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"Otolith and Vertical Canal Contributions to Dynamic Postural Control"

Summary: The objective of this project is to determine: 1) How do normal subjects adjust postural movements in response to changing or altered otolith input, for example, due to aging? and 2) How do patients adapt postural control after altered unilateral or bilateral vestibular sensory inputs such as ablative inner ear surgery or ototoxicity, respectively? The following hypotheses are under investigation: 1) Selective alteration of otolith input or abnormalities of otolith receptor function will result in distinctive spatial, frequency, and temporal patterns of head movements and body postural sway dynamics. 2) Subjects with reduced, altered, or absent vertical semicircular canal receptor sensitivity but normal otolith receptor function or *vice versa*, should show predictable alterations of body and head movement strategies essential for the control of postural sway and movement. The effect of altered postural movement control upon compensation and/or adaptation will be determined. These experiments provide data for the development of computational models of postural control in normals, vestibular deficient subjects and normal humans exposed to unusual force environments, including orbital space flight.

Key Words: Vestibular compensation, otolith, posture, posturography, human postural control, aging, ototoxicity, space flight, linear acceleration, microgravity.

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SPECIFIC AIMS & PROCEDURES

Project 1. Effect of Stable Unilateral & Bilateral Vestibular Abnormalities on Dynamic Postural Control.

Experiments were continued on subjects with well documented unilaterally or bilaterally abnormal vestibular function as demonstrated by a standard vestibuloocular (VOR) and/or vestibulospinal (VS) clinical test battery(1). Criteria for abnormality are vestibular function test values which lie outside 95% confidence intervals or > $\pm$2 SD, depending upon the reference data base(2-5).

Subjects who met the screening criteria were recalled for centrifuge and modified dynamic posturography (DP) experiments. A modified NeuroCom® EquiTest® device was used for the DP testing. For the centrifuge experiments, constant velocity trapezoidal stimuli were used.

Abnormal subjects were screened and baselined for possible participation in additional studies. During all project years, more than 400 abnormal subjects were tested.

Initial results from one patient with small bilateral vestibular schwannomas (neurofibromatosis type 2, or NF2) have been reported before and after surgical removal(6). Results from this patient have very important theoretical implications because the inferior division of the vestibular nerve was preserved on one side and the superior division on the other. (Auditory function was preserved on both sides.) This was the first documented case in the human demonstrating the ability of the brain to integrate partial (both otolith and canal) vestibular spatial domains from the two ears for normal sensorimotor interactive control of pitch plane eye and body movement.

A project designed to determine the stoichometrics of visual-vestibular (VVOR) interactions has been completed. Results support the hypothesis that VVOR interactions are non-linear in normal subjects, but become linear under some conditions in abnormal subjects. For example, when VOR and OKN functions are normal, a non-linear "saturation constant"-- e.g. "unity gain" -- appears to govern VVOR interactions. However, when a critical gain threshold is reached in either the VOR or OKN system, interactions appear to become algebraic, but inadequate for compensation (unity gain). This non-linear dynamic appears to persist until all vestibular function is lost. VVOR interaction phase relationships are more complicated and will require further study. These findings were presented at the American Otologic Society meeting in Palm Desert, California, on April 30, 1995 and later published in the American Journal of Otology(7).

Nineteen healthy subjects and eight vestibular deficient (VD) subjects were exposed to an inter-aural centripetal acceleration. At intervals during the rotation they performed a series of head saccades toward randomly-presented visual targets. Eight of the

normal subjects also performed the same head-saccade protocol in a static-tilt chair adjusted to specific angles (providing a change in angle (direction) but not in magnitude of gravito-inertial force). Postural center-of-pressure (COP) measures and multisegment sway kinetics were also gathered before and within ten minutes after centrifugation. Normal subjects overestimated roll-tilt during centrifugation, and made errors in perception of head vertical as estimated by directed saccades. Postural COP, segmental body motion amplitude, and hip sway frequency increased significantly after centrifugation. Abnormal subjects under estimated roll-tilt during centrifugation and their directed saccades revealed permanent spatial distortions. Bilateral VD subjects subjects had poor baseline postural control and showed no further decrements after centrifugation. Unilateral VD subjects had varying degrees of postural decrements, both before and after centrifugation. These results suggest that orientation of the gravito-inertial vector and its magnitude are both used by the central nervous system for calibration of multiple orientation systems. A change in the gravito-inertial force (otolith input) can rapidly initiate postural and perceptual adaptation in several sensorimotor systems, independent of a structured visual surround. A manuscript is currently in revision(8).

Projects 2 and 3. Studies on young and elder normals.

In order to study longitudinal aging effects in postural control, peak to peak sway on 6 SOT conditions were measured in 36 normal subjects 10 years ago(4, 5) and again recently. (We have previously demonstrated that peak-to-peak sway is a robust measure of human upright control of posture after more than a decade of comparison of various signal processing techniques. This finding has been independently confirmed using both clinical and laboratory techniques(9) Postural control was well within normal range for all subjects when tested, i.e. none of the subjects were subclinically abnormal. (Normal data published in 1990(4) included subjects who satisfied study admission criteria but who clearly had subclinical abnormalities. The abnormal postural sway exhibited by vestibular deficient subjects has been reported(4, 10-12) Differences between the first and second tests were analyzed for changes (paired t test). There were no discernible differences for SOTs 1-4 ($P>.15$). Averages of SOT 5 and 6 peak-to-peak sway however were clearly larger 10 years after the first test. SOT 5 increased about 50% ($t=4.86$, 35 df, $P=.000024$) and SOT 6 increased over 50% ($t=4.59$, 35 df, $P=.000055$). Fifty percent changes as seen in SOT 5 and SOT 6 would be detectable with a power exceeding 90%.

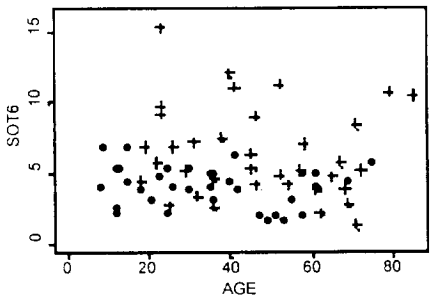

Figure 1: SOT 6 peak-to-peak sway as a function of age (first test, dark circles - second test 10 years later, plus signs). It is apparent that changes in SOT 6 are not due to a general age effect, since there is no age related trend.

The plot for SOT 5 against age has a similar appearance. The slopes of the linear regression of SOTs against age were not significantly different from zero. For SOT 6 (which showed the largest change), the maximum estimated decline of 0.51 in 10 years is small (about 33%) relative to the standard deviation.

Because the cross-sectional analysis published in 1990(4) indicated the presence of minima in some of the data sets, quadratic polynomials were fitted to the data. SOT 6 which previously seemed to have a pronounced minimum did not have statistically significant coefficients ($F(2,69)=.54$, $P=.58$).

The above findings are compatible with reports suggesting that the probability of disease (in this case, vestibular disorders) increases with age(13-16) and that balance may not worsen with age (<80years) *per se* unless there is concomitant or undiagnosed pathology. Our longitudinal study results support the latter conclusion, i.e. age *per se* is not associated with decline in postural control, at least until the age of 80 years. Recent results from the STS-95 study of a 77 year-old astronaut supports this conclusion(17). Quantitative analyses of a 77 year old astronaut's balance control performances revealed few differences between his neuro-adaptive responses to space flight and those from a younger group of astronauts, who ere tested following missions of similar duration. This suggests that the physiological changes associated with aging do not necessarily impair adaptive plasticity in the human following removal and subsequent reinsertion of gravity.

In addition, we have completed the baseline protocol on 6 elderly distinguished scientists in the fields of otology/audiology. This work has been done in conjunction with the "Old Time Ears" project (Principle Investigator Linda Hood, Ph.D.) Initial findings were presented as the Association for Research in Otolaryngology meeting in St. Petersberg, Florida, 1997. We are currently in the process of arranging for testing on the remaining 8 subjects (of 16 subjects in the "Old Time Ears" project, 6 have been tested, 2 (non-tested) have died, and 8 are yet to be tested.) Because of lack of funds, there has been no further progress on this study.

Project 4. Postural compensation/adaptation to abrupt changes in vestibular inputs.

During the first four years of this project, there were three main findings of interest to clinicians from the study of human postural control in astronauts: 1) the postural instability relative to preflight observed in all returning astronauts was demonstrated to be of vestibular origin, 2) previous experience ("efferent copy" or "re-afference") attenuates, but does not prevent postflight postural instability (at least for a total experience of three flights) and 3) visual inputs dominate during the early, rapid recovery and the somatosensory inputs dominate the later secondary phase of recovery. (Black, et al., Vestibular plasticity following orbital space flight: Recovery from postflight postural instability. Presented at the 18th Bárány Society Meeting, Uppsala, Sweden, 6-8 June, 1994)(18, 19).

During year four, we reported on the time constant of nystagmus slow phase velocity (SPV) to yaw-axis rotation as a function of the severity of unilateral canal paresis. We found that the time constant of the response both towards and away from the lesioned side decreased in proportion to increasing canal paresis; this supports the hypothesis that bilateral peripheral vestibular input is necessary for the mechanisms or processes underlying normal horizontal SPV storage(20).

As part of the Extended Duration Orbiter "Detailed Supplementary Objective 605" team, we completed the first large n study of balance control following spaceflight(21). We confirmed that postural ataxia following short duration spaceflight was vestibular in origin. Our results demonstrated that balance control is disrupted in all astronauts immediately after return from space, and concluded that otolith-mediated spatial reference provided by the terrestrial gravitational force vector is not used by the astronaut's balance systems immediately after spaceflight.

Our results demonstrate the positive adaptive control effect of prior space flight experience upon recovery of postural control after landing. The beneficial effect of previous experience upon improved performance immediately postflight has important implications for management of vestibular disorders on earth (including rehabilitation) and upon space flight countermeasure development.. This finding also suggests a reason for the variable results in vestibular physical therapy for peripheral vestibular disorders. Vestibular rehabilitation therapy (VRT) has proven to be one of the most effective management methods for some disorders such as benign paroxysmal positional nystagmus and vertigo, stable unilateral or incomplete bilateral vestibular loss. However if the disorder results from endolymphatic hydrops, including Meniere's disease which cause fluctuating vestibular function, VRT is usually not effective, depending upon status of residual vestibular function. That is, the hydrops must be controlled for optimal results from rehabilitation. The underlying principle appears to be the stability and normality of baseline vestibular function when the pathological process is superimposed and the status and stability of remaining vestibular function upon successful resolution of the pathology. Unpredictable changes in vestibular function invoke a search for an "efferent copy" or previous experience which may or may not exist in one's central nervous system. An efferent copy of a consistent change relative to baseline vestibular function is more likely to enable successful compensation strategies, allowing the brain to recognize the change and command appropriate neuromuscular responses(18, 22-24).

Adult subjects with the diagnosis of peripheral vestibular disorders were given a course of individualized vestibular rehabilitation therapy (VRT). Normal subjects and subjects with peripheral vestibular disorders who did *not* receive VRT served as controls. Results showed that an individualized program of VRT resulted in subjective and objective (documented by computerized dynamic posturography) improvement in all subjects with peripheral vestibular disorders, regardless of the diagnosis(25).

We have evaluated the recovery dynamics of ototoxicity in subjects who had received aminoglycosides(26). Partial or complete recovery of vestibular function occurred in 4 of 8 ototoxic subjects followed for one year, most of whom received gentamicin. There was no relation between cumulative gentamicin dose and ototoxicity. Of the most three severely affected subjects, two demonstrated complete or partial recovery of response HCVOR gain or time constant, relative to baseline. Dynamics of recovery were highly variable between individuals.

Six patients, 18-69 y/o, with unilateral vestibular loss were rotated in darkness on a fixed-chair centrifuge. Subjects were seated at 0.54 m from the center of rotation and were either 'facing the motion' or had their 'back to motion' for both clockwise and

counterclockwise rotations. Fixed radius angular velocity trapezoids (250 deg/s, acceleration/deceleration at 25 deg/s2) yielded a steady-state centrifugal force of 1.0g, which tilted the gravito-inertial force by 45deg. Somatosensory settings to perceived earth-horizontal were normal in 4 subjects and lower than normal in 2 subjects for some of the stimuli. This finding suggests that unilateral vestibular loss does not prevent normal perception of tilt during centrifugation. The effect of the centrifugal acceleration was estimated by subtracting horizontal eye movement responses (video-oculography recordings) during the 'back-to-motion' condition from the 'facing-motion' condition, for a same direction of rotation. When rotation occurs towards the healthy ear, the eye velocity resulting from this subtraction reaches 15 deg/s during the angular acceleration and then stabilizes around 1 deg/s. When rotation occurs towards the lesioned ear, there is no clear initial peak in eye velocity and the horizontal eye velocity remains around 2 deg/s during the whole duration of centrifugation. We conclude that the healthy ear produces a linear vestibulo-ocular reflex (VOR) for both direction of linear acceleration. During rotation towards the healthy ear, the combination of angular and linear VORs produces an eye movement response greater than the sum of each separate VOR. These results will be presented at the Ordinary Meeting of the Barany Society, Uppsala, Sweden, June, 2000. (Perceptual tilt and eye movement responses induced by centrifugation in patients with complete unilateral vestibular loss. Claire Gianna, F. Owen Black, and Daniel M. Merfeld.)

Technical Progress:

Hydraulic Pitch Axis Rotation Device. An existing hydraulic actuator has been modified for pitch and roll stimuli. The laboratory space for the device has been modified, a special wall mounted bracket supports the actuator and device frame, and the hydraulic lines and pump have been connected. Computer and safety control, and data analysis interfaces have been modified from existing software. All changes have been reviewed and approved by the Legacy IRB.

Human-rated Centrifuge. The human rated centrifuge has been completed and normal and abnormal subject experimental results have been summarized above.

Video eye movement recording and analysis techniques. An operational 3-D video eye movement and analysis system is in place in our laboratories. The binocular SMI VOG 3-D video eye movement recording and analysis system has been used successfully to conduct the above studies. We have reported our findings that noninvasive measurements of three-dimensional eye movements may be accurately achieved with video methods(27).

Modified dynamic posturography device. Progress has been made on the modification of the hydraulically powered computerized dynamic posturography device. The hydraulic system has been completely over-hauled. Software is being re-written for PC control and analysis (converted from DEC operating systems). In addition, the software is being "merged" with a "Flock-of-birds" multi-dimensional analysis system.

Budget.

The Final Financial Report (SF272) has been submitted and received by the Office of Naval Research, Seattle, WA.

Bibliography

1. von Gierke HE, Barber HO, Cohen B, et al. Evaluation of tests for vestibular function. Working Group on Evaluation of Tests for Vestibular Function. Committee on Hearing, Bioacoustics, and Biomechanics (CHABA); Commission on Behavioral and Social Sciences and Education; National Research Council. Aviation Space and Environmental Medicine. 1992;February:A1-A34.
2. Peterka RJ, Black FO, Schoenhoff MB. Age-related changes in human vestibulo-ocular reflexes: Sinusoidal rotation and caloric tests. Journal of Vestibular Research. 1990;1:49-59.
3. Peterka RJ, Black FO, Schoenhoff MB. Age-related changes in human vestibulo-ocular and optokinetic reflexes: Pseudorandom rotation tests. Journal of Vestibular Research. 1990;1:61-71.
4. Peterka RJ, Black FO. Age-related changes in human posture control: Sensory organization tests. Journal of Vestibular Research. 1990;1:73-85.
5. Peterka RJ, Black FO, Schoenhoff MB. Age-related changes in human posture control: Motor coordination tests. Journal of Vestibular Research. 1990;1:87-96.
6. Black FO, Brackmann DE, Hitselberger WE, Purdy JK. Preservation of auditory and vestibular function after surgical removal of bilateral vestibular schwannomas (NF) in a patient with neurofibromatosis type 2. American Journal of Otology. 1995;16 No. 4:431-443.
7. Black FO, Wade SW, Nashner LM. What is the minimal vestibular function required for compensation? American Journal of Otology. 1996;17:401-409.
8. Kaufman GD, Wood SJ, Gianna CC, Black FO, Paloski WH. Spatial orientation and balance control changes induced by altered gravito-inertial force vectors. Experimental Brain Research. 1999;(Submitted).
9. Shepard NT, Schultz A, Alexander NB, Gu MJ, Boismier T. Postural control in young and elderly adults when stance is challenged: Clinical versus laboratory measurements. Annals of Otology, Rhinology, and Laryngology. 1993;102:508-517.
10. Black FO, Shupert CL, Horak FB, Nashner LM. Abnormal postural control associated with peripheral vestibular disorders. In: Pompeiano O, Allum JHJ, eds. Vestibulo-spinal Control of Posture and Movement: Progress in Brain Research. 76 ed. Amsterdam: Elsevier; 1988:263-275.
11. Shupert CL, Horak FB, Black FO. Effect of peripheral vestibular disorders on head-trunk coordination during postural sway in humans. In: Berthoz A, Vidal P, Graf W, eds. The Head-Neck Sensory Motor System. New York: Oxford University Press; 1992:607-610.
12. Shupert CL, Horak FB, Black FO. Hip sway associated with vestibulopathy. Journal of Vestibular Research. 1994;4:231-244.
13. Horak FB, Shupert CL, Mirka A. Components of postural dyscontrol in the elderly: A review. Neurobiology of Aging. 1989;10:727-738.
14. Whipple R, Wolfson L, Derby C, Singh D, Tobin J. Altered sensory function and balance in older persons. The Journals of Gerontology. 1993;48:71-76.
15. Tinetti M, Speechley M, Ginter SF. Risk factors for falls among elderly persons living in the community. New England Journal of Medicine. 1988;319:1701-1707.
16. Paige GD. Aging and equilibrium: The vestibulo-ocular reflex and posture. In: Sharpe JA, Barber HO, eds. The Vestibulo-Ocular Reflex and Vertigo. New York: New Raven; 1993:55-67.
17. Paloski WH, Black FO, Metter EJ. Unimpaired neuro-adaptive plasticity in an elderly astronaut. . 2000;(Submitted).
18. Black FO, Paloski WH, Doxey-Gasway DD, Reschke MF. Vestibular plasticity following orbital spaceflight: Recovery from postflight postural instability. Acta Otolaryngologica (Supplement). 1995;Suppl 520:450-454.

19. Sawin CF, Baker E, Black FO. Medical investigations and resulting countermeasures in support of 16-day space shuttle missions. Journal of Gravitational Physiology. 1998;5(2):P1-12.
20. Wade SW, Halmagyi GM, Black FO, McGarvie LM. Time constant of nystagmus slow phase velocity to yaw-axis rotation as a function of the severity of unilateral caloric paresis. American Journal of Otology. 1997;20:471-478.
21. Paloski WH, Reschke MF, Black FO. Recovery of postural equilibrium control following space flight (DSO 605). In: Sawin CF, Taylor GR, Smith WL, eds. Extended Duration Orbiter Medical Project. Final Report. Houston: National Aeronautics and Space Administration; 1999:5.4 1-11.
22. Paloski WH, Black FO, Reschke MF, Calkins DS, Shupert CL. Vestibular ataxia following shuttle flights: Effects of transient microgravity on otolith-mediated sensorimotor control of posture. American Journal of Otology. 1993;14:9-17.
23. Black FO, Paloski WH. Computerized dynamic posturography: What have we learned from space?. In Vestibular Dysfunction: Lessons and Legacies from Space. Otolaryngology-Head and Neck Surgery (Supplement). 1998;118(3, Part 2):S45-51.
24. Paloski WH, Black FO, Reschke MF, Calkins DS, Gasway DD. Altered vestibular information processing disrupts sensory-motor control of balance immediately after space flight. J Neurophysiol. 1998;Submitted.
25. Black FO, Angel CR, Pesznecker SC, Gianna CC. Outcome analysis of individualized vestibular rehabilitation protocols. American Journal of Otology. 1999;(In Press).
26. Black FO, Wade SW, Pesznecker SC. Recovery from aminoglycoside ototoxicity? American Journal of Otology. 2000;In press.
27. Merfeld DM, Black FO, Wade SW. Clinical use of three-dimensional video measurements of eye movements. Otolaryngology- Head and Neck Surgery (Supplement). 1998;118(3, Part 2):S35-38.

- - Publications and Presentations - -

Refereed Articles

Paloski WH, **Black FO**, Reschke MF, Calkins DS and Shupert CL: Vestibular ataxia following shuttle flights: effects of microgravity on otolith-mediated sensorimotor control of posture. Am J Otol 14(1)9-17, 1993.

Shupert CL, Horak FB and **Black FO:** Hip sway associated with vestibulopathy. J Vest Res Vol. 4, No. 3:231-244, 1994.

Black FO, Brackmann DE, Hitselberger WE, and Purdy J: Preservation of auditory and vestibular function after surgical removal of bilateral vestibular schwannomas (NF) in a patient with NF 2. Am J Otol 16:431-443, 1995.

Black FO, Paloski WH, Doxey-Gasway DD, and Reschke MF: Vestibular plasticity following orbital spaceflight: Recovery from postflight postural instability. Acta Otolaryng. (Stockh); Suppl 520;450-454, 1995.

Paloski, WH, **Black, FO**, Reschke, MF: Recovery of postural equilibrium control following space flight (DS) 605). NASA Extended Duration Orbiter Medical Project Final Report 1989-1995.

Black FO, Wade SW, and Nashner L.M: What is the minimal vestibular function required for compensation? Am J Otol ,Vol 17, No. 3:1-9, 1996.

Sawin CF, Baker E, and **Black FO**: Medical investigations and resulting countermeasures in support of 16-day space shuttle missions. J Gravitat Phys, P1-P9, 1996.

Wade SW, Halmagyi GM, **Black FO**, and McGarvie LM: Time constant of nystagmus slow phase velocity to yaw-axis rotation as a function of the severity of unilateral caloric paresis. Am J Otol, 20:471-478, 1997.

Black FO: Computerized dynamic posturography: What have we learned from space? Otolaryngol Head Neck Surg, Vol 118, No. 3;545, 1998.

Paloski WH, **Black FO**, Reschke MF, Calkins DS, and Gasway DD: Altered vestibular information processing disrupts sensory-motor control of balance immediately after space flight. *Submitted*, J Neurophysiol, 1998.

Merfeld DM, **Black FO**, Wade S.W.: Clinical use of three-dimensional video measurements of eye movements. Otolaryngol Head Neck Surg 118:S35-38, 1998.

Wade SW, Halmagyi GM, **Black FO**, and McGarvie LM: Time constant of nystagmus slow phase velocity to yaw-axis rotation as a function of the severity of unilateral caloric paresis. Am J Otol, 20:471-478, 1999.

Black FO, Paloski WH, Reschke MF, Igarashi M, Guedry FE, and Anderson DJ. Disruption of postural readaptation by inertial stimuli following the first international microgravity (IML-1) space flight mission. J Vest Res. 9(5): 369-378, 1999.

Black FO, Angel CR, Pesznecker SC: Outcome analysis of individualized vestibular rehabilitation protocols. In press, Am J Otol, 2000.

Kaufman GD, Wood SJ, Gianna C., **Black FO**, Paloski WH: Spatial orientation and balance control changes induced by altered gravito-inertial force vectors. Submitted, Exp Brain Res, In revision, 2000.

Paloski WH, **Black FO**, Reschke, MF, Calkins, DS, and Gasway, DD: Altered vestibular information processing disrupts sensory-motor control of balance immediately after space flight. Submitted, 2000.

Paloski WH, **Black FO**, Metter EJ: Unimpaired neuro-adaptive plasticity in an elderly astronaut. Submitted, 2000.

Black FO, Wade SW, and Pesznecker SC: Vestibular and auditory function abnormalities in women with silicone breast implants. *In Review*, Am J Otol, 2000.

Black FO, Gianna C, Pesznecker SC, and Wade SW. Recovery from aminoglycoside ototoxicity? *In Review*, Am J Otol, 2000.

Presentations at Conferences and Symposia

Paloski WH, **Black FO**, Reschke, MF, Calkins, DS and Shupert, C: Vestibular ataxia following shuttle flights: Effects of microgravity on otolith-mediated sensorimotor control of posture. Presented at the 125th Meeting of The American Otological Society, Palm Desert, CA, April, 1992. Am J Otol, Vol. 14, No. 1:9-17, 1993.

Black FO. Brackmann DE, Hitselberger WE and Purdy J: Preservation of auditory and vestibular function after surgical removal of bilateral vestibular schwannomas (NF) in a patient with NF 2. Presented at the One Hundred Twenty-Seventh Annual Meeting, American Otological Society, May, 1994.

Doxey-Gasway DD, Paloski WH, **Black FO** and Reschke MF: Reliance on visual inputs for posture control increases following spaceflight. Aerospace Medical Association Meeting, May 1994.

Krug JA, Wood SJ, **Black FO** and Reschke MF: Vertical vestibulo-ocular reflex during earth-horizontal axis rotation. Aerospace Medical Association Meeting, May 1994.

Black FO, Paloski WH, Doxey-Gasway DD and Reschke MF: Vestibular plasticity following orbital spaceflight: Increased weighting of vision versus somatosensory inputs during recovery from postural instability. Presented at the XVIII Annual Bárány Society Meeting, Uppsala, Sweden, June 1994.

Black FO: New devices and diagnostic contribution of posture and locomotion measurement. Vestibular and Neural Front. Igarashi, M., Taguchi, K., eds., Proceedings of the International Symposium on Posture and Gait, Matsumoto, Japan, Elsevier, Amsterdam, pp. 13-26, 1994.

Black FO, Paloski WH, Doxey-Gasway DD, and Reschke MF: Effects of visual and somatosensory references upon vestibular plasticity and postural control. Presented at the Association for Research in Otolaryngology Midwinter Research Meeting, St. Petersburg, FL, February 5-9. 1995.

Black FO: Control of posture by otolith signals in normal subjects, vestibular patients and astronauts. Presented at the Medical Audiology Workshop, Breckenridge, March 1995.

Black FO, Wade SW and Nashner LW: What is the minimal vestibular function required for compensation? Presented at the American Otological Society Meeting, Palm Desert, CA, April 1995.

Black FO and Paloski WH: Vestibulospinal compensation: Critical components. Presented at the Association for Research in Otolaryngology Midwinter Research Meeting, St. Petersburg, FL, February 1996.

Black FO: Documentation of vestibular function test: Pathology. Presented at the 30th Annual Colorado Otology-Audiology Conference, Breckenridge, CO, March 1996.

Sawin CF, Baker E, and **Black FO**: Medical operations investigations and resulting countermeasures in support of 16-day space shuttle missions. Presented at the 17th Annual International Gravitational Physiology Meeting, Warsaw, Poland, April 1996.

Black FO, Paloski WH, and Wade SW: Vestibular adaptation: Critical components. Presented at the Vestibular Adaptation Meeting, Santa Monica, CA, May 1996.

Wade SW, Halmagyi GM, and **Black FO**: Horizontal semi-circular canal dysfunction and the time constant of response to rotational stimulation. Presented at the 19th Bárány Society Meeting, Sydney, Australia, August 1996.

Black FO, and Paloski WH: Space flight mal de débarquement and vestibular ataxia. Presented at the 19th Bárány Society Meeting, Sydney, Australia, August 1996.

Black FO: Computerized dynamic posturography: What have we learned from space? Presented at the National Aeronautics and Space Administration Symposium Lessons and Legacies from Space, Washington, D.C., 1996.

Merfeld DM, **Black FO**, and Wade SW: Clinical use of three dimensional video measurements of eye movements. Presented at the National Aeronautics and Space Administration Symposium Lessons and Legacies from Space, Washington, D.C., 1996.

Black FO, Hood LJ, and Pesznecker SC: Vestibular findings in aging populations: "Old Time Ears." Presented at the Association for Research in Otolaryngology, St. Petersburg, FL., 1997.

Black FO: Diagnostic and outcome uses of vestibulo-ocular and vestibulospinal function tests. Presented at the IFOS XVI World Congress of Otorhinolaryngology, Sydney, Australia, 1997.

Black FO: Determining pre-treatment vestibular reserve, Presented at the Prosper Meniere Society Winter Meeting, Aspen, CO., 1997.

Wade SW, Halmagyi GM, **Black FO**, and McGarvie LM: Time constant of nystagmus slow phase velocity to yaw-axis rotation as a function of the severity of unilateral caloric paresis. Annual Meeting of the Association for Research in Otolaryngology, February, 1997.

Herdman SJ and **Black FO**: Vestibular rehabilitation. Presented at the 1997 Annual Convention of the American Academy of Audiology, Fort Lauderdale, FL, 1997.

Black FO: Vestibular and auditory function abnormalities in silicone breast implant patients. Presented at the American Otological Society Annual Meeting, Scottsdale, AZ, 1997.

Arshi A, Wade SW, and **Black FO**: Roll-tilt perception measured using a somatosensory bar Task. Presented at the Association for Research in Otolaryngology Midwinter Meeting, February, 1998.

Black FO: Active versus passive tests of vestibular function. Presented at the 32nd Annual Colorado Otology-Audiology Conference, Breckenridge, CO, March, 1998.

Black FO, Wade SW, Pesznecker SC: Recovery from aminoglycoside ototoxicity??? Presented at the One Hundred Thirty-First Annual Meeting American Otological Society, Palm Beach, FL, May, 1998.

Black FO, Pesznecker SC: Surgical management of motion sickness in perilymph fistula patients. Presented at the XXth Bárány Society Meeting, Würzburg, Germany, September, 1998.

Black FO: Inner ear effects of manned space flight. Presented at the XXIVth International Congress of Audiology, Buenos Aires, Argentina, September, 1998.

Published Abstracts

Shupert CL, Horak F, and **Black FO**: Hip sway associated with vestibulopathy. Presented at the XIth International Symposium for Postural and Gait Research, Portland, Oregon, May, 1992. Accepted for publication, Journal of Vestibular Research, 1993.

Doxey-Gasway DD, Paloski WH, **Black FO,** and Reschke MF: Reliance on visual inputs for posture control increases following spaceflight. Aerospace Medical Association Meeting, May 1994.

Krug JA, Wood SJ, **Black FO,** and Reschke MF: Vertical vestibulo-ocular reflex during earth-horizontal axis rotation. Aerospace Medical Association Meeting, May 1994.

Merfeld DM, **Black FO**, Teiwes W, Clarke AH, Scherer H, and Young LR: Contributions of graviceptors to dynamic ocular torsion in humans. J. Vest. Res. Vol 6, Number 4S: OTO11. XIXth Meeting of the Barany Society, Sydney, Australia, August, 1996.

Wade SW, Halmagyi GM., **Black FO**, and McGarvie LA: Time constant of the vestibular response to rotation as a function of the severity of unilateral caloric paresis. J. Vest. Res. Vol 6, Number 4S: CLM 10. XIXth Meeting of the Barany Society, Sydney, Australia, August, 1996.

Black FO, Wade SW, and Pesznecker SC: Vestibular and auditory function abnormalities in women with silicone breast implants. American Otological Society Abstracts, 1997.

Arshi A, Wade SW, and **Black FO.**: Roll-tilt perception measured using a somatosensory bar task. Presented at the Association for Research in Otolaryngology Meeting, May, 1998.

Black FO, Wade SW, and Pesznecker SC.: Recovery from aminoglycoside ototoxicity?? Presented at the 1998 Spring Meeting of the American Otologic Society, May 9-10, 1998, Palm Beach, Florida.

Book Chapters

Black FO, and Pesznecker SC: Vestibular ototoxicity - Clinical considerations. Otolaryngologic Clinics of North America, Vol. 26(5):713-736. Editor: Rybak, L.P., W.B. Saunders Co., Philadelphia, 1993.

Black FO, Pesznecker SC, and Doucette SM: Meniere's disease: Medical management. Current Therapy in Otolaryngology-Head and Neck Surgery, fifth edition, pp. 72-79. Editor: Gates, G.A., Mosby Year Book, Philadelphia, 1993.

Black FO, Grimm RJ, Horak FB, Peterka RJ, and Pesznecker SC: Central vestibular disorders. Head and Neck Surgery -- Otolaryngology, Chapter 146, pp. 1883-1892. Editor: Bailey, B.J., J.B. Lippincott Co., Philadelphia, 1993.

Black FO: New Devices and diagnostic contribution of posture and locomotion measurement. Vestibular and neural front. Igarashi, M., Taguchi, K., eds., Proceedings of the International Symposium on Posture and Gait, Matsumoto, Japan, Elsevier, Amsterdam, pp. 13-26, 1994.

Black FO, and Pesznecker SC: Perilymphatic fistula: The method of F. Owen Black. In Gates GA (Ed.): Current Therapy in Otolaryngology, Head and Neck Surgery. 6 ed. St. Louis: Mosby; 1998:71-78.

Black FO, Pesznecker SC, and Grimm RJ: Central vestibular disorders. In Bailey BJ (ed): Head and Neck Surgery- Otolaryngology (Second Edition). pp. 2275-2285. Editor: Bailey BJ. Lippincott-Raven, Philadelphia, 1998.