Influence of Body Tilt Within the Sagittal Plane on Odor Identification Performance

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Odor identification performance, nasal airflow resistance, blood pressure, and heart rate were assessed in 8 men and 8 women in the following body tilt positions within the sagittal plane: 0° (upright), 90° (supine), 135°, and 180° (upside down). The order of testing across the tilt conditions was systematically counterbalanced using a Latin square procedure. Average odor identification performance decreased monotonically as a function of increased body tilt. Significant decreases in heart rate and blood pressure were observed as the body was tilted from the upright condition, although blood pressure was equivalent in the upright and upside down conditions. Nasal resistance was highly variable and was not systematically altered as a function of body tilt. These data support the hypothesis that olfactory function, like visual, auditory, and vestibular function, is significantly influenced by body position within a gravitational field.

The purpose of the present study was to determine if tilting the body within the 180° sagittal arc, extending from the upright position to the upside-down position, significantly alters olfactory function and, if so, whether such changes are related to alterations in nasal airflow resistance, blood pressure, and heart rate.

MATERIALS AND METHODS

Subjects: Eight men and eight women with mean ages (S.D.) of 24.0 (5.2) for men and 23.4 (4.3) for women served as subjects. None had a history of serious medical problems, and all were in good health at the time of testing. Most of the subjects were college students at the University of Pennsylvania and were paid $12 for their participation.

Procedures: The blood pressure, heart rate, olfactory function, and nasal resistance of each subject was tested in the following positions within the sagittal plane: 0° (upright), 90° (supine), 135°, and 180° (upside down). A hydraulic bed developed for myelography by the Department of Radiology in the University of Pennsylvania was used to rotate the subjects to these positions. Each participant was secured to the bed by waist, hip, and thigh straps. The head was maintained in the same plane as the body with the aid of a small pillow positioned behind the cervical vertebrae. Canvas shoes and anklets attached to the bottom of the bed bore the subjects’ weight in the upside-down position. The order of testing among the body tilt positions was counterbalanced us-

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THE SENSE OF SMELL largely determines the flavor and palatability of foods and beverages, and serves, along with intranasal afferents from the trigeminal nerve, as an early warning system for environmental toxins, including spoiled food, leaking natural gas, polluted air, and smoke (12). Despite these important functions, this major sensory system is only now receiving widespread scientific attention, largely as a result of its primary role in chemical communication in nonhuman forms.

To date, no scientific studies of the influences of body position on olfactory function have been made, despite a) the potential role of smell in the detection of dangerous fumes or burning electrical equipment in aircraft and space vehicles; b) reports that astronauts experience head-fullness, nasal congestion, and altered perception of food flavor in weightlessness (13); and c) evidence that tilting the body within the sagittal plane influences visual (15), auditory (8,17,19), and vestibular perception (5,20,22,27).

The purpose of the present study was to determine if tilting the body within the 180° sagittal arc, extending from the upright position to the upside-down position, significantly alters olfactory function and, if so, whether such changes are related to alterations in nasal airflow resistance, blood pressure, and heart rate.
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ing four 4 x 4 Latin squares (28). Each subject was allowed to adapt to the new position for 3-5 min before measurements were taken. Within a test position, the order of measurements was: blood pressure and pulse rate (first determination), nasal resistance (left and right, order counterbalanced), olfactory function, and blood pressure and pulse rate (second determination).

Systolic and diastolic blood pressure and heart rate were measured in the right upper arm alongside the chest at the heart level using an automated sphygmomanometer (Taylor A-200 Blood Pressure Monitor). Nasal resistance was assessed by anterior rhinomanometry. A Scott full-face mask with a screen pneumotachometer mounted on its airflow port was used to monitor the nasal airflow in one naris. Nasal pressure was measured simultaneously in the contralateral naris by a pressure transducer connected to a 1.4-mm-ID polyethylene tube which extended into the naris through air tight tape (18). The pressure and flow measurements were made separately for each naris for a minimum of four complete inhalation and exhalation cycles. The signals from the pressure and flow transducers were digitized (Interactive Structures AL 13 interface) and collected, stored, and analyzed on a microcomputer using a procedure analagous to that described by Pallanch et al. (21).

Overall nasal resistance was computed from the data collected from each of the two nares using the formula

\[
TNR = \frac{(LNR \cdot RNR)}{(LNR + RNR)},
\]

where TNR = total nasal resistance, LNR = left nasal resistance, and RNR = right nasal resistance. Following calculation of the total nasal resistance values, an exponential function was fit to the average pressure/flow values. The polar coordinate method of Broms, Jonson and Lamm (3) was used to establish resistance values at a radius corresponding to an inhalation 0.04 L \cdot s^{-1} flow and 0.4 cm of H_2O pressure, providing a common comparison point across subjects. The intersection of the pressure and flow values of the curves with this radius was determined by a successive approximation algorithm. This radius was chosen because it was the largest radius reached by the majority of subjects and provided measures strongly correlated (rs > 0.98) with higher radii reached by a smaller proportion of the subjects (e.g., 2 L \cdot s^{-1} flow and 20 cm H_2O pressure).

Olfactory function was measured in each body position by administering one of the four 10-item booklets of the University of Pennsylvania Smell Identification Test (UPSIT), a forced-choice test of high reliability and validity (11,12). The stimuli of this “scratch and sniff” test are imbedded in 10- to 50-µm microcapsules fixed on brown strips at the bottom of each booklet page. Above each odorant strip is a multiple-choice question with four alternative responses for each item. For example one of the items reads: “This odor smells most like: (a) chocolate; (b) banana; (c) onion; or (d) fruit punch.” With the aid of the experimenter (who released and held the odorants under the subject’s nose and read the response alternatives to the subject), each subject completed a different booklet of this microencapsulated odor test in each of the four body conditions, with the order of the booklet presentations systematically counterbalanced across subjects.

RESULTS

To assess whether body tilt was associated with changes in smell function, we compared the average odor identification scores (i.e., the number of correct responses out of 10 odorant items) of men and women among the four tilt conditions using a gender-by-tilt condition analysis of variance (ANOVA) with replications on the last factor (26). A significant tilt condition effect was present (\(F = 6.62, df = 3/42, p < 0.001\)). On the average, the odor identification scores decreased as a function of degree of tilt (Fig. 1). Although the women tended to perform slightly better than the men on this identification task, this effect was not statistically significant (\(F = 1.47, df = 1/14, p > 0.20\)). The gender-by-tilt condition interaction was also not significant (\(F = 0.80, df = 3/42, p > 0.20\)).

Orthogonal comparisons among the means of the tilt conditions with the Bonferroni correction for inflated alpha revealed a significant difference between the smell identification scores of the 0° tilt group and that of

Fig. 1. Mean (±1 S.E.M.) values for dependent measures of this study at four body tilt conditions.
the 180° tilt group (p < 0.025). None of the other comparisons were significant at the 0.05 protection level.

To examine the influences of body position on nasal resistance, total nasal resistance values were similarly subjected to a gender-by-tilt condition ANOVA following log10 transformation (nasal resistance data are log-normally distributed; 21). Since three subjects evidenced infinite resistance (i.e., no measurable airflow in one naris accompanied by clear pressure changes in the other naris) under the 180° tilt condition, one subject under the 135° tilt condition, and one subject under the 90° tilt condition, we conservatively assigned the maximum measured resistance for the appropriate sex to these points. Data from one subject were not included in the analysis because of equipment failure. Unlike smell function (Fig. 1) no significant influence of the degree of body tilt was observed (F = 0.08, df = 3/39, p = 0.735), although some individuals reported subjective feelings of heightened nasal resistance in the upside-down position and considerable individual variability of the nasal resistance measures was present. The main effect of gender approached the 0.05 level of statistical significance with women evidencing higher average resistance values than men (F = 3.77, df = 1/13, p = 0.074). The gender-by-tilt condition interaction was not significant (F = 0.426, df = 3/39, p = 0.735).

Since blood pressure and heart rate were measured twice within each body tilt condition, these measures were subjected to separate gender-by-tilt condition-by-test order (1st vs 2nd) ANOVAs with replications on the last two factors. Diastolic blood pressure, systolic blood pressure, and heart rate (Fig. 1) were all significantly influenced by body tilt position (respective F values = 22.72, 17.12, and 19.41, df's = 3/42, p's < 0.001). None of the other main effects or interactions were significant for either the heart rate or systolic blood pressure measures (all p's > 0.10). However, diastolic blood pressure (Table I) increased significantly from the time of the first to that of the second within-condition measurement (test order F = 5.93, df = 1/14, p < 0.03), an effect that reflected mainly a change within the 180° tilt condition (test order-by-body tilt interaction F = 4.44, df = 3/42, p = 0.009; Table I).

Orthogonal paired comparisons revealed that heart rate (Fig. 1) was significantly lower within the 90°, 135°, and 180° conditions than within the 0° condition (p's < 0.001), and that both systolic and diastolic blood pressure (Fig. 1) were significantly lower under the 90° and 135° conditions than under the 0° condition (p's < 0.001).

To ascertain whether relationships were present among the dependent measures within each of the tilt conditions, we computed Pearson correlations among them. As shown in Table II, few significant relations appeared. Aside from expected correlations among several cardiovascular measures, only one interesting finding emerged; namely, a −0.54 correlation between nasal resistance and odor identification within the 180° tilt condition. This correlation suggests that, in the upside-down position, olfactory sensitivity may be inversely related to nasal resistance.

**DISCUSSION**

The present data support the notion that odor identification ability is significantly altered by body position within the sagittal plane. Since measures of odor identification correlate highly with measures of olfactory sensitivity (11), it is likely that olfactory sensitivity per se is also influenced by body position. Unfortunately, olfactory sensitivity tests (e.g., threshold tests) require considerable time to administer and most persons who are not pilots or athletes find it discomforting to be kept in an inverted position for more than a few minutes. Therefore, we limited the current investigation to olfactory measures that could be completed within a short time.

Head-down tilt has been used to simulate the headward fluid shift and engorgement of the central circulatory system seen in the period immediately after entry into space (2,25). This model may be particularly valid in the acute phase of cardiovascular adaptation to weightlessness. In this period of space flight, the significant decrease in heart rate observed in the 90°, 135°, and 180° conditions relative to the 0° position likely reflects the phenomena of compensatory bradycardia, which has been demonstrated in other post-tilt studies (2,25). Blomqvist et al. found this reflex-induced phenomenon only in young men, while middle-aged men responded with vasodilatation (2).

The present research demonstrates that a primary sensory system whose stimulus is chemical in nature is influenced by gravitational factors in man. However, the physiologic basis of this phenomenon is unknown. Several hypotheses can be suggested. First, although we found no evidence that these changes were related to measurements of nasal resistance, it is possible that anterior rhinomanometry is not sensitive to subtle airflow alterations in the higher recesses of the nose (e.g., above the superior turbinate). Thus, alterations in re-
Heart rate and blood pressure data were collapsed over first and second determinations. Abbreviations: SIT = Smell Identification Test; NR = nasal resistance; HR = heart rate; DBP = diastolic blood pressure; SBP = systolic blood pressure; *p < 0.05; **p < 0.001.

Table II. Pearson correlation coefficients among dependent measures of the study under each body tilt condition.

<table>
<thead>
<tr>
<th></th>
<th>0° Tilt Condition</th>
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<th>90° Tilt Condition</th>
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<th>135° Tilt Condition</th>
<th></th>
<th>180° Tilt Condition</th>
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<tbody>
<tr>
<td>SIT</td>
<td>NR</td>
<td>DBP</td>
<td>SBP</td>
<td>NR</td>
<td>DBP</td>
<td>SBP</td>
<td>NR</td>
<td>DBP</td>
</tr>
<tr>
<td>0.46</td>
<td>-0.28</td>
<td>-0.03</td>
<td>—</td>
<td>0.22</td>
<td>0.07</td>
<td>0.15</td>
<td>0.02</td>
<td>-0.10</td>
</tr>
<tr>
<td>NR</td>
<td>-0.52*</td>
<td>-0.23</td>
<td>-0.35</td>
<td>0.74</td>
<td>-0.35</td>
<td>-0.26</td>
<td>0.49*</td>
<td>0.49**</td>
</tr>
<tr>
<td>HR</td>
<td>-0.05</td>
<td>-0.35</td>
<td>0.48</td>
<td>0.07</td>
<td>-0.35</td>
<td>-0.26</td>
<td>0.22</td>
<td>0.13</td>
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<tr>
<td>DBP</td>
<td>—</td>
<td>SBP</td>
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Regional nasal resistance cannot be ruled out as a potential basis for the observed changes. Second, it is conceivable that olfactory processing is altered by reflexes from kinesthetic and vestibular afferents, as may occur in vision (9) and audition (17). Such influence would not be unprecedented in the olfactory modality, in that both psychophysical and electrophysiological indices of olfactory function have been shown to be influenced by trigeminal stimulation (4, 23, 24). Third, it is possible that undue stress to the cephalic circulation (1, 2, 6, 14, 16, 25) as a result of the shift of blood from the lower part of the body to the upper may somehow alter the olfactory function. Finally, it is conceivable that at least some proportion of the effect demonstrated in the present study may reflect alterations in the ability to attend to odors. It is possible, for example, that persons in an uncomfortable inverted situation pay less attention to the task at hand and are more distracted by extraneous stimuli.

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REFERENCES