Werntz et al. measured integrated EEG amplitude, high-voltage alpha (and theta) activity probably contributed more heavily than low-voltage beta activity. They made the unusual assumption that greater integrated EEG amplitude over a particular hemisphere indicates that it is dominant at the time. The traditional interpretation of EEG data is that fast, low-voltage beta activity reflects increased cortical activation and that slow, high-voltage alpha (and theta) activity reflects decreased cortical activation (e.g., Donchin, Kutas, & McCarthy, 1977). Werntz et al.'s (1987) data forced them to question this, although they were able to cite data of Ray and Cole (1985) to bolster their unorthodox interpretation of EEG data.

Third, in their earlier study (Werntz et al., 1983), 14 of the 19 subjects were male, 2 of the females were left-handed, and 2 of the 3 right-handed females yielded some of their least significant data. In their later study (Werntz et al., 1987), out of 5 subjects, "the only subject in which the shifts in EEG asymmetry were . . . strikingly visible in the primary [EEG] recording" was a left-handed female.

Our findings are also somewhat surprising in the light of Klein et al.'s (1986) report that free-breathing subjects show a slight correlation between nostril dominance and cognitive performance and that unilateral nostril breathing apparently does not influence cognitive performance. Their findings suggest that free-breathing nostril dominance is correlated with contralateral hemispheric activation (or simply with individual differences in cognitive performance, as Klein et al. note), but that unilateral forced nostril breathing does not influence either hemispheric activation or cognitive performance. However, Klein et al. did not report their data separately for males and females. Had we not analyzed our data separately for the two sexes, we too would have reported no significant effect of unilateral nostril breathing.

Our findings reveal clearly that males and females perform differently on the two types of cognitive tasks. On the spatial task, males perform substantially better than do females; whereas on the verbal task, females perform substantially better than do males. This replication of other research both serves as a manipulation check and validates the potential sensitivity of the spatial and verbal tasks we used. On the basis of the relatively large size of the effects obtained, the tasks we used may be more sensitive measures of relative cerebral hemispheric activation than other kinds of tasks.

Assuming that our tasks yield sensitive measures of relative hemispheric activation, it is not clear what processes may influence the kind of sex differences we obtained. There are at least two possibilities. Unilateral nostril breathing may selectively activate the ipsilateral hemisphere, or the contralateral hemisphere may become more active as the brain attempts to regulate the nasal cycle. Thus, stimulation from the open nostril may have ipsilaterally facilitated cognitive performance of our male subjects, at least. Alternatively, the attempted regulation of the nasal cycle by the contralateral hemisphere may have interfered with performance on a

cognitive task controlled primarily by that hemisphere. Our finding of an interaction of sex and cognitive task suggests that there is a sex difference in one or both of these hypothetical processes—facilitation from ipsilateral hemispheric stimulation or interference from contralateral control of the nasal cycle. Although there is no apparent explanation for this kind of sex difference, there is also no widely accepted explanation for the reliable sex differences in cognitive performance. Our findings suggest that it may be fruitful to look for sex differences in cerebral processes involved in nasal input or regulation of the nasal cycle, as well as in cognitive performance.

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