# Respiratory and Pulse Changes Due to Vestibular Stimulations in a Motion-Based Simulator

Savas Ilbasmis; Safak Yildiz

**INTRODUCTION:** One of the mechanisms leading to spatial disorientation (SD) is overstimulation of the vestibular system by various aircraft maneuvers. The objective of this study was to observe respiratory rate and pulse changes during vestibular system stimulations with the help of two selected SD training profiles.

**METHODS:** The respiration and pulse rates of 15 subjects were recorded in response to 2 sequential SD training profiles on a motion-based simulator. The session started with a motionless instruction period (IP), continued with a Coriolis profile (CP) which stimulated the semicircular canals, and ended with a Dark Takeoff profile (DP) which stimulated the otolith organs. Recorded parameter means during profiles were statistically compared with IP mean values.

**RESULTS:** The average age of all subjects was 23.67 $\pm$ 1.11. Mean CP respiratory rate (23.43 $\pm$ 3.21) was higher than mean IP respiratory rate (21.39 $\pm$ 4.27) and mean DP pulse rate (79.88 $\pm$ 10.39) was lower than mean IP pulse rate (84.76 $\pm$ 14.26) of the subjects. These differences were statistically significant.

**DISCUSSION:** Data indicate that stimulation of the semicircular canals increased respiration rate while stimulation of the otoliths caused a reduction in pulse rate. This was considered to be a result of vestibulorespiratory reflex. Inputs from the vestibular otolith organs contribute to the control of blood pressure during movement and changes in posture. Predicting pulse and respiratory changes due to aerial maneuvers may be important for pilot safety during flight.

**KEYWORDS:** disorientation, otolith, semicircular, somatogyral, somatogravic.

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Spatial disorientation (SD) is a term in aviation that expresses misperception by pilots of an aircraft's position with regard to the surface of the Earth. In this condition, pilot's perception of direction does not agree with reality. This results from incorrect signals from the vestibular system during flight in poor weather conditions with low or no visibility.[2] Statistics show SD in military aviation contributed to at least 25–33% of all aircraft mishaps and resulted in the highest number of fatalities.[4] Because the human senses are adapted for use on the ground, navigating by sensory input alone during flight can be dangerous: sensory input does not always accurately reflect the movement of the aircraft, causing vestibular and visual sensory illusions.[2]

Two of the vestibular illusions are considered important in aviation because they are related to many kinds of misperceptions. First, somatogravic illusions are created by inertial forces that arise from acceleration or deceleration of the aircraft. The net gravitoinertial force sensed primarily by the otolith organs is not aligned with gravity, so perceptual misjudgment of the horizontal axis occurs. This illusion, simulated as the "Dark Takeoff profile" (DP) in motion-based simulator training, has the same mechanism as the head-up illusion sensed by the utricular otolith organ. It resembles the G excess effect that yields a false perception of aircraft attitude. The G excess effect is an exaggerated sense of body tilt that occurs when the sustained load is greater than that experienced in a normal 1-G environment. Second, somatogyral illusions, which are created by rotational accelerations in the pitch, roll, and yaw axes, are sensed by the semicircular canals in the inner ear. Prolonged rotation (about 10–15 s) results in a cessation of semicircular output and rotation thereafter can even result in the perception of motion in the opposite direction.[9] This illusion is simulated as the "Coriolis profile"

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(CP) in SD motion-based simulator training. More recently, the vestibular system has been shown to influence autonomic control and plays a role in postural-related adjustments in blood pressure.[1] In this study we aimed to observe respiratory and pulse changes during two selected SD training profiles in a motion-based simulator device designed to train pilots to counteract SD danger in a safe condition.

## METHODS

### Subjects

As part of initial physiological training, 15 healthy volunteer male pilot candidates participated in this study. Subjects ranged in age from 23 to 26 yr. A survey was given to subjects about their health history. No subject reported any medical history of cardiovascular disease or exhibited any illness at the time of their study, and subjects were not taking any medications at the time of their study. The study protocol was approved by the Eskisehir Osmangazi University Institutional Review Board and written informed consent was obtained from the subjects.

### Equipment

The Gyro-Lab® (GL-1500, Environmental Tectonics Corporation, Southampton, PA) motion-based simulator device is an interactive training system that provides training to aircrew on procedures and techniques that enable them to recognize, avoid, or successfully manage problems of SD and loss of situation awareness. The system has the capability of 360° pitch, roll, yaw, and planetary (up to 2.5 Gs) motion, wide field of view visuals, and an interactive profile editor. It also has biomedical monitoring capability that is integrated from a Biopac Systems, Inc., (Goleta, CA) data acquisition device and AcqKnowledge® 4 software. SD profile session and parameter recordings in this study constitute a part of the standard physiological SD training that is routinely performed at the Aeromedical Training Center. No other additional procedures were applied to the subjects.

### Procedure

The sessions consisted of three standard phases that started with a motionless instruction period (IP) for about 2 min, then continued with the first profile, the CP illusion, for about 90 s duration, which stimulates the semicircular canals, and finished with the DP illusion for about 90 s duration, which stimulates the otolith organs. There were about 30 s of motionlessness between the CP and DP.

During the CP, the gondola starts a counterclockwise yaw, turning at a rate of lower than 6 rpm (that is under the sensation limit of the vestibular system) and accelerates slowly to 10 rpm for the profile. The instructor then asks the trainee to turn his head to the right side and left and down, respectively. The trainee experiences the Coriolis misperception through the visual displays that show the virtual cockpit of an aircraft simulator.

During the DP, the gondola starts a counterclockwise planetary movement at 4 rpm, then accelerates to 10 rpm to simulate takeoff. After takeoff, the turn rate reaches 15 rpm and at the same time the gondola turns 30° pitch up.

During all three periods, respiratory rate (RR) and pulse rate (PR) parameters of subjects were recorded with the Biopac biomedical monitoring device. RR and PR were captured with a chest belt sensor apparatus and a finger pulse-oximeter device, respectively, all connected to an MP150 computer-based data acquisition system.

### Statistical Analysis

Recorded values were analyzed; the RR and PR means of the three periods (IP, CP, and DP) were automatically calculated by the Biopac software for each of the subjects. The mean RR and PR of the subjects during CP and DP were separately compared with the mean RR and PR of the IP. All data were analyzed statistically with SPSS 16.0 (SPSS Inc. Chicago, IL) software. Kolmogorov-Smirnov was used in order to assess the normality of data variance and the Levene test was used to provide homogeneity of variances. Paired samples *t*-test was selected as appropriate for comparing values between the initial and desired profile periods. A value of $P < 0.05$ was considered statistically significant.

## RESULTS

The average age of the 15 subjects was 23.67 ± 1.11 yr. The CP respiratory rate mean was significantly higher than the IP respiratory rate mean [$t(14) = -2.680$, $P = 0.018$] and the DP pulse rate mean was significantly lower than the IP pulse rate mean [$t(14) = 2.587$, $P = 0.022$] (see **Table I** for mean and SD values). The graph of significant respiratory rate and pulse rate changes during related profiles is presented in **Fig. 1**. There was no significant difference between the IP pulse rate and the CP pulse rate means. Also, there was no significant difference between the IP respiratory rate and the DP respiratory rate means.

## DISCUSSION

Although the clinical significance of these small differences between the instruction period and the profile period parameters seems trivial, the statistical significance of these differences may be considered to expose small but important autonomic responses of vestibular stimulations. The physiological effects of vestibular stimulations have been an intriguing subject of

**Table I.** Statistical Comparisons of Data Means.

| VARIABLES | N | IP | PROFILES | P-VALUE |
|---|---|---|---|---|
| IPR – CPR (breaths/min) | 15 | 21.39 ± 4.27 | 23.43 ± 3.21 | 0.018* |
| IPR – DPR (breaths/min) | 15 | 21.39 ± 4.27 | 20.02 ± 3.17 | 0.159 |
| IPP – CPP (bpm) | 15 | 84.76 ± 14.26 | 83.92 ± 13.93 | 0.544 |
| IPP – DPP (bpm) | 15 | 84.76 ± 14.26 | 79.88 ± 10.39 | 0.022* |

Data are presented as mean ± SD. IPR: instruction period respiratory rate; CPR: Coriolis profile respiratory rate; DPR: dark takeoff profile respiratory rate; IPP: instruction period pulse rate; CPP: Coriolis profile pulse rate; DPP: dark takeoff profile pulse rate.
* $P < 0.05$.

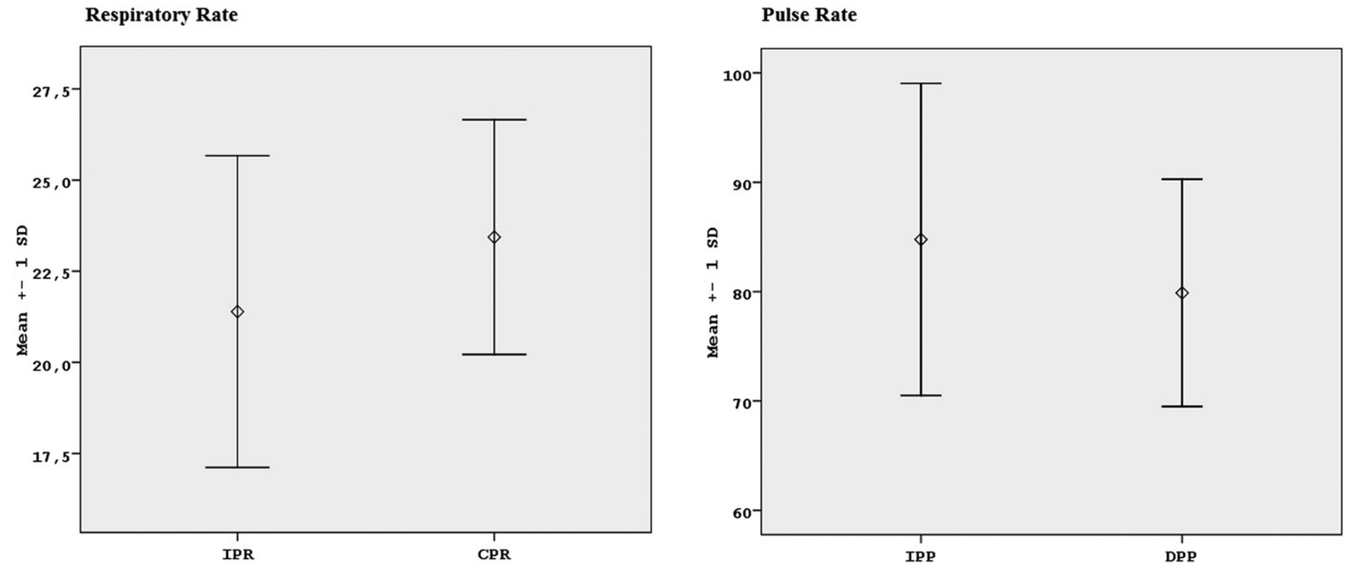


**Fig. 1.** Graph of the mean and standard deviation of respiratory and pulse alterations during the instruction and profile periods. SD: standard deviation; IPR: instruction period respiratory rate; CPR: Coriolis profile respiratory rate; IPP: instruction period pulse rate; DPP: dark takeoff profile pulse rate.

some studies. There is research demonstrating the presence of a vestibular-mediated sympathetic reflex that contributes to blood pressure regulation in humans.[5,6,14] Despite the unknown positive or negative contribution of the Coriolis effect, the major finding of this study was that semicircular canal stimulation (somatogyral illusion) increased respiratory rate significantly, but otolith stimulation (somatogravic illusion) did not, when compared with IP means. Increased respiratory rate due to semicircular canal stimulation was considered to be the result of the vestibule-respiratory reflex.[7] Previous studies about this subject indicated that the semicircular canals, but not the otolith organs or neck muscle afferents, mediate increased ventilation in humans and support the concept that vestibular activation alters respiration in humans.[8] The vestibular system also influences the respiratory muscles; these effects contribute to making adjustments to the activity of the respiratory muscles that is necessary to offset the mechanical constraints on these muscles that occur during changes in body position. These results suggest that the influences of the vestibular system on the autonomic and respiratory systems serve to maintain homeostasis during movement.[14] It is practical for the vestibular system to participate in the control of respiration, to provide for rapid adjustments in ventilation such that the oxygen demands of the body are continually matched during movement and exercise.[12] The reason for the higher than normal resting (12–18 breaths/min) respiratory rates of the subjects may have been excess arousal from psychological factors (anxiety or stress related tachypnea) because of training in a closed, dark, and unfamiliar environment for the first time.

The other finding of this study was the otolith stimulation during DP reduced the pulse rate significantly, but did not change respiratory rate when compared with IP means. From experiments on animal and human subjects, it was demonstrated that inputs from the vestibular otolith organs contribute to the control of blood pressure during movement and changes in posture.[13] It has been previously reported that otolith inputs may contribute to the early transient adjustments to orthostasis.[10] Also, Wood et al. reported that, during transient cardiorespiratory responses to visually induced tilt illusions, visual-vestibular input contributes to the initial cardiovascular adjustment to a change in posture.[11] In humans, head-down neck flexion (HDNF) has been used as a model to study vestibular-sympathetic reflex because static HDNF stimulates the otolith organs. The subjects were positioned on a table such that the neck could be maximally flexed without interference from the end of the table. Each study began with the neck in the baseline position for 3 min. While in the baseline position, the neck was maximally extended and the chin was supported. This position approximates gravitational orientation of the head when an individual is in the upright posture. The face was directed downward and the neck was parallel to the floor. During HDNF, the head was maximally lowered over the edge of the table (i.e., chin to chest). After 3 min in the new position, the head was returned to the baseline position for a 3-min recovery period.[5] In this model, otoliths move forward like deceleration. Using head-down rotation as a model to activate the vestibular otolith organs, marked increases have been demonstrated in muscle sympathetic nerve activity (MSNA) and peripheral vasoconstriction.

In the head-down neck extension (HDNE) model, the subjects were supine, positioned on a table so that the neck could be maximally extended downward without interference from the table. Each study began with the subject's neck in the baseline position for 3 min. While in the baseline position, the neck was maximally flexed in a chin-to-chest manner. After the 3-min baseline period, the neck was extended backward, lowering the head below the level of the heart. In HDNE, MSNA would not change because the otolith stimulation would be opposite to that of HDNF. Also, mean arterial pressure and heart rate were both decreased during HDNE for

2 min.[5] The otolith stimulation in the Dark Takeoff profile resembles this HDNE model and explains why heart rate means decreased significantly. Finally, Cui et al. showed a decrease in MNSA during passive linear acceleration along the naso-occipital axis.[3] A learning effect during the experiments and a less aroused state in the later exposure (DP) may be a possibility for reduction of PR during DP.

As a limitation of this study, the default procedure of SD training that consisted of CP and DP phases was applied to the subjects, respectively, so we did not have the opportunity to observe the pure responses of semicircular canal and otolith stimulation; however, when we considered the dynamics in each phase, we concluded that the semicircular canals were predominantly stimulated by CP and the otoliths were stimulated by DP. Therefore, we thought that this limitation did not adversely affect our results. The CP generates a very strong sense of tumbling that is several times greater than any aircraft can generate, so a long damping period should be expected. The lack of a reasonable damping period between CP and DP gives less chance for desensitization of the vestibular system before DP. Another limitation was the sessions comprised of phases in succession, so there was no IP or resting period before DP. So we were obliged to compare DP with the first IP that was right before CP. It should be remembered there are differences in forces in the air versus in experimental designs. For example, HDNE of 30°, head on chest, is not the same force environment as an aircraft in a 30° dive: the aircraft will be accelerating, the pilot's head will be upright, and the otoliths will be neutral.

This study demonstrated, in accordance with other studies, that vestibular stimulations during aircraft maneuvers may have some effects on the respiratory and circulatory reflex mechanisms. The novelty of this study was the effects of vestibular stimulations on some of the autonomic controls have been shown for the first time in a motion platform that simulates a real flight environment. These effects are considered important for flight safety and pilot survival from SD. While biomedical monitoring of pilots during flight is becoming more important in aviation medicine, having the information to predict expected vital signs of pilots on exact aerial maneuvers may be advantageous during air combat maneuvers.

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