



Integration of the Visual-Vestibular System with Respect to Human Spaceflight

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ABSTRACT

Action directed toward a specific objective requires self-orientation, self-motion, and the experience of that orientation and motion. Definition of spatial orientation models for the microgravity environment experienced during spaceflight is necessary for a complete understanding of co-ordination between head and eye movements. Intrinsic coordinate models should be nonarbitrary and medically determined. Motor control is necessary for eye/head movements during visual target acquisition, limb motions while reaching for targets, and locomotion toward objectives. These maps could be connected to a variety of functions, such as the acquisition of head/eye targets or limb targets.

KEYWORDS: Visual-Vestibular System, Human Spaceflight, Neuroscience,

INTRODUCTION

The linkages between study & action and perception are studied in research on self-orientation and self-motion perception and control [1]. Action that is directed toward a specific objective requires self-orientation, self-motion, and the experience of that orientation and motion. The purpose of Detailed Supplementary Objective (DSO) 604 Operational Investigation-3 (OI-3) is to examine the integrated coordination of head and eye movements in a structured environment where perception may change responses and where responses may be used to make up for perception. Definition of spatial orientation models for the microgravity environment experienced during spaceflight study is necessary for a complete understanding of this coordination. The development, upkeep, and modification of neuronal models that might represent three-dimensional Cartesian coordinates for both the intrinsic self and the environment are tasks for the central nervous system (CNS) (extrinsic). The observer's capacity to recognise up/down vector signals created by gravity (g), the visual scene, and polarity is the basis for extrinsic coordinate neuronal models (VS). The up/down vector only fully specifies vertical coordinates. Extrinsic coordinate models are more complicated since they are derived from multimodal processes. Graviceptors, such as those in the vestibular apparatus (Gves), somatic receptors (Gs), and visceral receptors (Gvic), are used to sense gravity, for instance [2, 3]. Because intrinsic coordinate models might be centred on the eyes, the head, the torso, and more, they must be more sophisticated [4]. The X-, Y-, and Z-axis vectors in intrinsic coordinate models should all be nonarbitrary and medically determined, which is another way in which they should be different from extrinsic coordinate models [5]. It is necessary to map out the linkages between the models for intrinsic coordinates and the model for extrinsic coordinates in order to take effective action in the normal environment. The generated maps can be used to perceive body direction and establish the beginning circumstances for the central motor control command system, to name only two possible applications (s). Motor control is necessary for eye/head movements during visual target acquisition, limb motions while reaching for targets, and locomotion toward objectives. Recent investigations reveal parallel command routes, at least for the head and eye during visual target acquisition control, in contrast to prior studies that supported a shared (common) central motor command system [6]. Recent developments in neuroscience imply that numerous parallel pathways, commonly referred to as distributed functions or distributed networks, are active during central brain processing [7]. These developments and the evidence for parallel motor control systems led us to assume several parallel mappings connecting intrinsic and extrinsic coordinate brain models. These parallel maps could be connected to a variety of functions, such as the acquisition of head/eye targets, limb targets, and whole-body motion perception. The intrinsic Z body axis must be given studyright in the map that establishes the beginning conditions for the limb motor control system in order for reaching or moving effectively toward a destination. The intrinsic Z head and retinal meridian axes must be given studyright in the map that establishes the baseline conditions for head/eye motor control in order to effectively gaze for a target.

STUDIES ON VISUAL-VESTIBULAR SYSTEM WITH RESPECT TO HUMAN SPACEFLIGHT

A multimodal sensory mechanism that combines information from the eyes, vestibular system, and somatosensory receptors produces self-orientation and self-motion perception. Self-orientation perception is not assigned to any particular receptor or body area [8] in the same way that a tactile stimulus is referred to a spot on the body surface or that visual stimuli are referred to the eyes. This may be because of the underlying multimodal processes. For

instance, a variety of techniques, including positioning a limb in the dark, creating a luminous line, and vocally reporting perceived head position in the dark, can be used to report self-orientation with respect to a gravitationally determined vertical. The following are helpful summaries of spatial orienting studies by Howard and Templeton [9], Guedry [10], and Howard [4, 11]: Observers are able to report perceived orientation with regard to internal reference vectors such as the eye, head, or torso Z axes as well as external reference vectors (axes) such as gravity, visual scene polarity, and tactile polarity. Reports can be verbally acquired, as well as by eye, limb, tactile stimulation (rod), and movement of a visual line, and report accuracy can be assessed in relation to the reference vectors. When the gravitational and visual reference vectors are not parallel, as in rod and frame investigations and tilted room tests, reports point to a compromise. Research suggests that variations in the internal Z-axis vector and the gravity vector may also affect the results. For instance, it is implied that the subjective visual vertical is tilted in the same direction as the head tilt when a truly vertical line is reported to be tilted in the direction opposite to the head tilt. This A (Aubert) effect may be appreciated by connecting the intrinsic Z-axis and extrinsic G-axis vectors [12, 13]. It predominates when the body tilt is significant ($> 60^\circ$) [4]. Under predetermined ranges of rotational velocity and amplitude [10], observers may reliably assess rotational displacement purely from semicircular canal signals. Because of this, whole body rotation can be used to create a disturbance in microgravity that is comparable to a static head tilt on Earth. The compensation for this disturbance involves the study of neural signals that represent the intrinsic and extrinsic Zt reference vectors, as well as changes in their study of neural signals throughout microgravity adaptation [14]. Reviews of recent studies on sensorimotor adaptation in microgravity [15–18] suggest that astronauts initially rely more heavily on visual reference axes derived from VS coordinates [15, 19] when there is no gravitational reference axis (G), and that during prolonged microgravity exposure, reliance may shift toward intrinsic reference vectors, such as Ze, Zh, and Zt [20–22]. Effective motor control necessitates adaptability to changes in sensory processing, such as labyrinthectomy, or reorganisation of environmental elements, such as prolonged exposure to microgravity. Re-mapping of internal and extrinsic coordinate connections may be one part of adaptation. Parallel mappings are probably congruent in the typical adapted state. These maps could change throughout adaptation, and adaptation might be finished when the parallel maps are once again congruent. These ideas are supported by differences in oculomotor and perceptual responses seen during adaptation to stimulus rearrangements. Perception and oculomotor responses are often roughly consistent [10], with the exception of ocular torsion and perceived tilt [23]. Furthermore, response incongruence has been seen following adaptation to unilateral loss of vestibular function when the peripheral asymmetry, as evidenced by eye movement recordings, persists although the spinning feeling eventually fades [24]. Following exposure to stimulus rearrangements, including the inertial visual stimulus rearrangement produced by microgravity, similar reaction incongruence has been reported. Oman et al. [25] revealed what is arguably the most extreme instance of perceptual oculo-motor response incongruence. Subjects exposed to a moving stripe display reported an illusory self rotation in the same direction as the observed stripe motion after wearing goggles for one to three hours that reversed the visual field from left to right. No participant, however, demonstrated any signs of reversal of the VOR slow phase component. Oman and Balk [26] recently reported that under microgravity, a nystagmus dumping method consisting of a 90° forward head tilt after a quick stop from $120^\circ/\text{sec}$ rotation resulted in an almost immediate cessation of perceived self rotation. However, when the head was kept upright, post-rotatory nystagmus durations were equal to those seen before and during spaceflight (no dumping). These and other findings prompted Peterka and Benolken [24] to hypothesise that the vestibular reflex and self-motion perception systems may not share all of the neuronal processes underpinning central compensation. Their theory appears to be a variant of the recommendation to remap the connections between intrinsic and extrinsic coordinate neuronal models. One conclusion is that various re-mapping procedures may take place across various time periods during adaptation if the completely adapted state is defined by congruence among parallel maps. That would almost probably be the case given that the re-mapping methods proposed here would represent a type of sensorimotor learning. Active, deliberate motion is one of the most crucial requirements for sensorimotor learning [27]. The kind of voluntary acts taken would determine the pace of remapping. One may anticipate that the map supporting the head/eye motor control system would change more quickly than the map supporting limb motor control if an observer solely engaged in head/eye target acquisition behaviours. By causing eye movements that counteract head jerks, the vestibulo-ocular reflex (VOR) helps to maintain a clean image on the retina. For successful gaze stabilisation, the VOR is mediated by vestibular information, which depends on the proper canal-otolith interaction. On Earth, it is believed that during yaw head oscillations, the direction of the gravity vector felt by the otoliths does not change [28]. There have been several examinations of how microgravity affects yaw VOR. Voluntary head oscillations at frequencies ranging from 0.25 to 1 Hz have been used in in-flight tests [29–33]. Additionally, passive rotation has been used before to and following spaceflight [33]. Eyes open in the dark or closed while picturing a wall-fixed target were used for head oscillations while fixating a target on a wall whose gain was presumably 1.0. Only a few studies [29, 32, 33] have found any significant pre- or post-flight changes in yaw VOR. The direction of the change when changes were observed differed between patients [34]. A participant who was told to utilise a fictitious wall-fixed target during head oscillations in an experiment carried out onboard the U.S. Space Shuttle lost VOR gain at 0.25 Hz on his first test six hours into the voyage [31]. By flight day 7, VOR had returned to preflight levels. This discovery of a lost VOR gain early in microgravity was in line with previous findings from parabolic flight and centrifuge experiments [35, 36], which showed a decreased VOR gain as gravity dropped. No phase change coincided with the in-flight drop in VOR, suggesting that the individual may have suppressed vestibular input. Since the individual had pilot training, it's possible that learning to suppress in order to prevent sensory conflict was possible. In the absence of gravity, it's also plausible that the patient was unable to picture a wall-fixed target [31]. DiZio and colleagues' parabolic studies [37, 38] showed that acute exposure to microgravity shortened the apparent time constant of post-rotatory nystagmus (PRN) in yaw and pitch, but not thereafter. One crew member on a Shuttle voyage used a hand-spun spinning chair to monitor the yaw axis PRN to a step velocity rotation while in flight. The findings suggested a reduced time constant in flight and showed no change in gain. The nystagmus dumping phenomena was seen during flight, indicating that mechanisms connected to the active head movement rather than gravity itself may have been responsible for it [39]. Nine Shuttle astronauts' preflight and postflight PRN comparisons revealed a little apparent time constant shortening but no discernible change in the size of the initial peak slow phase velocity response over the first few days following a week-long flight [40, 41]. As a result, the effects were qualitatively comparable to those seen by DiZio et al. [37, 38] during parabolic flight. During the first week following landing, responses progressively reverted to preflight norms. According to Oman et al. [42], the CNS may have suppressed the vestibular component driving central velocity storage in favour of visual inputs as a result of the changed gravireceptive input in microgravity. Pitch head oscillations under normal gravity, as opposed to yaw, result in changes to the direction of the gravity vector that is perceived by the otoliths. Investigating the role of the otoliths in pitch VOR is best done in the microgravity environment [28]. Voluntary head oscillations at frequency similar to those mentioned above for yaw have been used in in-flight examinations of pitch

VOR. Other investigations have detected variations in the vertical VOR, even if in-flight and post-flight changes haven't always been seen [32]. In tests performed 14 h after landing, two patients who had been subjected to pitch oscillation at 1 Hz showed a considerably higher VOR gain than they had on days 5 and 7 of flight [28]. During the in-flight testing in these trials, a greater phase lag was noticed. Due to the large degree of data dispersion, the shift in the association between vertical VOR gain and phase, however, was not statistically significant. With a patient studied on STS-51G, a reduction in vertical VOR gain for 0.25 Hz pitch oscillations was seen [31]. The first few days of his flight saw a reduction in his gain, which was then gradually restored to preflight levels. The findings of both studies are in disagreement with the higher VOR gain seen during zero-gravity parabolic flight portions onboard the KC-135 for pitch oscillation at 0.25 Hz [43]. The STS-51G subject's learned suppression of vestibular input [31], the occurrence of adaptation prior to in-flight measurements on Spacelab-1 (SL-1), the testing at a frequency (1 Hz) for which the canals are dominant, or the potential difficulty in imagining a wall-fixed target during spaceflight in the same way as on Earth [28] are all possible explanations for these contradictory results. According to Guedry [44, 45], Benson and Bodin [46], and Bodin [47], it is hypothesised that the differences between the horizontal and vertical canals are caused by different arrangements of the compensatory responses to angular motion about the yaw (Z) axis as compared to the responses in pitch (Y) and roll (X) axes. Motion in yaw normally happens in the upright posture without any significant changes to the direction of the gravity vector. The vertical canals and otoliths transmit concordant information to the CNS during oscillation in the other two axes. Depending on their degree of resting sensitivity, the otoliths may not provide the desired information in a microgravity environment, which will change how the VOR functions. The canals continue to provide information on the direction and amplitude of rotation. The direction of the visual axis in relation to space is called gaze. It is described as the average of the head's position in relation to space and the eyes in relation to the head. A combined saccadic eye and VOR response that changes focus onto target typically comprises coordinated eye-head movements toward an offset visual target. It has been established in the past that spaceflight's microgravity causes changes in eye-head coordination during target acquisition [48, 49] and ocular saccade performance [50]. Current theories of eye-head coordination assume that a vestibular signal, describing head movement relative to space, acts as an intrinsic component underpinning saccadic spatial programming during head-free gaze changes in order to achieve this sensorimotor transition [51, 52]. In these models, a comparison between the intended gaze position and an internal representation of the actual gaze position is made. By combining an efferent copy of eye location in the head with a vestibularly derived reconstruction of current head position, actual gaze position is determined. A gaze position error signal is generated when the planned and actual gaze positions mismatch. This signal drives saccadic motor activity until it is cancelled and eye movement ceases. Current findings have shown that saccadic eye movements produced in complete darkness may successfully acquire a recently sighted Earth-fixed object after ceasing head angular [53, 54] and linear displacement [55]. These saccadic eye movements are spatially targeted utilising semicircular and otolithic vestibular information that has been stored in memory. The development of this capacity suggests that a vestibular signal with functional significance has access to the mechanism that generates saccades and may, thus, be crucial in shifting eye-head focus. This study's initial objective was to look at the eye and head target acquisition system before and after adaptation to microgravity in light of the known changes to VOR function during spaceflight and the probable vestibular coding that underlies saccadic spatial coding. It is possible to focus the eyes on a small item of interest that is moving in relation to a fixed background and follow it voluntarily without moving the head thanks to a unique oculomotor system found in the brain (smooth pursuit response). The velocity differential between the object (target) and the immediate eye motion is what largely drives this process. However, to maintain moving things in study field of vision and study eyes focused within the orbit of the skull, study often track moving items of interest with a mix of eye and head motions. The vestibulo-ocular reflex (VOR), which is activated by impulses from the vestibular system, attempts to counter-rotate the eyes as study spin study head to follow a target in an effort to maintain the gaze position, which is defined as the location of the eye with regard to space. It is necessary to somehow nullify the eye movement command signal from the VOR in order to allow gaze position to shift in tandem with target location in order to track the moving target while simultaneously moving the head. Although other signals may also contribute [59-61] and the internal strength of the VOR may be slightly dampened [58, 62], studies have demonstrated that the smooth pursuit system is where the predominant signal that cancels the VOR during eye-head tracking originates [56-58]. The saccadic system offers a mechanism that quickly corrects for gaze position mistakes by coding ballistic eye movement commands based on perceived positional changes between the target and the centre of focus, which is physically represented by the foveal region of the retina. These saccadic eye movements can be utilised to adjust the gaze for any shortcomings in the smooth pursuit system's capacity to send out enough eye movement command signals to cancel the VOR's command signals. According to Russian researchers' findings [63], reductions in eye movement amplitude (under-shooting) and the emergence of correcting saccades were seen early in flight on days 3 and 5, which indicated modifications in pursuit tracking of vertical pulsing motions of a point stimulus. The pursuit of a stimulus travelling vertically or diagonally during flight also declined, while the corresponding saccadic movements remained unaltered. Following prolonged exposure to microgravity on flight days 50, 116, and 164, as well as after flight, the effects of microgravity on the pursuit function were most noticeable early on day 3 of the study. Following the in-flight execution of active head motions, pursuit was seen to be enhanced, suggesting that the defects in pursuit function identified in microgravity may have been of central origin [63]. Even while postflight tracking appeared to reveal gaze alterations equivalent to target motion, further analysis of these data shows that the relative contributions of saccades and smooth pursuit eye movements to the overall gaze varied in comparison to preflight values. Postflight gazing depended substantially more on saccadic inputs that were both more frequent and had greater amplitudes because of location mistakes. Additionally, slow phase eye velocity was actually moving in the opposite direction of head motion, showing that the smooth pursuit system only partially cancelled the VOR. The latter indicates that spaceflight adaptation either resulted in a significant change in the gain of the VOR, a decrease in the effectiveness of the smooth pursuit system, or both. On the other hand, testing performed by two cosmonauts during the ARAGATZ mission in the Mir Station revealed that smooth horizontal and vertical pursuit remained constant in flight [64]. Results of related saccadic tasks, however, revealed: (1) a propensity toward overshooting a horizontal target early in flight with high accuracy later in flight; (2) an increase in saccade velocity; and (3) a tendency toward a decrease in saccade latency. When the inertial environment changes, the brain interrupts a complicated physiological integration of inputs and perception that is necessary for the stability of the visual world during voluntary eye and head movements. The ocular motor system's performance is constantly calibrated and adjusted to provide optimal visual acuity during microgravity adaptation and eventual return to Earth. For optimal physiological function in another inertial environment, vestibulo-ocular motor motility adaptation in one inertial environment is not acceptable. Additionally, compensatory eye movements that are improper for the changing inertial environment are caused by an incorrect perception of one's own motion or that of the surroundings. This causes the sensory-motor system to further deteriorate. The best way to

characterise physiological failure of eye movement is to take function into account. Images of the visible world are stabilised on the retinal fovea thanks to the coordination of the vestibular, optokinetic, and visual fixation systems. Their job is to maintain a steady stare. Vergence, saccades, and smooth pursuit combine to find and hold items of interest on the fovea. Their purpose is to direct the eyes. In order to determine if spaceflight crew members could carry out both of these tasks, DSO 604 OI-3 was created. Particularly, during and soon after a gravito-inertial transition, such as exposure to microgravity and return to Earth, physiologic loss of eye movement function occurs. When this occurs, the ability to perform one or more of the following tasks may be hindered: (1) maintain an image on the retina when the head is stationary; (2) maintain an image on the retina during brief head movements; (3) maintain an image on the retina during sustained rotation of oneself or one's surroundings; (4) maintain an image of a moving target on the retina; (5) bring images of objects of interest onto the fovea; or (6) Keep correct impressions of one's own motion and the motion around them. Failure to acquire and/or sustain an image of interest on the fovea is the ultimate common pathway of dys-function in all of these reactions. During spaceflight activities, a vestibulo-ocular sensory-motor system that is improperly adapted for the inertial environment may cause errors in spatial orientation, delays in visually capturing operationally relevant targets, switch throws, satellite capture, object location, or object manipulation. Errors in information gathering from instruments, switch throws, attitude control, altitude perception, pursuit of an object that is moving or stationary in relation to the crew member, or delays in chase and capture of visual, tactile, or aural targets might happen during a trial. Errors during nominal egress activity may include trouble acquiring a visual target, pursuing a moving object, or having incorrect perceptions that lead to incorrect head stabilisation techniques that can compromise locomotion and postural stability. Emergency egress mistakes may result in issues that might lead to injuries to people. The following factors are thought to influence the chance of an operational failure: (1) flight length—the longer the trip, the greater the risk; (2) smoke, darkness, crew size, and situations where the Shuttle is in an unusual attitude; and (3) previous spaceflight experience. The result of improper reaction patterns that culminate in failure in an operational context is risk. Eye movements must be exact and accurate to avoid putting the crewmember at risk of being exposed to the hazards of the flying environment. Environments that demand continual attention, prompt action, and precise visual target identification and/or location are linked to higher risk. Therefore, danger is determined by the crew members' capacity to accurately assess their direction in three dimensions. Specifically, orientation is understood to include accurately determining one's own or a spacecraft's dynamic location and attitude in three dimensions. The crucial term here is "dynamic," which denotes complete awareness of the spacecraft's velocity as well as the instruments' static positions and a geographic point of reference. Operationally, spatial disorientation is defined as crew member loss of veridical orientation. Spatial disorientations are divided into one of two groups for ease of use and nomenclature uniformity in the aerospace environment. Loss of orientation without the crew member's knowledge is referred to as a spatial disorientation in the Type I category. In this situation, crew members may identify instruments and geographic landmarks incorrectly, fail to accurately perceive their position in space, and act based on false impressions. In the Type II disorientation category, crew members may resolve the sensory conflict and are aware that they are bewildered. It is crucial to understand that spatial disorientation may happen without the knowledge of the pilot/commander or any other crew members, and that it really is extremely probable to do so. Even when crew members fully understand the immediate consequences of their spatial disorientation, and realise that head movements cause vision to blur or that they threw the wrong switch, it is frequently given less importance than it deserves, and the importance decreases with time since the incident. Accurate and prompt foveation of visual targets is necessary, in part, to prevent spatial disorientation. The basic performance standards that will enhance foveation and the veridical impression of accurate spatial orientation are defined by anatomical, physiological, and physical characteristics. Depending on the author or measuring method, it has been stated that the anatomy of the eye's fovea subtends a viewing angle ranging from 0.25° to 4.0°. Hostudyver, it is evident that a linear function (as explained psychophysically) demonstrates that visual acuity declines by a factor of two to three by the time gaze has deviated by as little as 1.0° from absolute foveal centre. Therefore, to retain the chosen object within roughly 0.5° relative to the central foveal gaze is necessary for clear, unambiguous perception. The command procedure used to acquire a target affects how long it takes to foveate a target physiologically. Only approximately a tenth of study visual field is typically seen clearly, but study are not blinded since study eyes are constantly moving (small saccades) to focus the centre fovea toward the object of interest. Hostudyver, the physiological cost of the brief corrective saccades is about 200 milliseconds each saccade. Target acquisition physically depends on the target's nature (spatial frequency) and position (distance and direction the head and eye must be turned to foveate the target). Researchers have evaluated the function of vestibular-based subsystems before, during, and just after exposure to microgravity [17, 18, 65]. Although these assessments offer information unique to one or more sensorimotor subsystems, there is minimal evidence of changes in the methods used to coordinate the subsystems or in the methods used to facilitate the performance of normal, goal-directed actions. The following methods studyre chosen to be used during the process of adapting to microgravity: (1) festudy head movements during the mission's early stages; (2) reliance on either an internal coordinate system (intrinsic) or environmental coordinates (extrinsic) for spatial orientation; and (3) compensation for the shifting importance of proprioceptive information as the mission progressed. Techniques learned while in space are applied to behavistudy right after a return from orbit. Performance will suffer as a result of the newly learned behavistudy, which is inappropriate, and reactions, particularly in non-nominal settings. Goal-directed head-and-eye coordination exercises can be used to evaluate these methods. In order to investigate the emergence or alteration of goal-oriented strategies needed to maintain effective gaze when the interactive sensorimotor systems required for this function studyre altered after exposure to the stimulus rearrangement of spaceflight, the study's primary goal was to link changes in the newly developed strategy to changes in parameters that would impair performance.

METHODS FOR TARGET ACQUISITION:

An orienting gaze movement typically involves a head movement, a saccade of the eyes, and an eye movement directed by the VOR as a reflexive compensating eye movement to bring a particular area of the visual field onto the fovea. When the angular displacement of the target exceeds either the physiological or physical limits of eye rotation, a saccade normally guides the eye either onto the target for targets with a minor angular displacement or toward the target. The head normally moves after the eye has moved in the orbit because it is a larger mechanical device and has more inertia than the eye. The semicircular canals are stimulated by head movements, which results in an eye movement through the VOR that is swifter and moving in the opposite direction from the head movement. The compensatory VOR swaps the final angular position of the head for the original eye saccade, bringing the eye back to its natural straight-ahead position in the orbit of the skull. Prior to flying, the majority of observations relied on regular head and eye

motions to aid with target acquisition. Immediately after flight, gaze-bringing tactics studyre adopted that didn't always match those shown by other researchers who have looked into changes in strategies related to verbal instructions and target predictability. Following flight, there was a constant tendency for targets close to or beyond the effective oculo-motor range (50°), as determined by Guitton and Volle [76], for the head movement to the target to be delayed. A VOR that occurs after the initial eye saccade and tends to divert attention might emerge from such a delay. First, in comparison to preflight, the head's travel to the target in postflight is delayed, and both the head's ultimate location and its velocity are decreased. As a result, the VOR was started at the wrong moment and diverted attention away from the target during the postflight measurement. Large anti-compensatory saccades studyre necessary to refocus on the object as a result of the postflight delay. Studies show how to acquire a target in the vertical plane beyond the EOM at all times of flight. The subject attempted to acquire the target using the eyes, as observed in the preflight experiment. Eye movement preceded head movement, and gaze was created by the location of the eyes. The visually aided vestibulo-ocular reflex (VVOR), which was created as the head started moving, diverted attention away from the object. Then, to keep the attention steady, both the head and a corrective eye saccade studyre employed. During the flight, a new plan of attack was created. Even though the head movement was considerably decreased in both velocity and displacement, the eye was still employed to establish gaze (flight days 1 and 8). The frequency and speed of the eyes' saccades did not correspond to a typical VVOR response, but instead had a larger gain than usual. Most of the strategy's elements, such as eye target attainment, low head velocity, and many saccades, are evident in the ansstudyrs for R+0 and R+1 days. R+4 saw a return to pre-flight levels. Data from several studies and subjects studyre combined in an initial effort. The findings on five subjects chosen at random are shown below, hostudyver because each astronaut chose a different strategy, individual patterns studyre lost in the standard descriptive and multivariate statistical analysis. So, instead of using traditional analysis, study tried to create strategic groups. One method involved categorising ansstudyrs according to Zangemeister and Stark's [77] observations of head and eye movement patterns. Only the 68° target shostudyd a substantially different delay betstudyen the start of the eye and head motions during horizontal gaze changes (preflight 0.0100.076 sec vs. post-flight 0.0700.102 sec, $p=0.015$; implies head leads eye). This delay was only significant for targets reaching the EOM range limitations (50°) and only for targets pointing upwards for vertical target acquisition (preflight 0.0420.077 sec vs. postflight 0.177184 sec; $p=0.045$). There was a considerable but not statistically significant tendency for the head to be delayed during postflight testing for all other targets in the vertical plane, including those that studyre pointing downhill. When data from all five participants studyre combined, there was a significant difference in two of the five subjects for both horizontal and vertical tar- gets within the EOM range, resulting in an average head delay of around 50 msec. When the eye and head movement techniques are effective and the interplay betstudyen the saccadic and VOR eye movements is appropriately timed, the maximal eye and head velocities define the time to bring gaze on target. The maximum eye and head speeds after flying studyre consistently lostudyd than those noticed before flight. The difference was not substantial for small target displacements (20°), but it did follow the same pattern as eye and head velocities applied to targets beyond the EOM range. Only 80% of the preflight values studyre reached for the 30° targets (pre-flight: head = $12735^\circ/\text{sec}$ vs. postflight: $10532^\circ/\text{sec}$; eye = $32946^\circ/\text{sec}$ vs. postflight: $27471^\circ/\text{sec}$; $p=0.037$). Both head and eye velocity for the 68° target in the horizontal plane studyre reduced by more than 30% (preflight: head = $19636^\circ/\text{sec}$ vs. post-flight $15044^\circ/\text{sec}$, $p=0.003$; eye = $30535^\circ/\text{sec}$ vs. post-flight $20860^\circ/\text{sec}$, $p=0.0005$). The final averages of the horizontal eye and head amplitudes before and after flying did not differ substantially from one another. The eyes, hostudyver, seemed to contribute to gaze displacement more postflight than preflight. The post-flight testing for targets beyond the EOM range revealed reduced head amplitudes ($>20\%$) in three of the five participants. Although significance levels studyre lostudyd, vertical velocities for upward target acquisition trials also reduced. No differences studyre found for the 15° target. The head velocity for the 20° target was unchanged, but the gaze and eye velocity dropped (gaze = preflight $343^\circ76^\circ/\text{sec}$ vs. postflight $274^\circ90^\circ/\text{sec}$, $p=0.021$; eye = preflight $330^\circ82^\circ/\text{sec}$ vs. postflight $244^\circ88^\circ/\text{sec}$, $p=0.038$). Beyond the EOM range, both eye and head velocities declined, hostudyver they varied more than those inside the EOM range. These variations only appeared for upward motions. Mean eye and accompanying gaze velocities rose after flight for the close target (15° ; eye: preflight $30882^\circ/\text{sec}$ vs. postflight $351238^\circ/\text{sec}$), while head velocities remained constant. Instead of combining subject data, one approach to qualitatively displaying and describing the changes in strategy includes identifying the sort of gaze movement elicited. By figuring out the order in which the directive to move the head and the command to move the eyes are given, Zangemeister and Stark [77] have made an attempt to do this. According to eye-head latencies, they have discovered that gaze shift motions may be divided into fstudy different categories. Study used a technique created by Wolfgang Zangemeister and Lawrence Stark in an effort to classify gaze shift tactics used in the target acquisition job. The latency of eye movement onset, especially the difference betstudyen the time of eye muscle stimulation (tEs) and the time of neck muscle stimulation (tHs), relative to head movement initiation, is used by this approach to identify five unique groups, referred to as Stark Types. The time of eye and neck muscle stimulation was calculated from observed values of eye movement onset (tEo) and head movement onset since head or eye EMG studyre not monitored (tHo). To do this, the relative masses of the head and eye studyre considered. Since the eye's mass is very tiny, study assumed that the commencement of the observed eye movement and the stimulation of the eye muscles occur at the same time and that the delay betstudyen the two is insignificant ($tEo - tEs = 0$). After neck EMG stimulation, the head does not move immediately because it has a considerably bigger mass. The timing of neck muscle stimulation (tHs) and the time of head movement onset (tHo) are 50 msec apart, according to Zangemeister and Stark. In order to determine the time of neck muscle stimulation, 50 msec must be removed from the recorded time of head movement beginning ($tHo - 50 \text{ msec} = tHs$). Each gaze shift may be classified as either a Stark Type I, II, IIIa, IIIb, or IV based on the latency information derived from the formula ($tEs - tHs$), depending on where the latency falls within the temporal ranges specified by Zangemeister and Stark. It is quite improbable that the delay will be precisely equal to zero, though, given that these are physiological systems and that the neck and ocular EMG are not being recorded. Because of this, study have selected a time frame, t , of approximately 25 msec around tHs where variations in tEs and tHs are almost identical. The difference betstudyen neck and ocular muscle activation must thus fall within the 25 msec t time interval in order to be a Stark Type I. A late head movement (Stark Type II) is one in which the interval betstudyen the stimulation of the neck and the ocular muscles is less than the 25 msec time frame. Because the subject was told to move their eyes and heads as rapidly yet correctly as possible to acquire the object, this kind was extremely infrequently observed in study study. The latency of neck and ocular stimulation must be within the range of the $+t$ time window to 150 msec for a Stark Type IIIa early head movement. This indicates that the head can move up to 150 milliseconds before the eye is given an instruction. In study analysis, this type was the most prevalent, with Type IIIb appearing on occasion. The definition of Stark Type IIIb also includes an early head movement in relation to the eye, but the head movement is ordered 150 msec to 500 msec before the eye movement. Before a saccade moves the eye toward the target, this kind typically causes an initial eye movement in the opposite direction of the head. A gaze change that totally depends on head movement is referred to as a Stark Type IV gaze shift. Either

the VOR is suppressed, in which case the head carries the eye to the target, or the VOR is not suppressed, in which case the head first arrives at the target and the gaze is changed there with a late eye saccade. This sort of attention shift—never observed in study study—means that the crew member was not performing the task properly. The head's velocity, its end location, and the quantity of saccades produced before gaze stabilisation all clearly demonstrate the main differences between the preflight and postflight techniques. The head movement helped the eye make a significant saccade toward the object before taking flight. A gain little above one was used to establish a typical VVOR. There were other saccades after takeoff that occurred before the ultimate gaze position, and since the gain of these saccades was significantly higher than unity, they could not have been part of the VVOR. The region shown in blue (head position 0° to maximum gaze displacement) may be integrated to obtain the total gaze error. Gaze error is mostly caused by three causes. These three factors are: (1) reaction latency; (2) time to reach ultimate gaze position; and (3) the quantity of saccadic eye movements produced. Total gaze error was much higher on R+0 over time than it was before flight, and it was substantially higher on R+6. Particularly for the objects outside of the EOM, absolute values of gaze error at R+6 were as much as 40% higher than the preflight readings. Studies also conclusively show that total gaze error was highest for objects outside the EOM, and that when postflight recovery took place, the discrepancies between the targets outside the EOM and those inside the EOM diminished. Utilizing total gaze error as a performance indicator is arguably one of the most crucial components of total gaze error analysis as a function of time. Large gaze mistakes lead to less precise target acquisition responses over time when it is crucial to get a target in the least period of time. Preflight behavior can likewise be utilised to forecast postflight or in-flight performance. This hypothesis was evaluated by calculating the absolute gaze error from preflight trials, only employing targets outside of the EOM, and then linking the absolute gaze error to the head and eye motion in the vertical plane for a given trial collected during target acquisition. The mistake was classified as either a big or small gaze error when linking it to head and eye velocity, with a small gaze error being the smallest amount in comparison to a normal Stark Type III response. The target acquisition response, which is related to the target acquisition response where the preflight gaze error was associated, is shown in studies to be a function of the head and eye motion. This evidence indicates that it is not possible to forecast postflight performance using preflight gaze error. A small trend emerged when the gaze error resulting from the in-flight responses was assessed as a function of the vertical head and eye velocities recorded after the flight. The absolute gaze errors did not clearly segregate into different groups, despite the fact that large gaze errors seemed to be linked to slow vertical eye velocities. A distinct pattern emerged when postflight vertical head and eye velocities were linked to absolute gaze errors as a function of time. Small gaze mistakes were connected to greater head and eye velocities, whereas large gaze errors were more frequently related to slow head and eye speeds. This discovery shows, among other things, that the neuronal adaptation techniques to microgravity may not have been the best for postflight performance. Higher head and eye velocities may have made things easier for astronauts and decreased gaze mistake.

STABILISED GAZE

The slope of the eye versus head velocity after saccade removal, gaze error after head movement, and maximum eye and head velocities and amplitudes were all computed as gaze stability parameters. Only the decrease in vertical head peak velocity for downhill movements revealed a significant change (preflight $80.9 \pm 15.4^\circ/\text{sec}$ vs. postflight $64.0 \pm 18.7^\circ/\text{sec}$). Once vision was recovered for the first trial or two, postflight performance typically needed a considerable saccadic eye movement to put the eye back on target. In both planes and orientations, subsequent post-flight trials immediately began to trend toward preflight baseline values, often returning to normal after first gaze stabilisation attempts. Saccadic eye movements frequently impacted postflight performance. When starting to shift their heads, subjects frequently locked their eyes in the process. Even without vision, this needed further saccades to bring the eye back to its original position. Early in-flight gaze stability tests mirrored those seen before takeoff. However, readings made later in the flight were closer to those made right after takeoff. The only VHM used during entrance, landing, and the early aftermath of landing while the crew members were still inside the spacecraft and wearing their space suits was gaze stabilisation. There was no equivalent VOR for the head movement in the horizontal and vertical planes during orbit to peak sustained gravity, the phase of entrance where the shift in gravitational forces was largest. Small head motions commonly elicited feelings of surround or self-motion that were linear in response to an angular input during this stage of flight. The lack of VOR and consequent gaze drift can be explained, among other things, by the eye movement correcting for the sense of surround and self motion.

HEAD TREMBLES WITH SINUSOIDS

The subject attempted to maintain fixation on the target while smoothly oscillating the head in either the horizontal or vertical plane in cadence with an audio tone that was sinusoidally modulated at each of the frequencies while maintaining visual fixation on the target during sinusoidal head shakes (0.2, 0.3, 0.8, and 2.0 Hz). The participant chose the angle of head oscillation because it was more comfortable. Special focus was placed on cross-axis head movements, related compensatory eye movements, and changes in head movement control when doing the analysis of the head shakes. The yaw cross axis head motions are seen in studies [45] when the head is pitched at each of the distinct frequencies. There was a good deal of secondary cross axis yaw movement, but it was modest. As anticipated, the cross axis yaw motions were highest at the lowest frequency and got smaller as it got higher, to 2.0 Hz. When the subject received visual feedback on their head position, the subject's bigger total cross-axis movement was unexpected. The postflight performance between vision and no vision, with the exception of 0.20 Hz, was inverted in comparison to preflight values, demonstrating that after flight, the absence of visual feedback led to the maintenance of head plane to the primary axis. When the head was pitched, there was no convincing evidence of roll head motions. The displacement was greater at the lowest frequencies, and it got smaller as frequency went up. For velocity, the inverse was accurate. The head did not gradually move from its original peak displacements, centred around up and down during the head shakes, to seek a new centre, therefore there was very little evidence of precession. There wasn't any variation in amplitude or velocity as a function of flight phase aside from the 0.20 Hz head shaking. Similar to head shakes caused by vision, those caused by blindness displayed a gradual decrease in displacement with rising frequency and a rise in velocity with rising frequency. Immediately following space travel (R+0), there was a continuous trend toward decreasing head shaking velocity, which was more clearly indicated at the lowest frequencies. Precession was also supported by evidence, once more

at lostudy rates. Precession is significant because it signals a loss or alteration in the spatial orientation of a crew member. At the higher frequencies, the precession tendency was stronger.

HEAD MOVEMENT

Spaceflight is thought to have a significant effect on the sensory-motor systems in charge of balance and locomotion, as shown by studies of alterations in the main postural muscles [16]. The newly modified postural control is more suited to operate in microgravity than under the influence of the gravitational pull of the Earth because of the stimulus rearrangement of the flying environment. The alterations seen in sensory-motor control as a result of space flight may also be due to muscle mass loss and ensuing strength declines. Control of the neck muscles may be impacted by all of these variables that may affect the main postural muscles. In particular, there's a chance that sensory/motor nerve terminals might experience modifications that would make controlling the neck more challenging in the environment of Earth after spaceflight. Examining head movement control after flight and contrasting it to preflight functional performance might be one method to look at these changes.

CONCLUSION

The researcher came to the conclusion that the rate sensors used to calibrate the head position in space studyre utilised to measure the horizontal head position as a function of time. This review implies that alterations in descending vestibular information and/or a change in the substrate of the sensory-motor physiology may have affected motor function.

References

1. Shaw RE, Kugler PN, Kinsella-Shaw J. Reciprocities of intentional systems. In: Warren R, Wertheim AH, editors. Perception and control of self-motion. Hillsdale, New Jersey: Lawrence Erlbaum; 1990. p 579-620.
2. Mittelstaedt H, Fricke E. The relative effect of sacular and somatosensory information on spatial perception and control. *Adv Oto-Rhinolaryngol* 1988; 42:24.
3. von Gierke HE, Parker DE. Differences in otolith and abdominal viscera graviceptor dynamics: Implications for motion sickness and perceived body position. *Aviat Space Environ Med* (in press).
4. Howard IP. Human visual orientation. New York: John Wiley & Sons; 1982.
5. Cornilleau-Peres V, Droulez J. Three-dimensional motion perception: sensorimotor interactions and computational models. In: Warren R, Wertheim AH, editors. Perception and control of self-motion. Hillsdale, New Jersey: Lawrence Erlbaum; 1990. p 81-100.
6. Bock O. Coordination of arm and eye movements in tracking of sinusoidally moving targets. *Behav Brain Res* 1987; 24:3-100.
7. Calvin WH. The cerebral symphony. New York: Bantam Books; 1989.
8. Parker DE, Parker KL. Adaptation to the simulated stimulus rearrangement of weightlessness. In: Crampton GH, editor. Motion and space sickness. Boca Raton, FL: CRC Press; 1990. p 247-62.
9. Howard IP, Templeton WB. Human spatial orientation. London: John Wiley & Sons; 1966.
10. Guedry, F. Psychophysics of vestibular sensation. In: Held R, Liebowitz HW, Tueber HL, editors. Handbook of sensory physiology; vestibular system part 2: psychophysics and applied aspects and general interpretations. Berlin: Springer Verlag; 1974. p 3-154.
11. Howard IP. The perception of posture, self motion, and the visual vertical. In: Boff KR, Kaufman L, Thomas JP, editors. Handbook of perception and human performance, vol 1. New York: John Wiley & Sons; 1986. p 18-1 to 18-62.
12. Mittelstaedt H. A new solution to the problem of subjective vertical. *Naturwissenschaften* 1983; 70:272-81.
13. Parker DE, Poston RL. Tilt from a head-inverted position produces displacement of visual subjective vertical in the opposite direction. *Perception & Psychophysics* 1984; 36:461-5.
14. Parker DE, Poston RL, Gullledge WL. Spatial orientation: visual-vestibular-somatic interaction. *Perception & Psychophysics* 1983; 33:139-46.
15. Young LR, Oman CM, Merfeld D, Watt D, Roy S, DeLuca, C, Balkwell D, Christie J, Groleau N, Jackson DK, Law G, Modestino S, Mayer W. Spatial orientation and posture during and following weightlessness: Human experiments on Spacelab Life Sciences 1. *J Vestib Res* 1993; 3:231-9.
16. Reschke MF, Harm DL, Parker DE, Sandoz G, Homick JL, Vanderploeg JM. Physiologic adaptation to space flight: neurophysiologic aspects: space motion sickness. In: Nicogossian AE, Leach CL, Pool SL, editors. Space physiology and medicine. Philadelphia: Lea & Febiger; 1994. p 228-60.
17. Reschke MF, Bloomberg JJ, Paloski WH, Harm DL, Parker DE. Physiologic adaptation to space flight: neurophysiologic aspects: sensory and sensory-motor function. In: Nicogossian AE, Leach CL, Pool SL, editors. Space physiology and medicine. Philadelphia: Lea & Febiger;

- 1994, p 261-85.
18. Clément G, Reschke MF. Neurosensory and sensory- motor function. In: Moore D, Bie P, Oser H, editors. *Biological and medical research in space*. Berlin: Springer-Verlag; 1996. p 178-258.
 19. Paloski WH, Black FO, Reschke MF. Vestibular ataxia following shuttle flights: effects of transient microgravity on otolith-mediated sensorimotor control of posture. *Am J Otolaryngol* 1993; 1:9-17.
 20. Friederici AD, Levelt WJM. Resolving perceptual conflicts: the cognitive mechanisms of spatial orientation. *Aviat Space Environ Med* 1987; 58(9 Suppl):A164-9.
 21. Harm DL, Parker DE. Perceived self-orientation and self-motion in microgravity, after landing and during preflight adaptation training. *J Vestib Res* 1993; 3:297-305.
 22. Mittelstaedt H, Glasauer S. Crucial effects of weightlessness on human orientation. *J Vest Res* 1993; 3:307-14.
 23. Wolfe JM, Held R. Eye torsion and visual tilt are mediated by different binocular processes. *Vis Res* 1979; 19:917-20.
 24. Perterka RJ, Benolken MS. Relation between perception of vertical axis rotation and vestibulo-ocular reflex symmetry. *J Vest Res* 1992; 2:59-70.
 25. Oman CM, Bock OL, Huang JK. Visually induced self-motion sensation adapts rapidly to left-right visual reversal. *Science* 1980; 209:706-8.
 26. Oman CM, Balkwill MD. Horizontal angular VOR, nystagmus dumping, and sensation duration in Space-lab SLS-1 crewmember. *J Vest Res* 1993; 3:315-30.
 27. Welch RB. Adaptation of space perception. In: Boff KR, Kaufman L, Thomas JP, editors. *Handbook of Perception and Human Performance*, vol 1. New York: John Wiley & Sons; 1986. p 24-1 to 24-45.
 28. Berthoz A, Grantyn A. Neuronal mechanisms underlying eye-head coordination. *Prog Brain Res* 1986; 64:325-43.
 29. Thornton WE, Biggers WP, Thomas WG, Pool SL, Thagard NE. Electronystagmography and audio potentials in space flight. *Laryngoscope* 1985; 95:924-32.
 30. Thornton WE, Uri JJ, Moore T, Pool S. Studies of the horizontal vestibulo-ocular reflex in space flight. *Arch Otolaryngol Head Neck Surg* 1989; 115:943-9.
 31. Vieville T, Clement G, Lestienne F, Berthoz A. Adaptive modifications of the optokinetic vestibulo-ocular reflexes in microgravity. In: Keller EL, Zee DS, editors. *Adaptive processes in visual and oculomotor systems*. New York: Pergamon Press; 1986. p 111-20.
 32. Watt DGD, Money KE, Bondar RL, Thirsk RB, Garneau M, Scully-Power P. Canadian medical experiments on shuttle flight 41-G. *Can Aeronaut Space J* 1985; 31:215-26.
 33. Benson AJ, Vièville T. European vestibular experiments on the Spacelab-1 mission: 6. Yaw axis vestibulo-ocular reflex. *Exp Brain Res* 1986; 64:279-83.
 34. Grigoriev AL, et al. Medical results of the Mir year-long mission. *Physiologist* 1991; 34:S44-48.
 35. Vesterhauge S, Mansson A, Johansen TS, Zilstorff K. Oculomotor response to voluntary head rotations during parabolic flights. *Physiologist* 1982; 25:S117-18.
 36. Lackner JR, Graybiel A. Variations in gravito-inertial force level affect the gain of the vestibulo-ocular reflex: implications for the etiology of space motion sickness. *Aviat Space Environ Med* 1981; 52:154-58.
 37. DiZio P, Lackner JR, Evanoff JN. The influence of gravito-inertial force level on oculomotor and perceptual responses to sudden stimulation. *Aviat Space Environ Med* 1987; 58:A224-30.
 38. DiZio P, Lackner JR. The effects of gravito-inertial force level and head movements on post-rotational nystagmus and illusory after-rotation. *Exp Brain Res* 1988; 70:485-95.
 39. Oman CM. Personal communication. 1991.
 40. Oman CM, Kulbaski M. Spaceflight affects the 1-g postrotatory vestibulo-ocular reflex. *Adv Oto-Rhino-Laryng* 1988; 42:5-8.
 41. Oman CM, Weigl H. Postflight vestibulo-ocular reflex changes in space shuttle/Spacelab D-1 crew. *Aviat Space Environ Med* 1989; 60:480.
 42. Oman CM, Lichtenberg, BK, Money KE. Space motion sickness monitoring experiment: Spacelab 1. In: Crampton GH, editor. *Motion and space sickness*. Boca Raton, FL: CRC Press; 1990. p 217-46.
 43. Clément G, Reschke MF, Verrett CM, Wood SJ. Effects of gravito-inertial force variations on optokinetic nystagmus and on perception of visual stimulus orientation. *Aviat Space Environ Med* 1992; 63:771-77.
 44. Guedry FE. Orientation of the rotation-axis relative to gravity: Its influence on nystagmus and the sense of rotation. *Acta Otolaryng* 1965;

- 60:30-48.
45. Guedry FE. Psychophysiological studies of vestibular function. In: Neff WD, editor. *Contribution to Sensory Physiology*. New York: Academic Press; 1965.
 46. Benson AJ, Bodin MA. Comparison of the effect of the direction of the gravitational acceleration on post-rotational responses in yaw, pitch and roll. *Aerospace Medicine* 1966; 37:889-97.
 47. Bodin MA. The effect of gravity on human vestibular responses during rotation in pitch. *J Physiol* 1968; 196:74-75.
 48. Kozlovskaya IB, et al. The effects of real and simulated microgravity on vestibulo-oculomotor interaction. *The physiologist* 1985; 28(6):51-56.
 49. Thornton WE, Moore TP, Uri JJ, Pool SL. Studies of the vestibulo-ocular reflex on STS 4, 5 and 6. *NASA Technical Memorandum* 1988; 100 (461):42.
 50. Uri JJ, Linder BJ, Moore TP, Pool SL, Thornton WE. Saccadic eye movements during space flight. *NASA Technical Memorandum* 1989; 100(475):9.
 51. Lauritis VP, Robinson DA. The vestibulo-ocular reflex during human saccadic eye movement. *J Physiol (Lond)* 1986; 373:209-233.
 52. Guitton D, Volle M. Gaze control in humans: eye head coordination during orienting movements to targets within and beyond the oculomotor range. *J Neurophysiol* 1987; 58:427-59.
 53. Bloomberg J, Melvill Jones G, Segal B, McFarlane S, Soul J. Vestibular-contingent voluntary saccades based on cognitive estimates of remembered vestibular information. *Adv Oto-Rhino-Laryng* 1988; 41:71-75.
 54. Bloomberg J, Melvill Jones G, Segal B. Adaptive modification of vestibularly perceived self-rotation. *Exp Brain Res* 1991; 84:47-56.
 55. Israel I, Berthoz A. Contribution of the otoliths to the calculation of linear displacement. *J Neurophysiol* 1989; 62:247-63.
 56. Barnes G.R. Visual-vestibular interaction in the coordination of eye and head movements. In: Fuchs & Becker, editors. *Progress in oculomotor research*. New York: Elsevier; 1981. p 299-308.
 57. Halmagyi GM, Gresty MS. Clinical signs of visual-vestibular interaction. *J Neurol Neurosurg Psychiatry* 1979; 42: 934-39.
 58. Huebner WP, Leigh RJ, Thomas CW. An adjustment to eye movement measurements which compensates for the eccentric position of the eye relative to the center of the head. *J Vestib Res* 1992; 2:167-73.
 59. Robinson DA. A model of cancellation of the vestibulo-ocular reflex. In: Lennerstrand G, Zee DS, Keller EL, editors. *Functional Basis of Ocular Motility Disorders*. New York: Pergamon Press; 1982. p 5-13.
 60. Cullen KE, Chen-Huang C, McCrea RA. Firing behavior of brain stem neurons during voluntary cancellation of the horizontal vestibuloocular reflex. II. Eye movement related neurons. *J Neurophysiol* 1993; 70(2):844-56.
 61. Cullen KE, McCrea RA. Firing behavior of brain stem neurons during voluntary cancellation of the horizontal vestibuloocular reflex. I. Secondary vestibular neurons. *Neurophysiol* 1993; 70(2):828-43.
 62. McKinley PA, Peterson BW. Voluntary modulation of the vestibulo-ocular reflex in humans and its relation to smooth pursuit. *Exp Brain Res* 1985; 60: 454-64.
 63. Kornilova LN, et al. Pathogenesis of sensory disorders in microgravity. *Physiologist* 1991; 34:S36-39.
 64. André-Deshays C, Israel I, Charade O, Berthoz A, Popov K, Lipshits M. Gaze control in microgravity: I. Saccades, pursuit, eye-head coordination. *J Vest Res* 1993; 3:331-43.
 65. Young LR. Space and the vestibular system: what has been learned. *J Vestib Res Equilibrium & Orientation* 1993; 3:203-06.
 66. Rashbass C, Russell GFM. Action of a barbiturate drug (Amylobarbitone Sodium) on the vestibulo-ocular reflex. *Brain* 1961; 84:329-35.
 67. Kowler E, Martins AJ, Pavel M. The effect of expectations on slow oculomotor control-IV. Anticipatory smooth eye movements depend on prior target motions. *Vision Res* 1984; 24:197-210.
 68. Robinson DA, Gordon JL, Gordon SE. A model of the smooth pursuit eye movement system. *Biol Cybern* 1986; 55:43-57.
 69. Blakemore C, Donaghy M. Coordination of head and eyes in the gaze changing behavior of cats. *J Physiol (Lond)* 1980; 300:317-35.
 70. Collewijn H, Conijn P, Tamminga EP. Eye-head coordination in man during the pursuit of moving targets. In: Lennerstrand G, Zee DS, Keller E, editors. *Functional basis of ocular motility disorders*. Oxford: Pergamon Press; 1982. p 369-78.
 71. Wist ER, Brandt T, Krafczak S. Oscillopsia and retinal slip. Evidence supporting a clinical test. *Brain* 1983; 106:153-68.
 72. Virre E, Tweed D, Milner K, Vilis T. A reexamination of the gain of the vestibuloocular reflex. *J Neurophysiol* 1986; 56:439-50.

-
73. Hine T, Thorn F. Compensatory eye movements during active head rotation for near targets: effects of imagination, rapid head oscillation and vergence. *Vision Res* 1987; 27:1639-57.
 74. Collewijn H, Erkelens CJ, Steinman RM. Binocular coordination of human horizontal saccadic eye movements. *J Physiol (Lond)* 1988; 404:157-82.
 75. Leigh RJ, Zee DS. *The neurology of eye movements*. Philadelphia: F.A. Davis Co.; 1991.
 76. Guitton D, Volle M. Gaze control in humans; eye-head coordination during orienting movements to targets within and beyond the oculomotor range. *J Neurophysiol* 1989; 58:427-59.
 77. Zangemeister WH, Stark L. Gaze latency; variable interactions of head and eye latency. *Exp Neurol* 1982; 75:389-406.