Modulation of Optokinetic Nystagmus in Humans by Linear Acceleration, and the Effects of Spaceflight.

by

Jock Robert Ian Christie

B. S. E., Princeton University, 1987

Submitted to the Department of Aeronautics and Astronautics in Partial Fulfillment of the Requirements for the Degree of Master in Science at the Massachusetts Institute of Technology

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MODULATION OF OPTOKINETIC NYSTAGMUS IN HUMANS
BY LINEAR ACCELERATION, AND THE EFFECTS OF SPACEFLIGHT.

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JOCK ROBERT IAN CHRISTIE

Submitted to the Department of Aeronautics and Astronautics on 25 November 1991 in partial fulfillment of the requirements for the Degree Master in Science.

ABSTRACT

Buizza et al. (1980) demonstrated that sinusoidal linear acceleration along the subject’s Y axis can cause modulation of the slow phase velocity (SPV) while viewing a constant velocity optokinetic stimulus. They concluded that the modulation in the amplitude of the slow cumulative eye position was proportional to the maximum displacement of the sled. These findings have not been confirmed by other investigators (Bles, 1991). This thesis verifies the modulation of optokinetic nystagmus (OKN) by linear acceleration, while clarifying some aspects of the interaction of visual and vestibular stimuli.

All healthy subjects exhibit reflexive eye movements in response to vestibular stimuli. These eye movements are less sensitive to otolith input than to semicircular canal input. Canal Ocular Reflexes have received more attention than the relatively weak, but observable, Otolith Ocular Reflexes. The otolith dependent Linear Vestibular Ocular Reflex (LVOR) is highly variable. LVOR gain is an inverse function of focal distance. The available visual cues during these experiments effectively decreased the focal distance and increased the gain, without serving as a tracking target.

Two independent experiments are considered in this thesis. Experiment 1 was conducted at MIT in the summer of 1991. Experiment 2 involved preflight and post-flight testing of the crew of Spacelab Life Sciences 1 (STS-40) which flew in June 1991. Both experiments used a wide field optokinetic stimulus moving horizontally at ±60 deg/sec relative to the subject. Sinusoidal sled profiles had a peak acceleration of 0.5 g, and frequencies of 0.25 Hz, 0.50 Hz, and 1.00 Hz. Eye movements were recorded using scleral search coils in Experiment 1 (MIT) and Electro-oculography (EOG) in Experiment 2. The eye position data was ‘desaccaded’ using MatLab algorithms, and sinusoidal responses were fit to the edited SPV using a least squares paradigm. Preliminary comparisons of data quality indicate the superiority of scleral coils.

Higher frequencies produced significantly larger modulation of the horizontal SPV and increased phase lags. Vertical eye movements were analyzed in Experiment 1 to explore the preliminary observation that vertical eye movements may correspond to the 'hilltop illusion.' The vertical eye movements were more erratic than the horizontal movements. There were some weak sinusoidal variations in the vertical eye velocity, and a significant downward bias component. The data from Experiment 1 was fit to several primitive transfer functions and to one previous model of the otoliths. Data from Experiment 2 was used to test for habituation and asymmetries as well as the affects of a nine day spaceflight. Significantly reduced modulation was found postflight suggesting a reduced sensitivity to otolith input. Better understanding of the interaction between visual and vestibular inputs may eventually facilitate adaptation to a zero-g environment.

Thesis Supervisor: Dr. Laurence Retman Young
Title: Professor of Aeronautics and Astronautics, Director: Man-Vehicle Lab
This opus is dedicated to the memory of Ruth A. Campbell Christie

.. Then took the other, as just as fair,
   And having perhaps the better claim,
Because it was grassy and wanted wear;
   . . I took the one less traveled by,
And that has made all the difference.
   - R. Frost

The heights by great men reached and kept
   Were not attained by sudden flight,
But they, while their companions slept,
   Were toiling upward in the night.
   - H. W. Longfellow

Truly the human eye is nothing more than a window,
   of no use unless the man looks out of it.
   - B. Torrey

That which does not kill us, makes us stronger.
   - Some naive grad student.
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Many thanks to Debbie Douglas, Lilac Muller, and Michelle Zavada for their patient analysis of tonnes of SLS-1 data.

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I am very grateful to my eager subjects, who tolerated more than I probably would of endured. To ensure subject anonymity, I can only refer to you as M, N, P, S, T, A, and B. Without your eyes and otoliths, none of this would have been possible.

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I INTRODUCTION

This thesis explores the combination of visual and vestibular stimuli by the central nervous system (CNS), and the resulting eye movements in human subjects. The utilization of visual and vestibular information by the CNS is important for spatial orientation in humans and animals. This information is used for postural control and for generating oculomotor commands. Several reflexes work concurrently to stabilize the retinal image of the outside world. It is possible to stabilize vision for a moving visual field, as well as for self-motion through stationary surroundings. Fortunately, these reflexes can also compensate for self motion through moving surroundings. The CNS mediates the combination of visual and vestibular information. The routine combination of different types of stimuli may be occasionally complicated by the absence or diminution of either visual or vestibular information. Conflicts between the sensory modalities can cause disorientation, irregular eye movements and / or nausea. Individuals may develop response patterns that favor a sensory modality that seems to be more reliable. Because of this, some subjects respond well to visual stimuli, yet respond poorly to vestibular stimuli. Conversely, other subjects prioritize vestibular information and are relatively insensitive to visual cues. Furthermore, the CNS is highly adaptable and can respond to major changes. For example, if the vestibular organs become diseased, the CNS will gradually de-emphasize vestibular information, whether the person is visually or vesticularly dependent.

This thesis examines the modulation of optokinetic nystagmus by linear acceleration. The experimental protocol for both experiments had a seated subject undergoing horizontal sinusoidal oscillations along their Y axis. They were instructed to look straight ahead at a large striped optokinetic stimulator moving to the subject's left or right at 60 deg/sec. All sled profiles had a maximum acceleration of 0.5 G, with a frequency of 0.25 Hz, 0.50 Hz, or 1.00 Hz. Buizza et. al. (1980) found that this experimental protocol elicited eye movements that were a combination of the Linear Vestibular Ocular Reflex (LVOR) and optokinetic nystagmus (OKN). They found that this protocol actually enhanced the gain of the relatively weak LVOR. The resulting slow phase velocity alternated sinusoidally about some steady state level of OKN. This fluctuation in eye speed is noticed by the subject as a slowing down and speeding up of the windowshade during a run.

Another objective of this thesis is to investigate the changes in modulated OKN that occurred following the nine day space flight of STS-40. In microgravity (freefall), there is no net gravity force field for orientation, and this produces unusual signals in the
otoliths. Presumably the semicircular canals are unaffected by exposure to weightlessness, but there is some evidence to the contrary. The absence of gravity means that the concepts of 'down' and 'tilt' are no longer relevant. The CNS must adapt to these changes in the otolith information. There are two schools of thought relevant to this adaptation process, and they predict changes in opposite directions. One interpretation is that exposure to weightlessness results in erratic and confusing otolith information. In response to these changes the CNS may reduce the gain of the vestibular system, thereby decreasing all vestibular reflexes inflight and postflight.

The alternate theory is known as the tilt-translation hypothesis. It claims that during spaceflight, all otolith information is reinterpreted as translation, since the 'tilt' concept is no longer relevant. Upon return to a 1 G environment the subject would initially interpret all otolith cues as translation and have enhanced vestibular reflexes. Both of these responses may exist and may depend on the individual and the duration of exposure to weightlessness.

1.0 Relevance of Research

The hypothesis underlying this thesis is that the central nervous system is capable of utilizing both visual and vestibular stimuli simultaneously. This thesis demonstrates that the presence of visual stimuli actually enhances the LVOR response compared to the case of purely vestibular stimuli. This was originally shown by Buizza et. al. (1980) using a similar setup. The merging of the two different sensory stimuli by the central nervous system is not linear. A simple block diagram of the relevant systems is shown in Figure 1.0. By better understanding how the brain combines these inputs and the resulting eye movements, it is possible to better understand the functions of the central nervous system. The tilt-translation hypothesis states that after exposure to weightlessness the subject should regard most otolith stimulation as translation rather than tilt. This implies that the modulation should increase postflight. Reduced modulation postflight implies that the subject has learned to ignore erratic vestibular signals. It is also possible to understand how various stimuli may combine to produce various motion sickness problems.
The Central Nervous System utilizes input from the otoliths, semicircular canals, and from the eyes. The CNS generates postural and oculomotor commands.

1.1 Coordinate System

Data was collected using both EOG and scleral search coils. Although the conventions differed for the two experiments, sign corrections were made during the analysis to ensure consistency in the presentation of all results. This was done to facilitate the analysis and clarify the presentation of data. In order to use several pre-existing analysis programs written by Merfeld (1990), the right handed coordinate system shown in Figure 1.1 was chosen. As Merfeld explains, this system is different from the left handed system commonly used by vestibular researchers elsewhere. In this case, the X axis projects out of the anterior of the subject, the Y axis extends from the subject's left side, and the Z axis is parallel to the spine, oriented upwards. The rotation measurements of roll, yaw and pitch are coincident with these axes also. Displacement of the eye to the left and down is considered positive, as is clockwise torsion from the subject's point of view. The eyeball is confined in the eye socket and can not translate. Downwards eye movements indicate positive rotation about the pitch axis. The orientation of the axes is also important in the programs written by Merfeld since rotation is not commutative.
1.2 Thesis Organization

The background chapter (II) contains a brief review of the limited literature associated with the modulation of optokinetic nystagmus. The background chapter also explains some of the relevant physiological subsystems and how they interact to produce vestibular reflexes. The experimental design (III) chapter considers the important parameters for modulated OKN and other constraints imposed by the experimental setup. The equipment chapter (IV) describes the linear acceleration sleds, the optokinetic stimulators, and the means of measuring eye movements. Differences between the two experimental setups is also explained. The analysis chapter (V) explains how the eye position data is processed to obtain velocity and Slow Phase Velocity measurements with the program NysA. Other topics include modifications to NysA to facilitate simultaneous manual editing of two axes, and the least squares method employed for curve fitting. There is also an introduction to the use of Adaptive Asymmetrically Trimmed Mean (AATM) filters to use for nystagmus analysis, followed by a brief introduction to the field of statistics of directional data. The data from both experiments is summarized in the results chapter (VI). A short modelling chapter (VII) precedes the discussion chapter (VIII). Finally, the conclusions (IX) are presented including suggestions for future research. Several Appendices provide further relevant information, including additional data summaries, introductory explanations of new equipment, numerous MatLab scripts used during the analysis, and the human use protocols.
II BACKGROUND

Scientists have examined eye movements in humans over the course of the last 200 years, because eye movements offer non-invasive evidence of the brain's activity. Vestibular stimuli, transduced by either the otoliths or the semicircular canals, can evoke an oculomotor response. Obviously, visual stimuli can also elicit eye movements. The combination of simultaneous visual and vestibular stimuli should produce an oculomotor response that is some combination of the two individual responses. In particular, this thesis will address a specific case of interaction between two different reflexive eye movements, OKN and LVOR. Research by Buizza et. al. (1980) suggests that by combining these two stimuli, it may be possible to strengthen the erratic LVOR.

2.0 Optokinetic Nystagmus

Optokinetic Nystagmus (OKN) is a fairly well known, and often studied phenomenon. OKN can be easily produced by fixating on a moving wide field image, such as a nearby train. The spatial frequency, direction, speed and extent of the image determine the nature of the response. The intensity of illumination and the subject's mental capacity / attitude are also important. For large, well lit, fields of view, the eye speed will closely match the speed of the stimulus up to 60 degrees per second, in alert subjects. This is for targets that are 90° by at least 20°, in the direction of motion, with stripes spanning seven and half degrees (RPB p. 522). At stimulus speeds below 60 deg/sec the gain is typically around 0.9. As the speed increases, the gain decreases until the oculomotor system becomes saturated. This means that even if the speed of the stimulus increases, the slow phase velocity (SPV) remains roughly constant (RPB p 523). For large optokinetic stimuli, saturation does not generally occur before the stimulus exceeds 120 deg/sec, but may occur at lower speeds for smaller stimuli.

Another important consideration while inducing Optokinetic Nystagmus is the subject's attitude, which can be partially controlled by the instructions of the experimenter. In particular, the quality of the OKN will be different if the subject is instructed to 'look' ahead or to 'stare' ahead. Generally the gain is higher for 'look' nystagmus. It is not possible to produce consistent nystagmus during all trials.

Repetitive exposure to any stimulus may cause habituation or a gradual diminution of the sensory response after several trials. Vestibular habitation and the effect of mental capacity is discussed by Collins (1974). Nearly 100 years ago Bach reported that 'weak
nystagmus was generally produced in "stupid, indifferent or phlegmatic personalities". Conversely, alert subjects and those who have taken stimulants tend to produce more robust nystagmus. The signals from the vestibular organs are presumably unchanged by repetition, therefore, any reported changes are most probably occurring in the central nervous system. Mental tasks, particularly arithmetic, have been shown to limit the diminution of the response. Other effective tasks involve answering trivial pursuit questions or naming vegetables. Habituation can be very narrow in scope. Collins reports that subjects may become habituated to a visual stimulus in one direction only, but have a 'normal' response when the stimulus is in the opposite direction. Unfortunately, the topic of habituation is poorly understood. Some authors claim that repeated exposure to an optokinetic stimulator actually increases OKN gains. Both visual and vestibular adaptation are probably taking place concurrently and at different rates during these experiments.

2.1 Vestibular Reflexes and the Hilltop Illusion

Both translational and rotational accelerations can produce reflexive eye movements. These reflexes are known as ocular reflexes and rely on vestibular input to produce eye movements. These ocular reflexes are generally divided into two categories Canal Ocular Reflexes (COR) and the less studied Otolith Ocular Reflexes (OOR).

The most common example of a COR is known ambiguously as the Vestibular Ocular Reflex (VOR). This name is somewhat misleading since VOR is a canal dominated reflex. For the sake of clarity, the canal modulated VOR will be referred to as Angular VOR (AVOR). AVOR is responsible for eye movements during head rotations. For example, if the subject's head were involuntarily or voluntarily rotated (yawed) to the left, the semicircular canals sense this rotation and convey this information to the brain via the afferent nervous system. The vestibular nucleus of the brain reflexively initiates a compensatory eye movement, to the right at approximately the same speed as the head is rotating to the left. Essentially this leaves the eyes pointing the same direction in space, preventing the image from blurring. This is a fairly fast reflex since it operates through a series of three direct synaptic connections. For this reason it is known as a ‘Three Neuron Arc.’ There are other neuronal pathways through the vestibular cerebellum that contribute to this reflex. These supplementary pathways are considerably slower and are involved in more complex responses, such as velocity storage.

The extent of the compensatory phase is limited by the size of the eye socket. For this reason, rapid anticompensatory eye movements reset the eye position during larger
rotations. The combination of alternating fast (anticompensatory) and slow (compensatory) phases is known as nystagmus. The direction of the nystagmus is labelled by the direction of the fast phases. During nystagmus, the mean eye position is typically off center in the direction of the fast phases. This can be explained by the kinematics of the eye ball, but it is advantageous because it allows the subject to see approaching targets a little bit earlier than if the mean eye position were straight ahead.

Unfortunately, AVOR does not function perfectly, and the eye speed is generally less than the head speed. The Gain (ratio of the eye speed to head speed) ranges from about 0.6 to 0.7 in humans in the dark to an ideal value of 1.0 in animals. However, humans do not suffer from perpetually blurry vision, because the retinal slip induced by the difference of head and eye velocities will also stimulate the brain to command faster eye movements. Retinal slip serves an important feedback path which allows for compensation of inaccurate vestibular based commands. If the subject can foveate on a visual target, the additional information produced as the visual image slips past the retina can be used by the brain to correct for any supra-threshold errors. The combined gain of the AVOR augmented with retinal slip is about 1.0 for humans in the light. Furthermore, the CNS is fairly plastic and can compensate for artificially induced retinal slip. Subjects can be taught to have high or low gain because of their inherent adaptability.

There are analogous reflexes driven by the otoliths known as the Ocular Otolith Reflexes (OOR). There is some anatomical evidence to suggest a three neuron arc involving the otoliths. Stimulation of the otoliths, either through tilt or translation, can thus produce eye movements. For example riding sideways in a train will produce fast phases towards the front of the train during forward acceleration. During linear acceleration, subjects tend to fixate on some object, either real or imagined. This is known as the Linear Vestibular Ocular Reflex (LVOR). Unlike AVOR which can be elicited quite easily, LVOR is rather erratic and may be sometimes absent.

LVOR is produced by an oscillating gravito-inertial force (GIF) vector. The amplitude of the net GIF actually varies at twice the stimulus frequency. Despite the lack of semicircular stimuli, the oscillating GIF vector may be interpreted by the subject as if they were travelling over the crest of hill and is therefore known as the 'hilltop' illusion. Subjective comments about the hilltop illusion typically fall into one of two categories; one aspect is the perception of subjective tilt particularly at the ends of the track. The other aspect is the feeling of going up and over the crest of a hill, but not necessarily tipping to the sides. Subjects may report either aspect individually or both together as shown in Figure 2.0.
The hilltop illusion: On Earth, oscillating linear acceleration will cause the net gravito inertial force (GIF) vector to rotate and vary in magnitude as shown in part (a). This may be interpreted by the subject in several ways illustrated above. Subjects typically feel that they are tilting at the ends of the sled motion and going over a small rise in the middle of the sled path as shown in part (c). These illusions may also appear separately. However, in weightlessness, the net GIF is always parallel to the sled rails, as shown in part (b). This is interpreted as pure translation rather than tilt.
2.2 Anatomy and Physiology:

There are four anatomical structures that are relevant to the discussion of modulated optokinetic nystagmus. These are the semicircular canals, the otoliths, the muscles of the eye, and the Central Nervous System, which sense angular acceleration, linear acceleration, produce eye movements, and command eye movements respectively. Since there is no rotational motion during this experiment, the signals from the semicircular canals should be constant and thus imply the absence of rotation. The otoliths are the only vestibular organ that should be stimulated. However, there are some anatomical irregularities that could produce a fictitious semicircular response during pure linear acceleration. Due to the sinusoidal accelerations, the net gravito-inertial force (GIF) vector oscillates at the same frequency as the sled, even though the subject does not rotate at all. The GIF vector has a peak angular acceleration over 50 deg/s², much greater than the threshold of approximately 0.1 deg/s². If the semicircular canals are not ideal, they may respond to rotating gravito-inertial force vector.

The functional unit underlying both the semicircular canals and the otoliths is the hair cell. Hair cells are minute organs that transduce displacement and are directionally sensitive, or morphologically polarized. This means that hair cells are quite sensitive to displacements along their primary axis, and respond by increasing or decreasing their firing rate. Displacements perpendicular to the primary axis have little or no effect on the firing rate of the hair cell.

The semicircular canals (SCC) sense angular acceleration by the displacement of fluid which subsequently deflects hair cells. Humans have three semicircular canals in each vestibule (inner ear) that are roughly orthogonal. It is therefore possible to sense supra-threshold accelerations about any axis. During angular acceleration, the fluid (endolymph) lags behind the rigid bone of the semicircular canal. The relative displacement of the fluid deflects the cupula, which displaces the haircells. Ideally the density of the cupula is equal to the density of the endolymph. If not, then tipping the head would deflect the cupulae and indicate a fictitious angular acceleration. It is possible for the central nervous system to compensate for minor irregularities in the density of the cupula.

The otoliths sense linear acceleration along a particular axis of the head. The threshold of detection for linear acceleration is roughly 5 milli g-s (0.05 m/s²). The otoliths consist of a flat area covered in hair cells upon which rests the otolithic membrane. This membrane contains the relatively dense (ρ = 2.94 gm/cm³) crystals of Calcium Carbonate known as otoconia. During linear acceleration the crystals tend to
remain at rest, and this causes displacement of the membrane and the underlying haircells. Tipping one's head in a gravitational field causes the otoconia to slide a short distance, displacing the hair cells.

The otoliths can be pictured as two perpendicular planes known as the utricle and the saccule. Figure 2.1 shows the hair cells in both sections are polarized in a variety of directions. The arrangement of the otoliths is not symmetric with respect to the X and Z axes, but is relatively symmetric along the Y axis. The afferent signals are conducted via the 8th Cranial Nerve to the central nervous system (CNS). The CNS presumably compares signals from haircells with a variety of polarization directions and decodes the otolith signals, estimating the direction of acceleration. However, the CNS can not accurately estimate the absolute magnitude of the acceleration. For this reason, it is difficult for subjects to estimate their orientation in high g environments. Without other sensory input, it is impossible for the CNS to determine whether the otoliths are indicating tilt or translation. Einstein's equivalence principle states that it is impossible to distinguish between a gravitational force field and translational acceleration.

Ideally the canals transduce only angular acceleration and the otoliths transduce only linear accelerations. Unfortunately this may not be universally true. Young (1972) summarizes many of the arguments regarding the possibility of crosstalk between the two vestibular organs. In the 1930's Lowenstein noted a change in the firing rate from hair cell units in the semicircular canal of the ray when inclined. He dismissed these findings as anomalous for many years. Pompiano suggested in 1971 that Lowenstein's results may have accidentally elicited caloric nystagmus due to poor thermal control. There are several theories that explain how the semicircular canals could transduce linear acceleration due to density differences within the canals. These theories include 'slosh' of the endolymph (Steer, 1964 ScD) and 'slosh' of the perilymph. Another popular theory posits that the cupula may not be neutrally buoyant, but a standard correction has been developed by the CNS for use in a 1-g environment. The cupula density has been fairly accurately measured and eliminated as a source of possible error in most cases. However, the density does change, particularly following the consumption of alcohol. A tiny discrepancy in the density of the cupula would make the semicircular canals sensitive to both tilt and translation in the uncompensated subject. Any compensation that is developed by the CNS would not hold in unfamiliar, high g regimes.

In conjunction with various other sensory systems, such as the semicircular canals, the CNS interprets the otoliths' afferent signals as either tilt or translation. This tendency can be affected by previous exposure to different gravito-inertial environments.
It is believed that weightlessness should have a profound affect on a subject's ability to
distinguish tilt from translation. Anecdotal evidence and posture studies from previous
flights confirm this hypothesis. Following spaceflight, astronauts and cosmonauts have
difficulty standing or walking in the dark, and some have reported Earth sickness. It is
believed that most otolith signals are classified as tilt before flight. During
weightlessness, astronauts learn that tilting their head is not accompanied by a vestibular
(otolith) signal. They may learn to reclassify all otolith signals as translations rather than
tilt. Theoretically this will lead to larger eye movements postflight. The changes in eye
movements after spaceflight are not well understood. One of the primary goals in
Experiment 2 is to quantify the changes in eye movements following weightlessness.

The positioning of the eye is performed by stimulation of the extra-ocular
muscles, which are attached to the eyeball and move it within the eye socket. Efferent
signals stimulate one of three pairs of extra-ocular muscles. Each pair is arranged in
push-pull fashion. The various groups are known as the horizontal (medial and lateral)
recti, the vertical (superior and inferior) recti, and the obliques. Contraction of the left
lateral rectus and the right medial rectus produces a horizontal eye movement to the left.
The oblique recti produce limited ocular torsion (± 6 degrees). Torsional nystagmus can
be produced by a rotating visual field (Jackson, 1991), or by a change in the direction or
magnitude of the net gravito inertial force vector (Law, 1991). Despite lateral
accelerations up to 0.5 g, it is anticipated that ocular torsion will not play a significant role
in these experiments due to the presence of strong vertical cues. Because the optokinetic
stimulator is attached to the sled, it may still be interpreted by some subjects as if the
entire sled were passing over the hilltop.
Figure 2.1 Details of the Vestibular System. The upper panel shows the components of the Vestibular system. The lower left panel shows a cross section of the otoliths. The lower right panel shows the morphological polarization of the otoliths. Hair cells have a primary axis along which they are most sensitive to stimulation. The axis of polarization is varies across the otolith surface. This variation enables the CNS to determine the direction of acceleration relative to the head by comparing different hair cells.
2.2 Related Research

LVOR gain is highest when subjects are focusing on near objects, which produces larger eye movements. Fixation of distant targets will suppress the LVOR response. Fixation of nearby objects is actually more of a tracking task than a reflex. Shelhamer (1990), cites a typical gain of the LVOR between 10 and 15 degrees per second per g of lateral acceleration based on Niven, Hixson & Correia (1966) and Kitchen (1983).

Niven et. al. tested four subjects in four orientations 1) Y erect 2) Y supine 3) Z supine and 4) X erect. The most pronounced LVOR was observed during modes 1 and 2. Tests were conducted both in the dark and using a glowing luminous line attached to the cart perpendicular to the stimulus direction. They recorded eye movement by measuring the corneoretinal potential, i.e. using EOG. One major drawback of using EOG is the dependence on luminance levels. Better illumination produces higher gain and better signals. Note that they did inspect the vertical eye movements for any nystagmus, however the low gain may have prevented them from observing anything noticeable. The following table summarizes an early attempt by Niven et. al. to quantify the LVOR.

<table>
<thead>
<tr>
<th>Accel. [m/s²]</th>
<th>Freq. [Hz]</th>
<th>Sled Amp. [m]</th>
<th>(A_{spv}) [deg/sec]</th>
<th>(\Phi) [deg]</th>
<th>(K) [rad/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.7</td>
<td>0.20</td>
<td>0.23</td>
<td>9.20 ± 3.03</td>
<td>26.0 ± 9.4</td>
<td>0.5556</td>
</tr>
<tr>
<td>5.7</td>
<td>0.40</td>
<td>0.90</td>
<td>9.61 ± 2.50</td>
<td>31.5 ± 11.1</td>
<td>0.0742</td>
</tr>
<tr>
<td>5.7</td>
<td>0.80</td>
<td>3.57</td>
<td>9.33 ± 2.89</td>
<td>38.0 ± 16.0</td>
<td>0.0091</td>
</tr>
</tbody>
</table>

Table 2.0 LVOR Results reproduced from Niven et. al. (1965) All trials by Niven were at 5.7 m/s². Values are shown for the amplitudes of modulation of the slow phase velocity. Phase lags are with respect to sled acceleration stimulus. The ratio \(K\) represents the amplitude of the slow cumulative eye position to the amplitude of the sled motion. This value is calculated for comparison with later tables.

Previous investigations by Buizza et al. (1980) examined a seated subject moving horizontally along the interaural (Y) axis. The subjects were looking directly at a horizontally moving Optokinetic Stimulator that spanned 60 degrees in the vertical direction, and could be adjusted to span between 15 and 90 degrees horizontally. The stimulus direction was parallel to that of the sled motion, and the stimulus frequency ranged between 20 and 120 deg/sec. The sled oscillated sinusoidally at a frequency of
0.2 Hz. By varying the amplitude of the sled's oscillations, one could adjust the maximum acceleration. Tests were conducted with peak accelerations of 0.10 g (Amp = 0.64 m) and 0.16 g (Amp = 1.03 m). During the 0.10 g runs the subject's head was fixed to a bite-board which increased the amplitude of the modulation by roughly 50% over the values in the non bite-board trials. This difference was statistically significant (p<0.1). The authors felt that the non bite-board trials may have been contaminated by unintentional stimulation of the semicircular canals. Use of a biteboard is somewhat dangerous at higher accelerations and was omitted in the 0.16 g trials. They also noted that as with stationary Optokinetic experiments that the Oculomotor response could be saturated. Saturation was not an issue at speeds below 60 deg/sec, but was quite pronounced at 120 deg/sec.

Buizza et al. reported their findings as the ratio (K) of the amplitude of the modulation of the slow cumulative eye position (Ascep) to the amplitude of the sled motion. To find the slow cumulative eye position (SCEP) it is first necessary to calculate the subject's raw eye velocity. Saccades were removed from the eye velocity to produce the Slow Phase Velocity (SPV). The integral of the SPV is essentially the slow cumulative eye position, and is essentially a desaccaded position estimate. This process is covered in more detail in the analysis chapter. The value of cumulative eye position is somewhat dependent upon the method used for 'desaccading' the raw velocity data, which had been produced by differentiating the eye position data. Buizza et. al. found the amplitude of the Ascep was less than 5° for all the trials. The results ranged from 0.034 radians / meter for subjects without a biteboard to 0.055 radians / meter for subjects with a biteboard. This modulation is equivalent to an LVOR gain of 25 deg/sec per g, which is nearly double the usual value. They also reported that the eye position generally lagged behind the sled position by 78° to 174°. Table 2.1 is reproduced from Buizza et. al. (1980), and summarizes their findings for biteboard and non biteboard cases.
Table 2.1 Modulated OKN Results reproduced from Buizza et. al. (1980) All tests conducted at a frequency of 0.2 Hz. Buizza calculated the amplitude of the modulation of the Slow Cumulative Eye Position. The phase lag was calculated relative to the sled position, and negative values indicate lag. Buizza claimed that the modulation of eye position was directly proportional to the amplitude of the sled motion. K is the ratio of the amplitude of eye position to the amplitude of sled position. K was significantly higher for the biteboard trials than for the non biteboard trials.

Buizza et. al. also claimed that vestibular stimulation enhanced the underlying LVOR. For subjects watching a shade moving at 30 deg/sec, they found that the OKN averaged 18 deg/sec while the sled was stationary and 22 deg/sec while the sled was moving. White noise was used in several trials but was later proven to have no significant impact on the amplitude of the slow cumulative eye position. They also observed that the amplitude of modulation of the slow cumulative eye position seemed to be proportional to the retinal slip velocity. In other words, subjects exhibiting strong OKN will exhibit relatively weak modulation. This suggests that subjects who respond well to the visual stimuli should have lower modulation of the SPV than subjects that are more 'vestibular' in nature.

Several observations can be made at this point about the work done by Buizza et. al. (1980). First of all, they tested only at low acceleration, supra-threshold levels. To record eyes movements they utilized the corneal reflex. But placement of a video camera in the subject's field of view undoubtedly affected the eye movements. Both experiments conducted for this thesis used higher acceleration levels, in particular 0.5 g versus 0.16 g in the Buizza study. Also the two experiments will utilize alternate means of recording eye movements, namely Scleral Search Coils (Experiment 1 ) and Electro-oculography (Experiment 2 )
Never let school get in the way of your education
- M Twain

Ye can lade a man up to th' university,
but ye can't make him think
- F P Dunne

Education is a journey, not a destination.
- unknown
III DESIGN

This thesis presents two independent but similar experiments. They have been designated Experiment 1 and Experiment 2. Although not in chronological order, Experiment 1 designates work done at MIT in July and August 1991. Experiment 2 indicates work done at various NASA facilities between March 1990 and June 1991 in conjunction with the Spacelab Life Sciences-1 mission.

Buizza et. al. limited all of their trials to 0.2 Hz with peak accelerations less than 0.2 g. They varied both the speed and the extent of the visual field. There are numerous other parameters which could contribute to modulation of optokinetic nystagmus. Several of the following factors have been previously tested.

3.0 Experimental Parameters :

a) Sled Acceleration : Both linear acceleration sleds are capable of sinusoidal profiles up to 0.8 g laterally. It is important to have the peak acceleration well above the perception threshold, which is given as 0.005 g by Arrott et. al.(1990)

b) Frequency of Sled Oscillation: Buizza et. al. (1980) tested only at 0.2 Hz. The track length determines the lowest frequency for a given acceleration level. Both sleds can generate profiles above 2.0 Hz, but such profiles have very low sled velocities and small amplitudes. Although the semicircular canals are responsive above 2.0 Hz, it is unlikely to find responses to linear acceleration above 2.0 Hz.

c) Sled Profile Shape: Only sinusoids will be used in these experiments, since they are continuously differentiable and easy to model. Buizza et. al. (1980) used sinusoids at 0.2 Hz.

d) Windowshade distance: This affects both vergence and accommodation. There is a natural preference for all subjects, typically this distance is between 2.0 meters and infinity.

e) Windowshade extent : Previous experiments used stimuli between 15° and 90° along the direction of motion. The windowshade in Experiment 2 subtended 87 by 87 degrees. The windowshade in Experiment 1 subtended 68 by 68 degrees. The windowshade was not occluded by the Helmholtz coils.
f) **Windowshade illumination**: Small fluorescent lights were added after the second data collection during Experiment 2 to ensure consistent levels of illumination. The batteries were changed regularly. The same type of lights were used throughout Experiment 1.

g) **Windowshade orientation**: The windowshade moved horizontally for both of these experiments, but a vertically moving shade could produce interesting results.

h) **Windowshade pattern**: Previous experiments and both of these experiments used a vertically-striped pattern moving horizontally. This may provide a visual clue about the vertical that suppresses the hilltop illusion.

i) **Windowshade speed**: Former experiments ranged from 20 deg/ sec to 120 deg/ sec. An intermediate value should prevent saturation of the OKN response. Saturation may inhibit modulated OKN.

j) **Windowshade type**: A planar stimulator is more realistic when undergoing simultaneous linear acceleration. However, the perceived angular speed varies as a function of the central angle, \( \omega_p = \omega_{\text{central}} / \sin(\theta) \). A painted display tends to produce stronger nystagmus than a projected display.

k) **Subject Attitude**: Alert subjects have more robust OKN. Mental tasking or distraction (Trivial Pursuit cards) helps maintain alertness. Habituation may occur after numerous exposures or if subjects are tired or apathetic.

l) **Subject orientation**: Much of the testing during Experiment 2 was in the Z axis. However this thesis is limited to results from Y axis testing only.

m) **Subject's instructions (stare versus Gaze)**: *Stare* nystagmus is generally weaker than *look* nystagmus. The subjects were instructed to 'look straight ahead and keep their eyes open.'

Both of these experiments focused on the relationship between modulated optokinetic nystagmus and the frequency of sled motion. One important constraint is the half track length (L). The maximum acceleration is \( g_{\text{max}} = 4.02 \times L \times f^2 \), where \( f \) is the frequency. Frequencies can be chosen so that all runs are the same duration.
3.1 Design of Experiment Two:

The SLS-1 vestibular experiments were initially proposed in 1978 and modified as a result of the findings of Buizza et. al. (1980) Five members of the SLS-1 payload crew were tested on the U.S. Labsled in Houston. Testing of one crew member was discontinued for medical / operational reasons. Tests were done in both the Y and Z orientations, although only the Y axis tests will be discussed here. Subjects viewed a horizontally moving optokinetic stimulator ('windowshade') while undergoing horizontal sinusoidal motion along their Y axis, with a maximum acceleration of 0.5 g. The stimulus frequencies were either 0.25 Hz or 1.00 Hz, and the trials were initially 44 seconds in length. Several subjects complained about the low frequency runs, reporting stomach awareness. For this reason, all trials were shortened to 24 second runs. This enabled more repetitions and a better assessment of the repeatability of this response. Horizontal and vertical eye movements were recorded using EOG. Eye position data was initially of quite poor quality due to numerous ground loops. These were slowly eliminated, at our request, which improved the data quality. Electrodes were placed the subjects 30 minutes prior to the windowshade test to allow the electrodes to stabilize before the beginning of the experiment.

SLS-1 experiments were conducted periodically before the mission. Nominally these tests were performed 150, 90, 45, and 15 days prior to launch. The five preflight tests were done in both Y (lateral or interaural) and Z (longitudinal or rostrocaudal) axes. There was subsequent postflight testing in the Y axis on the day of the landing (R+0), the second day postflight (R+2), and the seventh day (R+7). Due to scheduling constraints, we were unable to run complete protocols on the first two days postflight.

The protocol for Experiment 2 is shown in below in Table 3.0. It involved two runs in both direction at both 0.25 Hz and 1.00 Hz. The acceleration was 0.5 g for all moving runs. Runs included windowshade motion in both directions while the sled was moving and while the sled was stationary. Horizontal and vertical eye calibrations were done at the beginning, middle and end of the protocol.

One of the more interesting findings was based on anecdotal evidence of a strong 'hilltop illusion' in one subject. The oscillating lateral acceleration produces an increased net gravito-inertial force (GIF) vector, which rotates and may lead to the hilltop illusion as
Table 3.0: Protocol for Experiment 2 (SLS-1) There are three types of trials in this protocol. Calibrations were performed at the beginning, middle and end of the protocol using a 3 point horizontal and vertical calibration. There were dual sets of markings on both axes, between 10 and 20 degrees. The outer markings were generally used. During runs #4 and #10 (dynamic calibrations) the sled was stationary and the windowshade was moving at the regular speed. The remainder of the runs had the sled moving in 0.5 g sinusoids at 0.25 or 1.00 Hz. Negative windowshade velocity indicates the windowshade was moving to the subject’s right. Note that trials to the right always preceded trials to the left.

shown in Figure 2.0. The hilltop illusion occurs even though the semicircular canals are (ideally) not stimulated. All runs for SLS-1 experiment were conducted in the light, which would tend to suppress the illusion if the subjects could see the walls of the room. The subjects could only see the windowshade, which was attached to the sled. This tended to suppress the illusion somewhat, due to the presence of the vertical stripes on the windowshade. However, some subjects reported that the windowshade was tilting with them, and was not indicating up. Since the windowshade always moved with them, the hilltop illusion occurred in those individuals prone to observing it.

The data from the subject who experienced the strongest hilltop illusion revealed a noticeable pattern of vertical eye movement at twice the stimulus frequency. As the subject ascended and descended the perceived hill, she subconsciously responded as if she were keeping her eyes fixed on a vertically static target. This response was highly variable and typically corresponded to the subjective feeling of motion. Regular vertical eye movements were also observed in subjects that did not report the hilltop illusion.
3.2 Design of Experiment One:

In order to extend the data set obtained through the SLS-1 work, the peak sled acceleration was 0.5 g for all runs. Stimulus frequencies of 0.25 Hz, 0.5 Hz, and 1.00 Hz. were chosen so that all trials would have the same duration and contain an integral numbers of cycles. Recent results (Bles, 1991) have suggested that the modulation of Optokinetic nystagmus is much less pronounced than previously reported. It has been suggested that if the Optokinetic stimulus is too strong that it may dominate the resulting eye movements, suppressing modulation. On the other hand, inadequate Optokinetic stimulus will produce no nystagmus and the eye position will be a function only of the lateral acceleration and the subject’s focal distance. It remains to show what the best compromise is between the strength of the Optokinetic stimulus and the strength of the lateral acceleration. Furthermore, the right balance will vary between subjects, some of whom are more ‘visual’ and others who are more ‘vestibular.’

Buizza et. al. (1980) found an increased gain using the biteboard for acceleration levels of 0.1 g. It is unclear if this increased gain is due to reduced artifacts associated with subject head movements, including accidental canal stimulation. One other possible explanation is that the biteboard serves as a tactile cue, reinforcing the sensation of motion. A biteboard was not used during Experiment 1 due to the high acceleration levels of 0.5 g.

Buizza et al. claimed positional accuracy of 30’ of arc using an infrared camera to record the image of an infrared LED reflected in the convex surface of the Cornea. The signal was then processed to find the center of the reflection, known as the corneal reflex. The central part of the cornea has an approximately spherical cross section. This permits accurate calculation of the eye position based on reflections from the corneal surface (Young and Sheena, 1975) An other common measurement technique which was used in Experiment Two is called Electro-oculography (EOG). The eyes when exposed to light develop a weak electric (50 mV) corneoretinal potential which can be recorded using facial electrodes. The recorded voltage is proportional to the angular deflection of the eye. EOG data is quite variable from subject to subject, and is susceptible to biological noise due to facial movements or tension in facial muscles. This is rather disadvantageous in cases like this where the eye position data was differentiated to obtain eye velocity. Eye position data for Experiment One was obtained using the experimental Skalar Search Coils which are now installed on the MIT Linear Acceleration Sled. A new sled chair was built to accommodate the addition of the coils, which do not function
properly if there are large amounts of ferrous material within its fields. This apparatus is documented in the Master's Thesis of Glen W. Law (1991). In summary, the 'search coils', are wire coils embedded in a contact lens worn by the subject. The subject's head was restrained close to the center of some large Helmholtz coils (60 cm on a side) which produced a spatially constant magnetic flux in the test region. It was essential to minimize the amount of metal inside the large coils to ensure uniformity of the magnetic field. As the eye and search coil turn together the magnetic flux through the coil changes, which induces a measurable current. Separate field coils are modulated to provide data about the horizontal, vertical, and torsional position of the eye. The scleral search coils were not noticeably affected by the problems of facial tension or EMG activity, which yields cleaner data than was possible with EOG.

The Scleral search coils are more accurate than either the Corneal Reflex method used by Buizza or EOG. But there are several significant problems that limit the use of coils on a regular basis for gathering experimental data. 1) They are not easy to insert, requiring the use of a topical anesthetic such as Ophthetic (proparacaine HCl 0.5%) or oxybuprocaine hydrochloride 0.4% (recommended by coil manufacturer). 2) Training was necessary to ensure safety. Insertion lessons were given by Janis Cotter O. D. at the Mass Eye and Ear Institute. 3) Experimental protocol dictates that search coils should not be worn for more than 30 minutes at a time to prevent prolonged irritation. Previous experimenters have found an upper limit of ten 45 second trials in a half hour session, allowing for errors and equipment problems. 4) Finally, these disadvantages make human use committees reluctant to authorize their use.

Due to the 30 minute time constraint some previous experimenters have found that two runs per subject were necessary. Both experiments since the same stimulus was repeated to the left and to the right, with no large discrepancies*. The protocol includes one run in the dark at each frequency to investigate the hilltop illusion. One of the subjects in the SLS-1 experiments repeatedly noticed the hilltop illusion, and also exhibited noticeable vertical eye movements. The experimental protocol was subsequently modified to examine vertical eye movements during lateral linear acceleration in the dark, and to see if the eye movements corresponded to the subjective sensation of the hilltop illusion. Table 3.1 lists the protocol used in Experiment 1.
Table 3.1: Protocol for Experiment 1  There are four different types of runs in this protocol. Calibrations were performed at the beginning and end of the protocol using a 3 point horizontal and vertical calibration. Markings on both axes were at 7 degrees. During runs #5 and #9 (dynamic calibrations) the sled was stationary and the windowshade was moving at the regular speed. The remainder of the runs had the sled moving in 0.5 g sinusoids at 0.25, 0.50 or 1.00 Hz. Negative windowshade velocity indicates the windowshade was moving to the subject's right.

This protocol allowed for comparisons of trials with the windowshade going left and right. It also permitted comparison between modulated OKN runs (#2-8) with pure LVOR runs (#10-#12) would be conducted in the dark to further explore the apparent vertical eye movements associated with a hilltop illusion in some subjects. Calibrations were performed the beginning and end of the protocol to determine the appropriate scaling factors for the horizontal and vertical coils. Torsional calibrations with a subject are nearly impossible, so the torsional channel was precalibrated. In fact, calibrations are not essential with scleral search coils since the gain can be preset, however it offers a verification of the system and a double check of the calibration factors. For this experiment the gain was set at 0.0244 deg/unit for all three channels. Note that two runs were done while the sled was stationary, but with the windowshade moving at ±60 degrees per second. The data from these two 'dynamic calibrations' served as a reference for the experimental runs. These runs are needed to show the magnitude of the change in response at a particular frequency of sled motion.
### 3.3 Comparison of Protocols

There are several differences between the two experiments and the work of Buizza. Several important characteristics of each experiment are tabulated below to clarify these differences.

<table>
<thead>
<tr>
<th></th>
<th>BUIZZA</th>
<th>Experiment #1</th>
<th>Experiment #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>0.2</td>
<td>0.25, 0.50, 1.00</td>
<td>0.25, 1.00</td>
</tr>
<tr>
<td>g level</td>
<td>0.10, 0.16</td>
<td>0.50</td>
<td>0.50 (nominal)</td>
</tr>
<tr>
<td>Eye Pos.</td>
<td>IR camera</td>
<td>Coils</td>
<td>EOG</td>
</tr>
<tr>
<td>Pattern</td>
<td>Projected</td>
<td>Physical</td>
<td>Physical</td>
</tr>
<tr>
<td></td>
<td>(15° - 90° x 60° high)</td>
<td>(68° x 68°)</td>
<td>(87° x 87°)</td>
</tr>
<tr>
<td>Stripes</td>
<td>12°</td>
<td>3.2°</td>
<td>4.4°</td>
</tr>
<tr>
<td>Stim Speed</td>
<td>20-120 deg / sec</td>
<td>60 deg / sec</td>
<td>60 deg / sec</td>
</tr>
<tr>
<td>Desaccading</td>
<td>TAIS</td>
<td>NysA</td>
<td>NysA</td>
</tr>
<tr>
<td>Run Time</td>
<td>?</td>
<td>24 seconds</td>
<td>32 seconds</td>
</tr>
<tr>
<td>Discard</td>
<td>?</td>
<td>4 seconds</td>
<td>4 seconds</td>
</tr>
<tr>
<td>Other</td>
<td>Biteboard + Whitenoise</td>
<td></td>
<td></td>
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</table>
IV EQUIPMENT

The equipment used in the two experiments was generally quite similar. For both experiments a seated subject underwent horizontal acceleration along their Y axis using a linear acceleration sled. The peak acceleration was 0.5 g for all dynamic trials. The Optokinetic Stimulators ('windowshades') were similar and are described in Appendix A. The shade was at a different distance from the subject's eyes in the two experiments, but it subtended a minimum of $68^\circ$ by $68^\circ$. It was oriented to produce OKN along an axis parallel to the rails of the sled. Both windowshades used analog closed loop motor controllers with feedback from a driveshaft mounted tachometer to maintain the OKN stimulus at the nominal speed of 60 deg/sec. The issue of speed fluctuations is addressed at the end of the Analysis chapter. The windowshade was calibrated before each data session by timing 10 revolutions, in either direction, and adjusting the reference voltage.

All data was sampled at 200 Hz. using a 386 Compaq computer running Labtech Notebook. The data was then transferred to a Macintosh using the Maclink Program. Once on the Macintosh, the data was reformatted for use by Matlab, and scaled appropriately. The bulk of the analysis was done using Matlab routines such as NysA.

The eye position data in Experiment One was collected using Scleral Search Coils, and the data in Experiment Two was collected using EOG. The coil data may be compared to some of the EOG data since both experiments included trials at 0.5 g and at frequencies of 0.25 and 1.00 Hertz.

4.1 Equipment used in Experiment One:

Much of the equipment used during Experiment One had not previously been used in the Man-Vehicle Lab, and required extensive troubleshooting. This thesis indirectly verified several new devices, in particular, a new sled control computer and a relatively new eye measurement technique. Appendix B contains more information about the new SLED program.

Eye position data was obtained using the experimental Skalar Scleral Search Coils which were recently installed on the MIT Linear Acceleration Sled. The Scleral Coils and the calibration procedure are documented in Appendices C, D and F of Law (1991) The Skalar search coils used in the MVL were produced in the Netherlands and require nearly six months lead time for orders. The torsion coil has two separate wire windings, to provide position relative to the horizontal and vertical magnetic fields. It is possible to get
Figure 4.0 Combination scleral search coil schematic. This annulus contains two separate windings and can measure horizontal, vertical and torsional eye position. The horizontal/vertical coil is a simple multi-turn loop. The torsional coil is a three-dimensional wire loop in the shape of a figure eight. The two magnetic fields are in the plane of this figure.
three dimensional information from the torsion coil in conjunction with the two perpendicular magnetic fields. Figure 4.0 shows the torsional coil annulus. The inner surface has a radius of curvature of 12 mm to help the coil adhere to the sclera. This suction helps ensure accurate position data, but may lead to eye irritation.

The Sled has been previously documented in Arrott’s theses (1982, 1985). The sled seat was recently modified by Law (1991) to minimize the ferrous metal within the coils fields. The Sled was formerly controlled by the CART program written by Dr. Arrott and others. The LPS-11 computer that was used to drive the sled recently developed severe input/output problems. Fortunately, a new sled control program was implemented by Robert Grimes of Payload Systems and was tested and modified extensively during the course of this thesis. The controller resides on a 386 based PC that is used exclusively for controlling the MIT Linear Acceleration Sled. All data collection must be done by an independent computer. Future users of the new SLED program should read the introductory information contained in Appendix B.

Data was collected using a 386 Compaq (IBM compatible) machine running LabTech Notebook to record data from the coils and various other sled parameters. All five channels were sampled at 200 Hz, and were stored as binary files in the following order 1) shade 2) sled 3) heog 4) veog 5) teog. Although these labels are somewhat misleading since coils were used rather than EOG, they were retained to ensure compatibility with various sections of the NysA code.

The windowshade was built by undergraduates on the supervision of Dr. Merfeld. Figure 4.1 shows the experimental setup for experiment 1. The major pieces of equipment such as the sled chair and windowshade are evident in this figure.

4.2 Equipment used in Experiment Two:

The windowshade used on the U. S. Labsled was also designed by the MVL, and later modified by Cliff Hargrove at KSC under the auspices of Dr. Merfeld. It was located 45 cm in front of the subject and subtended 87° by 87° of the subject’s visual field. More details are given in Appendix B.

The general setup is nearly identical to that used in Experiment 1. The US Labsled was built and maintained by NASA. The control program used is a modification of the CART program formerly used at MIT. Four channels of data were taken using the same Compaq 386 computer. The only important difference was that EOG was used rather than coils. Data was also taken in the Z axis but that data is not discussed here.
Figure 4.1. Front and side view of sled apparatus used in Experiment 1. The upper view shows the windowshade open for subject access. Also visible are the large magnetic field coils and the five point safety harness. The head restraint prevents lateral head motion and contains an inflatable air bladder to ensure a snug fit. On either side of the subject's head are the two fluorescent lights used for illumination. The side view shows the windowshade in the closed position.
V  ANALYSIS

5.0  The Generalized Method of Analysis:

Data for both experiments was collected using LabTech Notebook operating on a Compaq 386. The data was then transferred to a Macintosh using Maclink and then converted to Matlab format using a program written by D. Balkwill. Although there were a couple of differences between the two experiments, the basic analysis was quite similar and is explained below. In particular, during Experiment 2 only four channels of data were recorded, but in Experiment 1 an additional channel was used to record the torsional signal from the scleral search coil. The coil data in Experiment 1 was preprocessed on the Compaq 386 to calculate Euler angles and Euler rates for the eye position and eye velocity. This step also allows the user to correct the measurements if the coils are not exactly orthogonal. The combination coils are very nearly orthogonal and this correction was unnecessary. However, it was necessary to correct for crosstalk between the channels due to rotational kinematics.

Figure 5.0 shows a simplified view of the analysis path for both Experiments 1 and 2. The Euler Angle corrections are not shown in this figure because they are used during Experiment 1 only.

Two prefatory guidelines must be clarified before explaining details of the analysis. The first four seconds of each trial were not analyzed due to the transients caused by the sudden start of sled motion which produced irregular eye movements. This thesis did not examine the time course of this transient response. Four seconds was chosen for simplicity and because it represented an integral number of cycles at each frequency. No a priori estimate of the time course of this phenomenon was made, but it was felt that most transients would have ended by four seconds. Another problem during the analysis was the presence of 'dropouts.' These periods of weak eye movements were probably caused by lack of concentration on the part of the subject and are characterized by weak OKN and by reduced modulation. Although it produces a greater estimate of the amplitude of modulation, all cycles that were more than 1.0 standard sample deviation below the mean of the original sample were discarded. 'Dropouts' were identified only by the amplitude of modulation, not by the phase or the bias component of the SPV. There is no clear statistical advantage to justify the removal of outliers. It generally produced a smaller sample with a smaller standard deviation.
For each data set, the following are performed

**SLED RUN**
Data is stored on 386 in Binary format

**MACLINK**
Converts data from 386 to Mac

**COILS_CONVERT**
Converts Binary data to Matlab Format

**NYSA**

**INIT**
Initializes Batch parameters (run once)

**BATCH**
Calculates SPV plot from position plot

**EDIT_SPV_DUAL**
Allows user to remove saccades and blinks from both channels

**JC_SINES**
Fits sine waves to sled and SPV and finds amplitudes and phases.
Also calculates circular statistics

Once the gains and phases of all runs are found, the following are performed

**DR_OKN**
Finds average amplitudes and phases

**LVOR_PLOT**
Plots the data in various formats

**BODE_JC**
Fits a Bode plot to the data

---

**Figure 5.0** Summary of basic steps in the analysis for both Experiments 1 and 2.
5.0.1 Euler Angle Calculations:

This section is applicable only to Experiment 1. Merfeld (1990) wrote several programs to calculate Euler angles and improve the accuracy of the coil data. Generally, the output from the scleral search coils is treated as if it were linear and independent. The assumption of linearity is valid to within 1.0% for eye movements less than 14 degrees in any direction from the central position. Although most eye movements are within this range this correction was used to achieve the greatest accuracy possible. This transformation is necessary because rotational transformations are not commutative. The problem is that a lateral deflection of the eyes may produce an illusory torsional response. For this reason a sign convention was set forth in the introduction to this thesis. These programs ensure that coil data is accurately transformed and this should prevent any fictitious findings. Another difficulty with using the combination search coils is that they must be exactly perpendicular to minimize crosstalk between channels. If the angle between the coils can be determined, then the crosstalk can be minimized. The interested reader should consult Merfeld (1990) for a more complete discussion.

A 3x3 matrix of direction cosines uniquely determines the orientation of the eye relative to the inertial [x y z] coordinate frame shown in Figure 1.0. Directions 1, 2 and 3 initially coincide with the x-axis, y-axis, and z-axis. $c_{ij}$ represents the cosine of the angle between the i'th direction in the rotated [x' y' z'] coordinate system and the j'th direction in the [x y z] coordinate system. Coil 1 encircles the iris and yields horizontal / vertical measurements. Coil 2 is the torsion coil which occupies nearly the same physical space as Coil 1 but behaves as if it were oriented 90 degrees to the side. The magnetic fields are parallel to the y-axis and the z-axis, so the three maximally sensitive measurements are $c_{12}$, $c_{13}$, and $c_{23}$. The 6 other direction cosines must be calculated from this information to exactly specify the orientation of the [x' y' z'] coordinate system. Table 5.1 gives the sign convention used for the data input to Euler angle program. It is possible to use Merfeld's auto4 program even if the user's coordinate axes are different since a negative sign for the scale factor effectively reverses the polarity.

<table>
<thead>
<tr>
<th>axis</th>
<th>direction cosine</th>
<th>convention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yaw</td>
<td>$c_{12}$</td>
<td>Left +</td>
</tr>
<tr>
<td>Pitch</td>
<td>$c_{13}$</td>
<td>Down +</td>
</tr>
<tr>
<td>Roll</td>
<td>$c_{23}$</td>
<td>CW +</td>
</tr>
</tbody>
</table>

Table 5.1 Sign convention used in Merfeld's auto4 routine.
The following corrections can be made if the coils are exactly perpendicular. Although the coils are very nearly orthogonal, these formulae were not used, even though the calculations would be greatly simplified. The Euler angle representation of coil orientation can be calculated from the following equations:

\[ \theta_2 = \sin^{-1}(-c_{13}) \quad \theta_1 = \sin^{-1}(c_{12}/\cos(\theta_2)) \quad \theta_3 = \sin^{-1}(c_{23}/\cos(\theta_2)). \]

which represent a rotation of the eye frame \([x' y' z']\) with respect to the coil-orthogonal frame \([x y z]\) first by rotation \((\theta_1)\) about the z axis, then by rotation \((\theta_2)\) about the intermediate \(y_1\) axis, and finally by rotation \((\theta_3)\) about the intermediate \(x_2\) axis. This represents a series of three (noncommutative) rotations, specifically yaw, then pitch, and finally roll. The complete equations used are explained in Merfeld (1990).

The combination search coil used in Experiment 1 contains two coils that are oriented at roughly 90 degrees to one another as shown in Figure 4.0. Wearne (1991) did a thorough analysis to estimate the actual angle between the two coils in a combination scleral coil. Using a set of 2 meter field coils Wearne measured the direction cosines from the two coils relative to both H and V fields, giving 2 direction cosines for each coil, and calculated the 3rd as \(c_{33} = \sqrt{1 - (c_{11}^2) - (c_{12}^2)}\). The 4 direction cosines were measured between -60 and +60 degrees horizontal deflection, in 20 degree increments. The angle between the two coils was calculated as the inverse cosine of the dot product of coil vectors 1 and 2 at each position. The estimates ranged from 89.87 degrees to 92.3 degrees, and averaged 91.04 degrees. The coils were treated as orthogonal throughout the remainder of this analysis, based on these estimates. The corrections are fairly insensitive to small errors in the angle if the coils are nearly orthogonal.

5.0.2 The basic NysA Algorithm:

A computer routine was developed to calculate the Slow Phase Velocity based on eye position data. It can identify and remove most of the fast phases of eye motion. Many previous and current members of the Man-Vehicle Lab, including Massoumnia, Merfeld and Balkwill, have aided in the development of the Massoumnia acceleration based algorithm for desaccading eye movements. This routine is written principally in Matlab and is known as NysA, or Nystagmus Analysis. It is capable of analyzing one, two, or three axes at the same time. This algorithm used digital filters to calculate three dimensional eye velocity and eye acceleration from the position signal. This algorithm
can remove a most of the saccades from the velocity signal to produce the eye's Slow Phase Velocity (SPV). According to Merfeld (1990), this process can identify roughly 95% of all saccades.

NysA first scales the eye position data and differentiates twice using a zero-phase filter, to get the velocity and acceleration profiles for each axis. The program adds the vectors from the all three axes to estimate the absolute magnitude of the acceleration as a function of time. Fast phases were identified statistically since higher accelerations were typically associated with saccades. An arbitrary cutoff was made whenever that magnitude of the total acceleration exceeded the mean plus two standard deviations of the magnitude of the total acceleration. A zeroth order interpolation of the velocity was made based on the velocity at the beginning of the saccade. Unfortunately, this was not an exact procedure and many saccades were not identified. Manual editing was used to identify and remove the remaining saccades from the slow phase velocity profile. The interpolations during manual editing are superior, in part because they are first order rather than zeroth order interpolations like during the automatic desaccading process. However, manual editing introduces a certain undesirable variability due to the human interaction. Ideally, the desaccading process would not involve any operator judgement and would be fully automated.

5.0.3 The modified NysA Algorithm (edit_spv_dual):

In its original form, NysA allowed the user to manually edit only one axis at a time. This was slightly inconsistent since the computerized routine desaccaded all axes at the same time. Furthermore, there may be meaningful information contained in the eye movements in the direction other than the one under scrutiny. In particular for Y axis tests the primary eye movements are horizontal, but may be erratic during a blink and should be ignored if possible. The exact location of a blink is difficult to determine by examining just the horizontal eye position or the horizontal eye velocity. For these reasons, an improved algorithm known as edit_spv_dual was developed jointly by the author and an undergraduate, Debbie Douglas. edit_spv_dual is simply a revised version of the basic NysA script edit_spv, but it displays both horizontal and vertical eye movements together. The computer interpolates with zeroth order saccades, which generally begin in approximately the right place. However, the end of the interpolation is generally not close to the actual velocity value. This produces unnecessary irregularities when fitting curves to the data. For this reason, edit_spv_dual allows the user to reinterpolate the computer generated saccades with two keystrokes. Saccades are removed
from both data sets simultaneously. This is also much faster than editing one axis at a
time. Due to the graphical limitations of MatLab, it is not possible to simultaneously
display a third axis, such as torsion, in a useable manner. The current implementation of
`edit_spv_dual` does not display the third axis until manual editing is complete. At that
time the modified routine will remove all saccades from the third axis using a first order
linear interpolation, based on the saccades in the first and second axes. If desired, any of
the channels could be individually edited with `edit_spv`, however this will complicate the
analysis if `edit_spv_dual` is used again later.

### 5.0.4 Adaptive Asymmetrically Trimmed Mean (AATM) Filtering

A new method for the desaccading of eye movement data was recently introduced
by Engleken and Stevens (1990). This method was not actually used in this thesis due to
discrepancies between NysA and AATM. This method is explained here only because it
will certainly be used during the remainder of SLS-1 analysis.

This method utilizes several newer filtering methods. In particular it uses Order-
Statistic filters and an adaptive asymmetrically trimmed mean (AATM) filter. One of the
more pronounced advantages of the AATM method is that it does not require manual
editing and therefore eliminates much of the uncertainty introduced by the operator, while
yielding a consistently reproducible result. The most noticeable problem with AATM is
the long computation times involved. Typically it takes one or two times the duration of
the trial for AATM to complete analysis, as it is currently implemented at MIT in C by
Dave Balkwill.

Order-Statistic filters, as the name implies, utilize the statistic properties of an
ordered set of data set to filter the data appropriately, instead of simply by using a
passive, non responsive filter. In this particular application, the OS filters examine each
point sequence and try to fit both a first and a second order polynomial based on the
adjacent points. By approaching the data point moving forward and backward through
the data we obtain several estimates of the 'best' estimate value for the point. We can
designate the estimates as $F_1$, $F_2$, $B_1$, and $B_2$, where the letter designates forward or
backward, and the order of the polynomial fit is defined by the number. If the old
estimate of the position is $x'$, then the new estimate is $x = \text{median} [F_1, F_2, B_1, B_2, x']$.
Thus this OS filter is also known as a Predictive FIR Median Hybrid filter. Repeated use
of an OS filter reveals a 'root' signal underlying the data, that is essentially a series of
second order polynomials, but is free of high frequency noise. Rather than rounding the
peaks and valleys in the data as happens during conventional linear low pass filtering, this
method actually sharpens these features. Numerous repetitions of the OS filter will slowly converge towards the polynomial root signal. However, two passes should be sufficient to clean the data.

The data from the OS filters is passed through a band-limited digital differentiator to yield the first estimate of the eye velocity. The adaptive asymmetrically trimmed mean (AATM) filter is then used to distinguish fast phases from slow phases. This is done solely on the assumption that the eye must spend less time undergoing fast phase motion than it does undergoing slow phase motion. Based upon that assumption, a histogram of the eye velocity during any sufficiently long interval should reveal a bimodal (two humped) distribution. By calculating the amount of skewness in the data (essentially mean-median) it is possible to determine which half of the histogram contains the data from the slow phases. The remaining data is averaged to estimate the Slow Phase Velocity at that particular instant.

The AATM method for desaccading eye movements seems very promising. It is apparently quite accurate in some test situations, such as with the rotating chair. However, the accuracy of AATM with this particular data could not be verified during the course of this thesis. Therefore, no data is presented based upon the AATM algorithm.

5.0.5 Gauss' Method of Least Squares:

After calculating the SPV it was necessary to determine if any sinusoidal oscillations at the stimulus frequency were present in the SPV. Various analysis routines were developed in conjunction with this thesis to investigate the gain and phase of the eye movements during an experiment. Fourier Analysis was unsatisfactory due to the large amount of noise with EOG signals. Autocorrelation provided clear evidence that the response was sinusoidal, but did not yield phase information.

Matrix inversion was used for all further analysis since it could quickly calculate the amplitude and phase response based on an assumed input. It is essential that the inputs are orthogonal over the region of interest, so the analysis was limited to offset, sine, and cosine terms. This type of matrix problem is clearly overdetermined, and requires the inversion of a rectangular matrix. The development of least squares analysis for vector quantities is explained in detail in Battin (1987 p. 646) This regression is readily accomplished using a built in MatLab function. The actual algorithm used by MatLab is not documented, but the author demonstrated that the result agrees with the calculations given below. The description in the MatLab manual also states that when solving $A x = B$ that it will solve for $x$ in a least squares fashion. The matrix $B$ is the data.
that is being analyzed. The matrix A is specified by the user, and in this case, it included terms for a constant, a sine wave and a cosine wave. A is shown in Equation 5.1 where 'f_1' denotes the primary stimulus frequency, and 'f_n' is the nth harmonic. The nth harmonic equals n times the harmonic or f_n = n*f_1. All vectors are the same length as the signal. Gauss' method of least squares is given in equation 5.2.

Eq. 5.1 \[ A = \begin{bmatrix} 1 & \sin(f_1 t) & \sin(f_2 t) & \sin(f_3 t) & \sin(f_4 t) & \cos(f_1 t) & \cos(f_2 t) & \cos(f_3 t) & \cos(f_4 t) \end{bmatrix} \]

Equation 5.2 if \( A x = B \) then \( x = (A^T A)^{-1} A^T B \)

\( B \) represents the signal, \( A \) represents the assumed disturbances from Equation 5.1 and \( x \) contains the response coefficients for the sine and cosine disturbances. These were then combined to produce a generalized amplitude and phase for both the sled velocity and the eye's slow phase velocity. A correction term was constructed during the analysis using the coefficients for amplitude and phase. The residue was calculated as the root mean square value of the signal less the correction.

Curve fitting was performed in two separate ways, hereafter called the all-cycles method and the cycle-by-cycle method. The cycle-by-cycle method analyzes each full cycle of the sled motion independently. The program automatically interrupts analysis if it detects a sled crash during a particular cycle. Outliers were previously defined as having an amplitude more than 1.0 standard deviation below the mean amplitude of the cycle-by-cycle method. These outliers were removed in some of the subsequent analysis. In the all-cycles method, multicycle sinusoids were fit to the SPV from the beginning to end of sled motion. The all-cycles response averages cycle to cycle variation and is indicative of the average response. Calculation of an average response from the cycle-by-cycle method was somewhat complicated because the values represent two dimensional quantities. Because of the different characteristics of the two methods the curve fit is always more accurate using the cycle-by-cycle method and has a larger amplitude modulation than for the all-cycles method.

The final version of this script determines the sinusoidal response at the stimulus frequency, and at the second, third, and fourth harmonics using both methods. The decision to include the fourth harmonic was based on an analysis of the amplitude of the net gravito-inertial force (gif) vector. It turns out that neither the direction nor the amplitude of the net GIF vector is purely sinusoidal, even though the lateral disturbance acceleration is a sinusoid.

Gain and phase were calculated in both experiments using both methods. As mentioned earlier, the first four seconds of each trial was discarded since the early part of
the response tended to be rather erratic. By testing at 0.25, 0.50 and 1.00 Hz, the
discarded four seconds always represented an integral number of cycles.

Least squares regression can only fit linear functions. MatLab has a built in
function to iteratively minimize the error for fitting non-linear functions. This function
was used to fit simple transfer functions to the amplitude data. A simple time delay, of
the form $e^{-j\omega t}$, was added to minimize the phase error. The time delay due to
neuromuscular transmission is about 400 milliseconds.

5.0.6 Statistics of Directional Data:

One common problem encountered while calculating the average phase was the
presence of a branch cut at +180°. The computer will average two measurements of
+179° and -179° and produce an answer of 0° with a standard deviation of +179°. A
more accurate value for the mean is 180° with a standard deviation of 1°. The branch
cut is a characteristic problem when averaging vectors, and it can not be eliminated simply
by switching the branch cut to +360°. The existence of a branch cut can lead to very
misleading answers if not treated accordingly. For this reason, there is a separate branch
of statistics dealing with directional data.

The problem of averaging vectors was first considered, not surprisingly, by
Gauss for use in astronomy. Much progress has been made during the 20th century and
it is clearly explained by Mardia (1972). Much of the data was shown to be unimodal, ie.
there was only one maximum in the data.

Phase measurements can be expressed either as an angle measured from a
reference direction or as two components, a cosine term ($c_i$) and a sine term ($s_i$) where
$\theta_i = \tan^{-1}(s_i/c_i)$ and $c_i^2 + s_i^2 = 1$. By expressing $\theta_i$ in terms of $c_i$ and $s_i$ the problem of a
branch cut is effectively eliminated. Equation 5.3 contains formulae for several basic
parameters that are frequently used.

Equation 5.3  

\[
\begin{align*}
\bar{C} &= \text{mean } (c_i) \\
\bar{S} &= \text{mean } (s_i) \\
R &= \sqrt{\bar{C}^2 + \bar{S}^2} \\
\mu &= \tan^{-1}\left(\frac{\bar{S}}{\bar{C}}\right)
\end{align*}
\]

The best estimate of the direction is given by $\mu$ and $R$ is a measure of the
concentration of the phases known as the Rayleigh parameter. The average phase was
calculated from the vector sum. The data was modelled with the most common
distribution of circular data known as the Von Mises distribution, $g(\theta, \mu_0, \kappa)$. The
concentration factor ($\kappa$), is analogous to the standard deviation ($\sigma$) for normal distributions.

Most of the scripts written for this analysis are listed in Appendix C. \textit{jc\_sines} was used to calculate gains and phases. It is rather general and can be modified to consider different stimulus frequencies. All internal phase calculations are done in radians to ensure Matlab compatibility, but the outputs are written in degrees. Average values of the gain and phase are calculated upon completion to determine if any cycles deviate substantially from the mean. Phase lags are defined as the phase difference between the sled acceleration and the slow phase velocity.

5.0.7 Possible Sources of Errors:

It is important to recognize that any signal can be represented as the sum of many sines, as is the purpose of Fourier analysis. Therefore, the analysis was limited to the first four harmonics of the stimulus frequency. This was adequate to closely replicate the SPV. A biological response at more than four times the stimulus frequency is unlikely and the residual can be treated as biological noise. Furthermore, it can be shown that quite often the third and even occasionally the second harmonics are not statistically different from zero. The fourth harmonic was chosen as the upper limit since the frequencies ranged from 0.25 Hz to 1.00 Hz.

Attempts to fit curves to finite data series can yield fictitious responses. This problem is more pronounced in shorter, noisier data series. This is one of the reasons that the data was analyzed using both the cycle-by-cycle and the all-cycles method. Therefore repeated attempts were made to fit various stimulus frequencies to a given response. By calculating the residual using the all-cycles method, it should be possible to determine which, if any, of the frequencies is present in the underlying data. This test was done for runs at both 0.25 and 1.00 Hertz. Results of these trials are shown in Fig 5.1, and the decrease in the residual is quite pronounced at the stimulus frequency.

Modulation of the Slow Phase Velocity may be due to fluctuations in the speed of the windowshade. This was investigated by fitting curves using the cycle-by-cycle method to the signal from the windowshade tach. This mean fluctuation was 0.107 deg/sec (at 0.25 Hz), 0.122 deg/sec (at 0.50 Hz), and 0.219 deg/sec (at 1.00 Hz). These fluctuations are roughly 50 times smaller than the modulation of SPV, and can be considered as irrelevant.
Figure 5.1 Residual noise as a function of fitting frequency. The upper plot shows the residue when the data was fit with sinusoids ranging in frequency between 0.10 and 1.00 Hz. The stimulus was 0.25 Hz. in the first panel, and a dip at that frequency indicates significant modulation at that frequency. Similarly the data in panel 2 is for a trial at 1.00 Hz. and was tested between 0.40 and 4.00 Hz. Note that the residues are higher for the 1.00 Hz run than for the 0.25 Hz run.
5.1 Analysis of Experiments 1 and 2:

Eye position data was recorded on the 386 using LabTech Notebook. Horizontal, and vertical eye position data was recorded, as well as sled acceleration and windowshade speed. EOG was used during experiment 2 and Scleral Search Coils were used during experiment 1. For experiment 1, torsional data was also collected and corrections were made using Merfeld's programs to reduce crosstalk between the eye position channels. The data for both experiments was transferred from the 386 using Maclink and converted to Matlab format using *Coil_convert* which was written by D. Balkwill. The Slow Phase Velocity was calculated using NysA. Manual editing was done using *edit_spv_dual* to complete the desaccading process.

Sinusoidal responses were fit using the all-cycles and the cycle-by-cycle method. Phase lags were calculated relative to the sled acceleration. Various statistical tests were performed during each trial. The parameter K was calculated for comparison with the earlier work by Buizza.

The data analysis was very similar for the two experiments and the basics steps in the analysis were shown in Figure 5.0. There are very few differences between the analyses for the two experiments.
VI Results

There were two male test subjects in both experiments one and two. The subjects in experiment one were designated A and B; and the subjects in experiment two were designated M and N. Subjects A and B were 26 and 24 years of age respectively and both were unscreened volunteers. Neither subject reported any previous vestibular inadequacies or difficulties. One of these subjects was reported suffering from graphorrhea but this was not believed to have any affect on their performance. Both subjects in experiment two underwent the entire battery of tests for SLS-1 and did not exhibit any pronounced vestibular deficiencies during this time. The second group included one NASA mission specialist who had flown previously, and a payload specialist without prior experience in space.

As explained in the Analysis chapter, sinusoids were fit to the data using two similar methods. In the all-cycle method, the entire data series was fit with one multi-cycle sinusoid. This data provides insight into the average response by examining 28 seconds of data at a time. However, it does not provide a confidence interval about the response. The other method was the cycle-by-cycle method which divided the data into individual cycles of 1, 2, or 4 second duration depending on the frequency. By dividing the data this way, it is possible to estimate the mean response and the standard deviation for the amplitude and phase. It is common for responses to disappear or 'dropout' for several seconds during a long trial. For this reason outliers were identified as cycles in which the amplitude of the modulation was more than 1.0 standard deviation below the mean value from the cycle-by-cycle method. These values were omitted from further calculation based only on the low amplitude. Therefore, the amplitude is always higher after removing outliers than before removing outliers. The all-cycle method always produces lower amplitudes than the cycle-by-cycle method.

6.1.0 Results of Experiment One: Horizontal Eye Movements

Subjects A and B were tested at 0.25, 0.50, and 1.00 Hz with a peak horizontal acceleration of approximately 0.50 g. There were three runs at each frequency, the last of which was in the dark. During the earlier runs, the windowshade was either moving left or right at 60 deg/sec relative to the subject, parallel to the sled rails. Several clear examples of modulated OKN are shown in Figures 6.0, 6.1 and 6.2 Trials with the windowshade moving left did not necessarily occur before trials with the windowshade moving right. There were also two baseline trials in which the sled did not move but the
Figure 6.0 Experiment 1: Subject B: Panels A, B, and C.
Figure 6.0 Experiment 1: Subject B: Representative graphs showing eye position (A), raw velocity (B), Slow Phase Velocity (C), and both curve fitting methods (D and E) for a run at 0.25 Hz. Positive deflections are to the subject's left. Sled motion took place between 10.0 and 42.0 seconds. Panel A shows the scaled horizontal deflection of the eye during a 12 second interval. The average eye deflection was -3.81 degrees during the interval of sled motion. The slow phases vary in speed, as shown by the steeper lines at about 28, 32, and 36 seconds. Panel B shows the raw horizontal eye velocity. Saccades occurred about every 0.3 seconds. Panel C shows the slow phase velocity, after desaccading the velocity shown in panel B. Panel D shows the Slow Phase Velocity (as dots) and the curve fit from the cycle-by-cycle method. Panel E shows the Slow Phase Velocity and the curve fit from the all-cycles method. Note that the cycle-by-cycle method fits the data better than the all-cycles method, and typically has a larger amplitude.
Figure 6.1 Experiment 1: Subject B: Panels A, B, and C.
Figure 6.1 Experiment 1: Subject B: Representative graphs showing eye position (A), raw velocity (B), Slow Phase Velocity (C), and both curve fitting methods (D and E) for a run at 0.50 Hz. Positive deflections are to the subject's left. Sled motion was took place between 10.0 and 42.0 seconds. Panel A shows the scaled horizontal deflection of the eye during a 12 second interval. The average eye deflection was -2.37 degrees during the interval of sled motion. The slow phases vary in speed, as shown by the steeper lines at about 31, 33, and 35 seconds. Panel B shows the raw horizontal eye velocity. Saccades occurred about every 0.3 seconds and lasted an average of 0.12 seconds. Panel C shows the slow phase velocity, after desaccading the velocity shown in panel B. Panel D shows the Slow Phase Velocity (as dots) and the curve fit from the cycle-by-cycle method. Panel E shows the Slow Phase Velocity and the curve fit from the all-cycles method. Note that the cycle-by-cycle method fits the data better than the all-cycles method, and typically has a larger amplitude.
Figure 6.2 Experiment 1: Subject B: Panels A, B, and C.
Figure 6.2 Experiment 1: Subject B: Representative graphs showing eye position (A), raw velocity (B), Slow Phase Velocity (C), and both curve fitting methods (D and E) for a run at 1.00 Hz. Positive deflections are to the subject's left. Sled motion was took place between 10.0 and 42.0 seconds. Panel A shows the scaled horizontal deflection of the eye during a 12 second interval. The average eye deflection was -3.02 degrees during the interval of sled motion. The slow phases vary in speed, even during individual saccades. This can be seen at time 36 and 37 seconds. Panel B shows the raw horizontal eye velocity. Saccades occurred about every 0.3 seconds and lasted an average of 0.12 seconds. Panel C shows the slow phase velocity, after desaccading the velocity shown in panel B. Panel D shows the Slow Phase Velocity (as dots) and the curve fit from the cycle-by-cycle method. Panel E shows the Slow Phase Velocity and the curve fit from the all-cycles method. Note that the cycle-by-cycle method fits the data better than the all-cycles method, and typically has a larger amplitude.
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### Table 6.0
**Experiment 1: Subject A: Horizontal eye movements**

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*Values for phase lag are not tabulated during dynamic calibrations due to lack of a reference signal. Outliers are defined as cycles with an amplitude less than 1.0 standard deviation below the mean of cycle-by-cycle method. Values are omitted from the 'After Removing Outliers' column if no outliers were present. Phase lags are denoted by positive values.*
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<td>11.03</td>
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Table 6.1 Experiment 1: Subject B: Horizontal eye movements: Upper half of table shows values from the all-cycle method. Lower half of table shows values from the cycle-by-cycle method. Bias, amplitude, residual, and phase lag are calculated for each method. * Values for phase lag are not tabulated during dynamic calibrations due to lack of a reference signal. Outliers are defined as cycles with an amplitude less than 1.0 standard deviation below the mean of cycle-by-cycle method. † Values are omitted from the 'After Removing Outliers' column if no outliers were present. Phase lags are denoted by positive values.
windowshade did. During these 'dynamic calibrations' the sled was stationary, and the nystagmus was more steady. Ideally the amplitude of SPV modulation was zero during these runs. However there was always some nonzero amplitude of modulation during dynamic calibrations due principally to biological noise.

Tables 6.0 and 6.1 contain the raw data for the horizontal eye movements of subjects A and B. Several statistical tests were performed on the bias, amplitude, and phase data from subjects A and B. These three parameters were obtained from the all-cycle method, and from the cycle-by-cycle method, both before and after removing outliers. Nine parameters were available for testing, however, the phase data was generally rather noisy and rarely used for testing. The first statistical tests examined whether habituation occurred for either subject. After proving that the values were generally repeatable, t-tests were done to show that the subjects could be grouped together. Finally the amplitude and the phase are shown to be a function of the stimulus frequency. The larger, more conservative, estimate of the t value was generally used regardless of the outcome of Bartlett test of variances.

To test for habituation, student t-tests were performed on both the bias component of the nystagmus and the amplitude of the modulation across both subjects. At each frequency the difference between the first and second trials was calculated, and there were no significant differences ($p > 0.100$) in any of the 6 categories. It was demonstrated that there were no significant directional asymmetries ($p > 0.100$). Using the same 6 categories, it was also shown that the responses of the two subjects did not differ significantly ($p > 0.100$) and they could be grouped if necessary.

A one dimensional Analysis of Variance (ANOVA) was used to prove that the variation in the amplitude of modulation was due to the frequency. Table 6.2 shows that both the amplitude and the phase of SPV modulation were significant functions of frequency. However, the bias component of the nystagmus was approximately constant at 38 deg/sec, and was not a function of frequency. Buizza found a small increase in the bias component during modulated OKN.

<table>
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<tr>
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<th>All-cycle method</th>
<th>Cycle-by-cycle (w/ outliers)</th>
<th>Cycle-by-cycle (w/o outliers)</th>
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Table 6.2 Experiment 1: Subjects A and B: Results of one dimensional Anova to determine whether the bias, amplitude, or phase was a function of the sled motion frequency (0.25, 0.50 or 1.00 Hz).
Student t-tests were performed between each frequency condition as well as for dynamic calibrations to ensure that the amplitude was a function of frequency. Table 6.3 shows grouped data for subjects A and B. Similar t-tests were done on both subjects individually. Subject A showed no significant difference in the amplitude of modulation in any condition. Table 6.4 shows that Subject B individually had some significant results. In all of the cases examined, the difference between the 0.50 Hz runs and the 1.00 Hz runs was not significant. This suggests the amplitude of modulation does not increase monotonically, but approaches some saturation value.

<table>
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<th>All-cycles at once</th>
<th>By Cycle (w/ outliers)</th>
<th>By Cycle (w/o outliers)</th>
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<td>0.25</td>
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<tr>
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<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>0.25 Hz</td>
<td>0.0126</td>
<td>0.0349</td>
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<tr>
<td>0.50 Hz</td>
<td>0.0071</td>
<td>0.0311</td>
</tr>
<tr>
<td>1.00 Hz</td>
<td>0.0020</td>
<td>0.0110</td>
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</table>

Table 6.3 Experiment 1: Subjects A and B: Comparison of modulation amplitudes by frequency. Probability values are shown for t-tests between the various conditions (ie. static v. 1.00 Hz.)

<table>
<thead>
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<th>All-cycle method</th>
<th>By-cycle (w/ outliers)</th>
<th>By-cycle (w/o outliers)</th>
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<td>0.25 Hz</td>
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<td>0.0164</td>
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Table 6.4 Subject B: Comparison of modulation amplitudes by frequency. Probability values are shown for t-tests between the various conditions (ie. static v. 1.00 Hz.)

Table 6.5 shows that for most trials the Rayleigh test is significant at the fundamental frequency but less significant at the higher harmonics. This implies that the phases of the fundamental frequency are significantly clustered. Finally, the results for subjects A and B, grouped together, are presented Tables 6.6 and 6.7. The values of K were calculated using Equation 6.1 for comparison with the values from Buizza et. al. (1980), which were shown in Table 2.1.
### Table 6.5 Experiment 1: Subjects A and B: Horizontal eye movements

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### Notes
- The fundamental is the stimulus frequency listed in the Freq. column. For dynamic calibrations, the frequency is listed as 0.00, but the analysis was performend using $f = 0.25$ Hz.
- The second harmonic equals twice the stimulus frequency. The third harmonic equals three times the fundamental frequency. The fourth harmonic is four times the stimulus frequency.
Equation 6.1 \[ K \text{ (in rad/m)} = \frac{A_{\text{sccep}}}{A_{\text{mp}}_{\text{sled}}} = \frac{A_{\text{pv}}}{2\pi f \cdot 180} \]
\[ = \frac{A_{\text{pv}}}{360 f \cdot \text{Acc}_{\text{sled}}} \cdot \frac{\pi^2 f}{90} \]

<table>
<thead>
<tr>
<th>Acc. [m/s/s]</th>
<th>Freq. [Hz]</th>
<th>Sled [m]</th>
<th>( A_{\text{pv}} ) [deg/sec]</th>
<th>( \Phi ) [deg]</th>
<th>( A_{\text{sccep}} ) [rad]</th>
<th>K [rad/m]</th>
</tr>
</thead>
<tbody>
<tr>
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<td>8.43 ± 0.53</td>
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<td>4.9</td>
<td>0.50</td>
<td>0.497</td>
<td>10.89 ± 2.87</td>
<td>56.66 ± 19.26</td>
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<td>0.1217</td>
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<tr>
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<td>1.00</td>
<td>0.124</td>
<td>13.91 ± 3.04</td>
<td>79.53 ± 3.39</td>
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Table 6.6 Summary of Experiment 1: Subjects A and B: Horizontal eye movements:
The bias, amplitude phase and K are based on the all-cycle method.

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<tr>
<th>Acc. [m/s/s]</th>
<th>Freq. [Hz]</th>
<th>Sled [m]</th>
<th>( A_{\text{pv}} ) [deg/sec]</th>
<th>( \Phi ) [deg]</th>
<th>( A_{\text{sccep}} ) [deg/sec]</th>
<th>K [rad/m]</th>
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<td>0.497</td>
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<td>56.38 ± 15.40</td>
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Table 6.7 Summary of Experiment 1: Subjects A and B: Horizontal eye movements:
The bias, amplitude phase and K are based on the cycle-by-cycle method.

K is the ratio of the amplitude of the Slow Cumulative Eye Position to the amplitude of the sled motion. This is equivalent to the ratio of the amplitude of the modulation of the Slow Phase Velocity to the amplitude of the sled velocity. If the subject were fixating on a stationary target, then K should in fact be constant as postulated by Buizza et. al. Tables 6.6 and 6.7, show that K is not a constant for either method of curve fitting. The amplitude of the SPV increases as the frequency increases, even though the peak sled velocity decreases. The amplitude and phase information from Tables 6.6 and 6.7 is presented graphically in Figures 6.3 and 6.4.
Figure 6.3 Experiment 1: Subjects A and B. Amplitude and phase plotted as a function of frequency for the all-cycle method. Error bars indicate one standard deviation. Positive phase values indicate phase lag with respect to sled acceleration.
Figure 6.4 Experiment 1: Subjects A and B. Amplitude and phase plotted as a function of frequency for the cycle-by-cycle method after removing outliers. Error bars indicate one standard deviation. Positive phase values indicate phase lag with respect to sled acceleration.
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<td>0.7±0.4</td>
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Table 6.8 Experiment 1: Subject A: Vertical eye movements: Upper half of table shows values from the all-cycle method. Lower half of table shows values from the cycle-by-cycle method. Bias, amplitude, residual, and phase lag are calculated for each method. * Values for phase lag are not tabulated during dynamic calibrations due to lack of a reference signal. Outliers are defined as cycles with an amplitude less than 1.0 standard deviation below the mean of cycle-by-cycle method. † Values are omitted from the 'After Removing Outliers' column if no outliers were present. Phase lags are denoted by positive values.
Table 6.9 Experiment 1: Subject B: Vertical eye movements: Upper half of table shows values from the all-cycle method. Lower half of table shows values from the cycle-by-cycle method. Bias, amplitude, residual, and phase lag are calculated for each method. * Values for phase lag are not tabulated during dynamic calibrations due to lack of a reference signal. Outliers are defined as cycles with an amplitude less than 1.0 standard deviation below the mean of cycle-by-cycle method. † Values are omitted from the 'After Removing Outliers' column if no outliers were present. Phase lags are denoted by positive values.
6.1.1 Results of Experiment One: Vertical Eye Movements

Tables 6.8 and 6.9 contain the raw data for the vertical eye movements at the stimulus frequency for both subjects. These vertical eye movements were analyzed because it has been hypothesized that regular vertical eye movements, may occur in subjects experiencing a hilltop illusion. The magnitude of the net gravito-inertial force vector increases and decreases at twice the frequency of the sled motion. As shown in Figure 2.0 the subject experiences maximum total acceleration at either end of the sled’s trajectory. During a 0.5 g run, the maximum GIF is 1.11 g, and the average is 1.06 g. The changes in magnitude of the GIF may be interpreted as variable weak vertical accelerations. These two effects may produce the hilltop illusion, which is an illusory sensation of passing over the crest of a hill. Variations in the vertical acceleration should produce LVOR eye movements. However, using the value of 15 deg/sec per g, this would imply a modulation of the Slow Phase Velocity of 0.9 deg/sec, which is essentially indiscernible.

Whatever modulation is present is fairly weak as shown in Tables 6.10 and 6.11. An analysis of variance (ANOVA) did not reveal any significant changes in the bias, amplitude or phase due to frequency based on the all-cycle method. The data from the cycle-by-cycle method revealed a frequency dependence before (p ≤ 0.0062) and after (p ≤ 0.0031) removing outliers. Both methods revealed a downwards tendency in bias component of the SPV, ie upwards beating nystagmus. For subject A the bias was 3.10 ± 1.05 deg/sec. (p < 0.025) and for subject B, the bias was 2.56 ± 0.68 deg/sec. (p < 0.005) This was true whether the windowshade was moving to the left or to the right, and thus cannot be explained as an alignment problem of the windowshade. This phenomenon might be explained by increase in the average magnitude of the gravito-inertial force vector. The GIF has a constant downward component of 1.0 g, however, the subject may interpret the increased force as an unsteady weak upward acceleration. This would lead to upward beating nystagmus, with downwards slow phases. This suggests an L-nystagmus of approximately 2.5 deg/sec per 0.06 g which is equal to L-nystagmus of 41 deg/sec per g. This is an order of magnitude above the value of 3 to 5 deg/sec per g for L-nystagmus reported on a centrifuge.
### Table 6.10 Summary of Experiment 1: Subjects A and B: Vertical eye movements

The bias, amplitude and phase are shown for the all-cycle method at the stimulus frequency from the sled acceleration.

<table>
<thead>
<tr>
<th>Acc. [m/s/s]</th>
<th>Freq. [Hz]</th>
<th>Bias [deg/sec]</th>
<th>(A_{spv}) [deg/sec]</th>
<th>(\Phi) [deg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.9</td>
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<td>2.90 ± 0.97</td>
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<td>4.9</td>
<td>1.00</td>
<td>3.56 ± 0.61</td>
<td>0.73 ± 0.32</td>
<td>49.5 ± 129.5</td>
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### Table 6.11 Summary of Experiment 1: Subjects A and B: Vertical eye movements

The bias, amplitude and phase are shown for the cycle-by-cycle method after removing outliers.

<table>
<thead>
<tr>
<th>Acc. [m/s/s]</th>
<th>Freq. [Hz]</th>
<th>Bias [deg/sec]</th>
<th>(A_{spv}) [deg/sec]</th>
<th>(\Phi) [deg]</th>
</tr>
</thead>
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<tr>
<td>4.9</td>
<td>0.25</td>
<td>2.82 ± 0.86</td>
<td>0.85 ± 0.31</td>
<td>60.1 ± 89.4</td>
</tr>
<tr>
<td>4.9</td>
<td>0.50</td>
<td>2.71 ± 0.98</td>
<td>1.63 ± 0.22</td>
<td>54.8 ± 84.8</td>
</tr>
<tr>
<td>4.9</td>
<td>1.00</td>
<td>3.58 ± 0.60</td>
<td>1.53 ± 0.19</td>
<td>51.4 ± 126.9</td>
</tr>
</tbody>
</table>

Although the ANOVA did not yield any significant results, there is some evidence that the vertical eye movements are somewhat regular. Table 6.12 contains the values from the Rayleigh test based on the cycle-by-cycle method after removing outliers. The Rayleigh test is a measure of whether the data is clustered or is random. Clearly, there were several trials in which the phases were significantly clustered. In nine of the 19 trials with sled motion, including three trials in the dark, the clustering was significant at the 0.01 level at the primary frequency. Furthermore, there was significant \(p < 0.05\) clustering in four of 19 trials when tested at four times the stimulus frequency. This implies a small but consistent sinusoidal modulation in the vertical direction. The phase of this modulation is consistent within runs, but not between runs.

#### 6.1.2 Results of Experiment One: Trials in the Dark

Several trials were conducted in the dark to determine whether LVOR was more pronounced following the windowshade runs. The subjects in Experiment 1 were given specific instructions to stare straight ahead during the runs in the dark. No fixation light was provided. However, the subjects were occasionally reminded to look ahead if their eyes seemed to drift from center, based on the strip chart recording of the
<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>JCA002</td>
<td>0.25</td>
<td>4</td>
<td>-60</td>
<td>0.890</td>
<td>0.0300</td>
<td>0.214</td>
<td>0.471</td>
<td>0.568</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JCA003</td>
<td>0.50</td>
<td>14</td>
<td>-60</td>
<td>0.133</td>
<td>0.324</td>
<td>0.127</td>
<td>0.190</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JCA004</td>
<td>1.00</td>
<td>23</td>
<td>-60</td>
<td>0.645</td>
<td>0.0000</td>
<td>0.230</td>
<td>0.016</td>
<td>0.390</td>
<td>0.050</td>
<td></td>
<td></td>
</tr>
<tr>
<td>JCA005</td>
<td>0.00</td>
<td>6</td>
<td>-60</td>
<td>0.143</td>
<td>0.208</td>
<td>0.934</td>
<td>0.010</td>
<td>0.105</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JCA006</td>
<td>0.25</td>
<td>5</td>
<td>60</td>
<td>0.130</td>
<td>0.578</td>
<td>0.045</td>
<td>0.852</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JCA007</td>
<td>0.50</td>
<td>14</td>
<td>60</td>
<td>0.399</td>
<td>0.504</td>
<td>0.050</td>
<td>0.131</td>
<td>0.362</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>JCA008</td>
<td>1.00</td>
<td>23</td>
<td>60</td>
<td>0.683</td>
<td>0.0000</td>
<td>0.260</td>
<td>0.202</td>
<td>0.470</td>
<td>0.010</td>
<td></td>
<td></td>
</tr>
<tr>
<td>JCA009</td>
<td>0.00</td>
<td>6</td>
<td>60</td>
<td>0.265</td>
<td>0.280</td>
<td>0.407</td>
<td>0.136</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JCA010</td>
<td>0.25</td>
<td>6</td>
<td>dark</td>
<td>0.410</td>
<td>0.543</td>
<td>0.594</td>
<td>0.804</td>
<td>0.050</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JCA011</td>
<td>0.50</td>
<td>14</td>
<td>dark</td>
<td>0.649</td>
<td>0.0016</td>
<td>0.171</td>
<td>0.184</td>
<td>0.337</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JCA012</td>
<td>1.00</td>
<td>28</td>
<td>dark</td>
<td>0.635</td>
<td>0.0000</td>
<td>0.577</td>
<td>0.001</td>
<td>0.339</td>
<td>0.050</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 6.12** Experiment 1: Subjects A and B: Vertical eye movements: Values from the cycle-by-cycle method after discarding outliers. R values are based on the Rayleigh test and indicate the clustering of the phases. Probabilities values indicate likelihood that R is from a random, essentially homogenous population. The critical values of R are dependent on the number of cycles, and are tabulated in Mardia (1972). Δ The fundamental is the stimulus frequency listed in the Freq. column. For dynamic calibrations, the frequency is listed as 0.00, but the analysis was performed using f = 0.25 Hz. θ The second harmonic equals twice the stimulus frequency. V The third harmonic equals three times the fundamental frequency. † The fourth harmonic is four times the stimulus frequency.
eye position. Focusing on the windowshade for several previous trials may have
disposed some of the subjects to focus at a distance of 63 cm. That may explain the
robustness of the LVOR. Several outstanding examples of LVOR were observed, as
shown in Figure 6.5. The modulation was quite pronounced but was not statistically
significant, primarily due to lack of repetitions. The saccades were less frequent and
noticeably slower during runs in the dark, possibly because there was no obvious target.
There was not a significant downwards bias to the SPV during runs in the dark, as there
was for runs in the light. The phase lag was generally lower than for comparable trials
during the light, but this difference was not significant. However, numerous diagonal
saccades were observed. Tables 6.13 and 6.14 summarize the findings for runs in the
dark.

<table>
<thead>
<tr>
<th>Acc. [m/s/s]</th>
<th>Freq. [Hz]</th>
<th>Bias [deg/sec]</th>
<th>$A_{spv}$ [deg/sec]</th>
<th>$\Phi$ [deg]</th>
<th>$K$ [rad/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.9</td>
<td>0.25</td>
<td>0.23 ± 0.12</td>
<td>5.72 ± 1.98</td>
<td>17.5 ± 8.8</td>
<td>0.0320</td>
</tr>
<tr>
<td>4.9</td>
<td>0.50</td>
<td>0.21 ± 0.45</td>
<td>5.66 ± 2.41</td>
<td>33.1 ± 17.5</td>
<td>0.0633</td>
</tr>
<tr>
<td>4.9</td>
<td>1.00</td>
<td>-0.75 ± 1.20</td>
<td>9.44 ± 1.21</td>
<td>60.6 ± 17.6</td>
<td>0.2110</td>
</tr>
</tbody>
</table>

Table 6.13 Summary of Experiment 1: Subjects A and B: Horizontal eye movements in
the dark: The bias, amplitude and phase are shown for the all-cycle method. The gain
($K$) is also shown.

<table>
<thead>
<tr>
<th>Acc. [m/s/s]</th>
<th>Freq. [Hz]</th>
<th>Bias [deg/sec]</th>
<th>$A_{spv}$ [deg/sec]</th>
<th>$\Phi$ [deg]</th>
<th>$K$ [rad/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.9</td>
<td>0.25</td>
<td>0.35 ± 0.05</td>
<td>4.65 ± 1.63</td>
<td>19.0 ± 6.5</td>
<td>0.0260</td>
</tr>
<tr>
<td>4.9</td>
<td>0.50</td>
<td>0.09 ± 0.44</td>
<td>6.25 ± 2.48</td>
<td>33.5 ± 16.7</td>
<td>0.0699</td>
</tr>
<tr>
<td>4.9</td>
<td>1.00</td>
<td>-0.92 ± 1.27</td>
<td>10.20 ± 1.41</td>
<td>60.0 ± 15.6</td>
<td>0.2280</td>
</tr>
</tbody>
</table>

Table 6.14 Summary of Experiment 1: Subjects A and B: Horizontal eye movements in
the dark: The bias, amplitude and phase are shown for the cycle-by-cycle method after
removing outliers. The gain ($K$) is also shown.
Figure 6.5  Experiment 1: Subject B: LVOR in the dark. Trials started at 10.0 seconds and typically ended at 42.0 seconds. The sled crashed after 32 seconds during trial JCB012.
6.2 Results of Experiment Two:

Subjects M and N were analyzed individually, and the intermediate results are tabulated in Appendix A. A preliminary visual inspection of the data revealed markedly different responses. This apparent difference was later verified statistically. Various trials were initially grouped together to produce a first estimate of the amplitude and phase of the modulation. Student T-tests were used to determine whether the groupings were statistically permissible. The majority of the statistical tests were performed using the values from the cycle-by-cycle method, after removing the outliers. Preflight data was used to estimate the bias component of the SPV, as well as the amplitude and phase of the modulation. Comparisons were made to the postflight values to determine if spaceflight had a discernible effect on the modulation. Generally speaking, increasing frequency was found to produce an increase in the amplitude of modulation, an increase in the phase lag, and increase in the residual noise.

6.2.2 Results for Subject N (preflight)

There were typically two repetitions of each condition at 0.25 Hz. and 1.00 Hz. during most of the test sessions. To address the question of habituation, parameters were compared at both frequencies to test whether trial 1 produced different results than trial 2. The difference in amplitude between trials of the cycle-by-cycle method was tested before and after removing outliers. Both tests reveal that the amplitude of the modulation is consistently higher during the first trial (p ~< 0.08). Furthermore, at 0.25 Hz, after discarding outliers, the first trial had significantly larger modulation than the second trial (p < 0.05). All subsequent tests were done using the values from the first trial only due to this evidence of vestibular habituation. Furthermore, postflight testing was often limited to only one trial.

Each frequency was tested at least eight times preflight; four times to the left and four times to the right. Tests to the right always preceded tests to the left during the four preflight sessions. Directional habituation was a possible problem, since habituation during a particular test session has already been shown to exist. Any directional habituation could be confounded with ordering effects. The amplitude of modulation was significantly higher for trials with the windowshade moving right than for trials with the windowshade moving left, based on the cycle-by-cycle data, both before (p ≤ 0.05) and after removing outliers (p ~< 0.05). The difference between bias ratios for trials to the right and trials to the left was also significant before (p ~< 0.025) and after removing outliers (p < 0.05). This suggests a difference of 12 deg/sec faster OKN when the
windowshade is moving right rather than left. This asymmetry was also noted in the
data from fitting all-cycles at once, but it was not tested statistically. The phase lag was
about 20 degrees more during trials to the right than for trials to the left and this
difference was significant \( p \approx 0.01 \). The concentration of the phases was tested to
ensure the clustering was not homogeneous. By grouping trials 1 and 2, the average
phase lag was 61 degrees and the clustering was highly significant \( p \approx 10^{-6} \).

To test for possible visual habituation, the slope of the SPV bias values as a
function of the test day were tested using regression analysis. At 0.25 Hz., the bias
decreased significantly over time when the windowshade was moving to the left, both
before \( p = 0.044 \) and after \( p = 0.036 \) removing outliers with the cycle-by-cycle
method. At 1.00 Hz., all 4 cases showed a trend to decay over time, but only the trials
to the right before removing outliers was significant \( p \leq 0.048 \).

The amplitudes were also tested across frequencies to verify that the amplitude of
the response did in fact increase as the frequency increased. Although the values were
not tested, similar trends were noted in the data that fit all-cycles at once, and in the data
from the cycle-by-cycle method after removing outliers.

<table>
<thead>
<tr>
<th></th>
<th>RIGHT SHADE</th>
<th></th>
<th>LEFT SHADE</th>
<th></th>
<th>COMBINED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>static 0.25 Hz</td>
<td>static 0.25 Hz</td>
<td>static 0.25 Hz</td>
<td></td>
<td>0.0042 0.0001</td>
</tr>
<tr>
<td>0.25 Hz</td>
<td>ns</td>
<td></td>
<td>0.0503</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.00 Hz</td>
<td>0.0161</td>
<td>0.0069</td>
<td>0.0324</td>
<td>0.0503</td>
<td>0.0020</td>
</tr>
</tbody>
</table>

Table 6.15 Experiment 2 : Subject N: Comparison of modulation amplitudes from the
cycle-by-cycle method before removing outliers. Probability values are shown for t-
tests between the various conditions (ie. static v. 1.00 Hz.)

The tendency of the response to decay over time was not present in the amplitude
of the SPV modulation at either frequency. However, the amplitude of modulation is a
highly variable quantity and is not constant across time. It is interesting to note that
while the bias decreased significantly over the course of the time, the modulation
amplitude is fairly stable.
Table 6.16: Results for Subject N (preflight) These values obtained from the cycle-by-cycle method including outliers. Left and right trials are presented separately due to asymmetries.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>4.9</td>
<td>0.25</td>
<td>-60 (R)</td>
<td>-48.9 ± 13.1</td>
<td>12.8 ± 1.4</td>
<td>55.8 ± 16.6</td>
<td>0.0715</td>
</tr>
<tr>
<td>4.9</td>
<td>1.00</td>
<td>-60 (R)</td>
<td>-49.8 ± 8.0</td>
<td>27.0 ± 7.7</td>
<td>92.9 ± 27.8</td>
<td>0.6036</td>
</tr>
<tr>
<td>4.9</td>
<td>0.25</td>
<td>+60 (L)</td>
<td>46.9 ± 8.0</td>
<td>12.4 ± 2.8</td>
<td>29.5 ± 7.7</td>
<td>0.0693</td>
</tr>
<tr>
<td>4.9</td>
<td>1.00</td>
<td>+60 (L)</td>
<td>26.3 ± 17.2</td>
<td>21.3 ± 6.0</td>
<td>78.7 ± 46.2</td>
<td>0.4762</td>
</tr>
</tbody>
</table>

Table 6.17: Results for Subject N (preflight) These values obtained from the cycle-by-cycle data after removing outliers. Left and right trials are presented separately due to asymmetries.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>4.9</td>
<td>0.25</td>
<td>-60 (R)</td>
<td>48.4 ±13.2</td>
<td>13.8 ± 1.5</td>
<td>51.9 ± 20.4</td>
<td>0.0193</td>
</tr>
<tr>
<td>4.9</td>
<td>1.00</td>
<td>-60 (R)</td>
<td>50.2 ± 7.3</td>
<td>29.7 ± 9.3</td>
<td>91.1 ± 34.7</td>
<td>0.6640</td>
</tr>
<tr>
<td>4.9</td>
<td>0.25</td>
<td>+60 (L)</td>
<td>47.7 ± 8.0</td>
<td>13.8 ± 2.8</td>
<td>26.1 ± 12.1</td>
<td>0.0193</td>
</tr>
<tr>
<td>4.9</td>
<td>1.00</td>
<td>+60 (L)</td>
<td>26.2 ± 17.2</td>
<td>23.6 ± 6.8</td>
<td>77.8 ± 43.9</td>
<td>0.5276</td>
</tr>
</tbody>
</table>

6.2.3 Results for Subject N (postflight)

The tabulated values above can be used as a baseline to determine whether the nine day SLS-1 mission had any noticeable affect on the vestibular system. 95% confidence intervals were established for the bias, amplitude and phase. Numerous repetitions were conducted preflight, however the values for left and right could not grouped together, nor could the values from trials one and two. Unfortunately, only four preflight samples were used to calculate each of these intervals which led to rather large confidence intervals. The first day of Y axis postflight testing occurred on landing day. The data from that day was particularly noisy for all subjects.

The amplitudes of modulation was tested using a multi-dimensional Anova to determine whether the amplitude was a function of frequency and if it changed after the flight. No significant changes were observed in the amplitudes or the phases. For trials with the windowshade moving right, the amplitude showed a significant (p < 0.04)
decrease from a preflight average of 38 deg/sec to 30 deg/sec postflight. This finding is not informative due to the downward trend of the SPV bias preflight.

<table>
<thead>
<tr>
<th>N of Cases</th>
<th>Shade RIGHT</th>
<th>Shade LEFT</th>
<th>RIGHT and LEFT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>0.0418</td>
<td>0.0520</td>
<td>0.0026</td>
</tr>
<tr>
<td>Preflight / Postflight</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Freq * Pre / Post</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>

Table 6.18 Subject N, Results of multi-dimensional ANOVA on the amplitude of modulation after fitting all-cycles at once.

<table>
<thead>
<tr>
<th>N of Cases</th>
<th>Shade RIGHT</th>
<th>Shade LEFT</th>
<th>RIGHT and LEFT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>0.0005</td>
<td>0.0016</td>
<td>0.0000</td>
</tr>
<tr>
<td>Preflight / Postflight</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Freq * Pre / Post</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>

Table 6.19 Subject N, Results of multi-dimensional ANOVA on the amplitude of modulation based on the cycle-by-cycle method before removing outliers.

Tables 6.18 and 6.19 indicate that there was no significant difference in the amplitude of modulation between the preflight and postflight data sessions. The only significant difference preflight versus postflight was due to the decrease SPV bias, but the bias had become progressively weaker during postflight testing. Such a complete lack of postflight change can be interpreted in two ways. The first view is that spaceflight has no effect on any subject's vestibular system and response to stimuli. The second hypothesis is that this individual is not receptive to changes in vestibular stimuli due to a reliance on visual stimuli.

Buizza et. al. found that sled motion caused the mean SPV to increase. Subject N showed a some increase in the absolute value of the bias component. The difference between the dynamic calibrations (mean SPV = 21 deg/sec ) and the dynamic runs (mean SPV = 35 deg/sec ) was significant (p ≤ 0.0158) for trials to the left only. The values for amplitude and phase are plotted in Figure 6.5 by frequency as a function of test day.
Figure 6.6 Experiment 2: Subject N: Results from the cycle-by-cycle method after removing outliers. Amplitude and phase of the SPV modulation at the two different stimulus frequencies is shown as a function of the BDC session number. (#1 = L-150, #2 = L-90, #3 = L-45, #4 = L-15, #5 = R+0, #6 = R+2, and #7 = R+7) Negative phase values indicate phase lag. Phase is the difference between SPV and sled acceleration.
6.2.4 Results for Subject M (preflight)

Subject M exhibited weak and erratic nystagmus during the first data sessions, and the quality further deteriorated during later trials. The steady state component of nystagmus was surprisingly low and was occasionally in the wrong direction. Subject M did not seem to respond to the optokinetic stimuli in any consistent manner. However, the slow phase velocity did exhibit pronounced modulation but with highly variable phases. The amplitudes were tested across frequencies to verify that the amplitude of the response did in fact increase as the frequency increased.

<table>
<thead>
<tr>
<th></th>
<th>RIGHT SHADE</th>
<th></th>
<th>LEFT SHADE</th>
<th></th>
<th>COMBINED</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>static 0.25 Hz</td>
<td>static 0.25 Hz</td>
<td>static 0.25 Hz</td>
<td>static 0.25 Hz</td>
<td></td>
<td>static 0.25 Hz</td>
</tr>
<tr>
<td>0.25 Hz</td>
<td>0.0088</td>
<td>ns</td>
<td>0.0248</td>
<td>0.0497</td>
<td>0.0007</td>
<td>0.0027</td>
</tr>
<tr>
<td>1.00 Hz</td>
<td>0.0425</td>
<td>0.0695</td>
<td>0.0425</td>
<td>0.0497</td>
<td>0.0007</td>
<td>0.0027</td>
</tr>
</tbody>
</table>

Table 6.20: Subject M, Comparison of modulation amplitudes for the cycle-by-cycle method before removing outliers.

Similar results were obtained when examining the amplitude after fitting all-cycles at once. Static versus 0.25 Hz. (p ≤ 0.0013), static versus 1.00 Hz. (p ≤ 0.0048) and 0.25 Hz. versus 1.00 Hz. (p ≤ 0.0105) were all statistically significant with left and right trials grouped together.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>4.9</td>
<td>0.25</td>
<td>-60 (R)</td>
<td>-21.7 ± 7.7</td>
<td>7.7 ± 4.5</td>
<td>-4.9 ± 88.7</td>
<td>0.0430</td>
</tr>
<tr>
<td>4.9</td>
<td>1.00</td>
<td>-60 (R)</td>
<td>-5.5 ± 22.1</td>
<td>48.0 ± 33.0</td>
<td>59.4 ± 97.6</td>
<td>1.0731</td>
</tr>
<tr>
<td>4.9</td>
<td>0.25</td>
<td>+60 (L)</td>
<td>5.9 ± 6.7</td>
<td>11.1 ± 2.9</td>
<td>5.5 ± 97.5</td>
<td>0.0620</td>
</tr>
<tr>
<td>4.9</td>
<td>1.00</td>
<td>+60 (L)</td>
<td>9.1 ± 21.2</td>
<td>49.8 ± 36.8</td>
<td>68.4 ± 104.5</td>
<td>1.1133</td>
</tr>
</tbody>
</table>

Table 6.21: Results for Subject M (preflight) These values obtained from fitting all-cycle method.
Table 6.22: Results for Subject M (preflight) These values obtained from the cycle-by-cycle method including outliers.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>4.9</td>
<td>0.25</td>
<td>-60 (R)</td>
<td>-21.7 ± 7.7</td>
<td>16.2 ± 3.5</td>
<td>-8.4 ± 82.3</td>
<td>0.0905</td>
</tr>
<tr>
<td>4.9</td>
<td>1.00</td>
<td>-60 (R)</td>
<td>-5.5 ± 22.1</td>
<td>56.8 ± 29.5</td>
<td>59.9 ± 100.6</td>
<td>1.2670</td>
</tr>
<tr>
<td>4.9</td>
<td>0.25</td>
<td>+60 (L)</td>
<td>5.9 ± 6.7</td>
<td>17.9 ± 2.7</td>
<td>-6.1 ± 91.3</td>
<td>0.1000</td>
</tr>
<tr>
<td>4.9</td>
<td>1.00</td>
<td>+60 (L)</td>
<td>9.1 ± 21.2</td>
<td>60.7 ± 27.0</td>
<td>61.2 ± 101.1</td>
<td>1.3570</td>
</tr>
</tbody>
</table>

Table 6.23: Results for Subject M (preflight) These values obtained from the cycle-by-cycle method after removing outliers.

<table>
<thead>
<tr>
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<td>4.9</td>
<td>0.25</td>
<td>-60 (R)</td>
<td>-22.1 ± 5.7</td>
<td>18.8 ± 4.4</td>
<td>12.6 ± 82.4</td>
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<td>-60 (R)</td>
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<td>60.0 ± 98.0</td>
<td>1.4599</td>
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<tr>
<td>4.9</td>
<td>0.25</td>
<td>+60 (L)</td>
<td>4.9 ± 4.7</td>
<td>20.5 ± 3.5</td>
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<td>0.1146</td>
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<tr>
<td>4.9</td>
<td>1.00</td>
<td>+60 (L)</td>
<td>8.4 ± 22.3</td>
<td>68.9 ± 30.9</td>
<td>69.4 ± 107.2</td>
<td>1.5403</td>
</tr>
</tbody>
</table>

6.2.5 Results for Subject M (postflight)

The amplitude of modulation was tested to determine if there had been a significant change from the preflight values. Although the amplitude was generally smaller postflight, no significant results were found when considering trials with the windowshade moving to the right or to the left. However, if the left and right trials were lumped together, there was a significant decrease at 1.00 Hz., whether the data was fit all-cycles at once (p ≤ 0.0658) or cycle-by-cycle before (p ≤ 0.0348) and after (p ≤ 0.0274) removing outliers. A non significant trend was also observed for the left and right trials at 0.25 Hz., during which the amplitude tended to decrease postflight. Grouping right and left trials, there was no significant changes in either the steady (bias) component of nystagmus or the phase lag at either frequency.

A fully factored Analysis of Variance was performed to investigate any possible changes in the bias component, the amplitudes, or the phases as a function of frequency.
There were no significant variations in bias or phase due to either the preflight/postflight factor. Tables 6.24 and 6.25 show that the frequency had a significant affect on the amplitude of modulation, and the preflight/postflight factor was

<table>
<thead>
<tr>
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<th>Shade LEFT</th>
<th>RIGHT and LEFT</th>
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<td>28</td>
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<tr>
<td>Frequency</td>
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<td>0.0605</td>
<td>0.0015</td>
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<tr>
<td>Preflight / Postflight</td>
<td>ns</td>
<td>ns</td>
<td>0.0466</td>
</tr>
<tr>
<td>Freq * Pre / Post</td>
<td>ns</td>
<td>ns</td>
<td>0.0688</td>
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Table 6.24: Experiment 2: Subject M: Results of ANOVA show that the amplitude from the all-cycles method was a significant function of the frequency. Due to insufficient samples, a preflight/postflight difference was not significant looking at only the left or right trials. Grouping the left and right trials together revealed a significant change postflight.

<table>
<thead>
<tr>
<th></th>
<th>Shade RIGHT</th>
<th>Shade LEFT</th>
<th>RIGHT and LEFT</th>
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<td>N of Cases</td>
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<td>14</td>
<td>28</td>
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<tr>
<td>Frequency</td>
<td>0.0074</td>
<td>0.0102</td>
<td>0.0201</td>
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<td>Preflight / Postflight</td>
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<td>0.0000</td>
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<tr>
<td>Freq * Pre / Post</td>
<td>ns</td>
<td>0.0987</td>
<td>0.0443</td>
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</table>

Table 6.25: Experiment 2: Subject M: Results of ANOVA show that the amplitude from the cycle-by-cycle method (including outliers) was a significant function of the frequency. A weak preflight/postflight difference was present for the trials with the windowshade moving left. Grouping the left and right trials together revealed a significant change postflight.

The preflight and postflight values of amplitude and phase at each frequency from the cycle-by-cycle method are plotted in Figure 6.7.
Figure 6.7 Experiment 2: Subject M: Results from the cycle-by-cycle method after removing outliers. Amplitude and phase of the SPV modulation at the two different stimulus frequencies is shown as a function of the BDC session number. (#1 = L-150, #2 = L-90, #3 = L-45, #4 = L-15, #5 = R+0, #6 = R+2, and #7 = R+7) Negative phase values indicate phase lag. Phase is the difference between SPV and sled acceleration.
Nature never did betray, 
the heart that loved her. 
- W Wordsworth

Accuse not nature! She hath done her part, 
Do thou but thine! 
- J Milton
VII Modelling

There have been several attempts to develop transfer functions relating linear acceleration and eye movements. One of the earlier models of the otoliths was proposed by Meiry (1965). Using a hydraulically powered device to produce sinusoidal horizontal acceleration, he measured the subject's response time for accelerations up to 0.2 g and frequencies between 0.01 Hz and 0.9 Hz. He found that the otoliths had linear characteristics for accelerations less than 1.0 g. He found that subjective sensation lead the stimulus for very low frequencies (f ≤ 0.064 Hz). The following second order model was derived.

Equation 7.0 Subjective Velocity (s) = Acc (s) * \( \frac{K}{(10s+1)(0.66s+1)} \)

This function is a lumped response that includes otolith characteristics, CNS responses, and neuromuscular lag. This provides limited insight regarding anticipated eye movements during LVOR, since the relationship between eye speed and subjective speed is not defined. However, Buizza found that \( K = \frac{A_{scep}}{A_{sled}} = \frac{A_{spv}}{V_{sled}} \) was a constant. Therefore the eye speed should be roughly proportional to the subjective velocity for supra-threshold accelerations.

Other modelling attempts have examined the visual vestibular interaction that controls various eye movements. This includes a model proposed by Buizza et al (1980). This experimental setup allows a new view of how the brain weighs various pieces of information, and how it interprets these bits of information to appear as a familiar signal.

Unfortunately the spaceflight data from Experiment 2 could not be used to determine an appropriate transfer function. This was principally due to the fact that data was collected at only two frequencies due to the tremendous time pressure associated with a baseline data collection. The decision was made to strive for complete trials with possible repetitions, rather than attempting to test once at every possible frequency. It is very easy and quite meaningless to fit a line or curve through two points. This is somewhat lamentable due to the importance of the SLS-1 investigations. This shortcoming led to the decision to use a minimum of three frequencies for experiment one. Despite this, several interesting results were obtained from the data, as shown in Chapter 6.
7.0 Modelling of Experiment One

The sled oscillated at frequencies of 0.25, 0.50 and 1.00 Hz. during experiment 1. There were three degrees of freedom available for curve fitting. The following models were chosen because they were very simple and were limited to only one or two degrees of freedom. Using a nonlinear optimization routine in MatLab, the following primitive transfer functions were fit to the amplitudes, and a phase lag was then added.

Equations 7.1

1) \( \frac{K_1(K_2+s)}{s} \)  
2) \( K_1(K_2+s) \)  
3) \( \frac{K_1s}{K_2+s} \)  
4) \( \frac{K}{(10s+1)(0.66s+1)} \)  
5) \( \frac{K_1(K_2s+1)}{K_3s+1} \)

None of these transfer functions proved satisfactory, including the Meiry function (#4). Table 8.0 summarizes the results of this fitting attempt. A nondimensional goodness of fit score was calculated to determine which function fit the amplitudes and phases most accurately. The score parameter is a non standard quantity that was established only to make simplistic comparisons.

<table>
<thead>
<tr>
<th>Amplitude Residue</th>
<th>Phase Residue</th>
<th>Time delay 1/( \omega ) [sec.]</th>
<th>Phase Residue after phase lag</th>
<th>Normalized score</th>
</tr>
</thead>
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<tr>
<td>Best transfer</td>
<td>2.172</td>
<td>0.191</td>
<td>0.00001</td>
<td>1.000</td>
</tr>
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<td>Equation 1</td>
<td>2.7839</td>
<td>1.071</td>
<td>0.56</td>
<td>0.202</td>
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<td>Equation 2</td>
<td>2.2706</td>
<td>1.577</td>
<td>1.27</td>
<td>0.347</td>
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<td>Equation 3</td>
<td>2.1890</td>
<td>1.550</td>
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<td>Equation 4</td>
<td>6.9263</td>
<td>0.205</td>
<td>0.08</td>
<td>0.779</td>
</tr>
<tr>
<td>Equation 5</td>
<td>2.1725</td>
<td>1.312</td>
<td>1.16</td>
<td>0.327</td>
</tr>
</tbody>
</table>

Table 7.0 Results of fitting transfer functions to data from subjects A and B together. Tolerance = 0.0001. Data from the all-cycle method. Residue values indicate goodness of fit. The 'best' fit would pass through the mean amplitude and phase at each frequency. The values given for the best transfer function are used to calculate a normalized score. This score is arbitrarily defined as 0.5*(best amp. residue/actual amp. residue + best phase residue/actual phase residue) The only clearly inappropriate transfer function is given by equation 4.
The scores in Table 7.0 indicate that equations 1 and 5 were the most accurate of the five simple functions created for curve fitting. However, as shown in Figure 7.0, the magnitude fit for equation 1 is extremely poor. Therefore the fifth transfer function seems to be the most satisfactory. The most obvious shortcoming of this particular transfer function is the presence of a 1.16 second time delay. This value is two or three times larger than the expected value of 400 to 500 milliseconds. The complete response to equation 5 is shown in different forms within Equations 7.2 and 7.3

Equation 7.2 \[ \frac{K_1 s + K_2}{K_3 s + 1} = \frac{5.64 s + 8.54}{0.35 s + 1} \]

Equation 7.3 \[ 16.11 \left( \frac{s + 1.51}{s + 2.86} \right) e^{-\frac{s}{0.86}} \]

Although the original form of the transfer functions was chosen for its simplicity, the solution shown in Figure 7.3 fit the data remarkably well. Testing over a larger frequency range may yield a more accurate transfer function in the future.
Figure 7.0 Panels A & B. Amplitude and phase information plotted against various transfer function. Figure is continued on the following two pages.
Figure 7.0 Panels C & D. Amplitude and phase information plotted against various transfer function. Figure is continued on the following page.
Figure 7.0 Panels A through E. Graphs depict various transfer functions fit to the amplitude and phase information from the all-cycles method in Experiment 1. The stimulus frequencies were 0.25, 0.50 and 1.00 Hz, and there were four points at each frequency. Phase lags are graphed with negative values. Error bars in all plots indicate the sample standard deviation. In the upper panel, the best fit for the given transfer function is shown in relation to the known amplitude data points. The corresponding phase for the particular transfer function is shown as a dashed line in the lower phase diagram. A pure time delay was added to correct phase errors introduced by the transfer function, and is shown as a solid line in the phase diagrams. Only transfer functions #1 and #4 can be easily discarded as wrong based on this graphical information. The other three transfer functions are reasonable close. The formulae for the transfer functions was given in Equation 7.1.
VII Discussion

Buizza et. al. (1980) demonstrated that modulation of optokinetic nystagmus may occur while undergoing linear acceleration. Two experiments were presented in this thesis. The purpose of these experiments was to verify the phenomenon identified by Buizza and to test the findings at different frequencies and accelerations. The existence of modulated OKN was verified through this work. Generally, the amplitude of the modulation and the phase lag both increased as the frequency did.

Two male subjects were tested once each in Experiment 1. Neither subject displayed a significant assymetry. Neither subject underwent habituation rapidly enough to be observed. Both subjects had decent OKN while stationary and both exhibited significant modulation of the SPV once the sled motion began. Subjects A and B had very similar responses and were grouped together for much of the remaining analysis. Nominally the amplitude of modulation during a dynamic calibration was zero, but there was always some noise. The results of Experiment 1 were internally consistent and were used for modelling of a transfer function. Although limited to two subjects, this data serves as a broad baseline for future studies.

Two male subjects were tested repetively in Experiment 2. Four tests were conducted before the SLS-1 flight and three were conducted postflight. Large asymmetries were noted in one subject, and some evidence of habituation to the optokinetic stimulus. The subjects had very different response patterns preflight. These differences can be used to explain postflight changes. In particular, subject M had weaker OKN and larger SPV modulation than subject N.

Buizza et al. claimed that the amplitude of modulation increased with increasing retinal slip velocity. Subjects with weak OKN experience large amounts of retinal slip and should therefore display large amplitude modulation. This may explain some of the discrepancies between subjects M and N in Experiment 2. Subject N had strong nystagmus and very regular SPV modulation between 10 and 30 deg/sec depending on the frequency. However, subject M had very poor underlying OKN. The modulation of the SPV ranged from 10 to 80 deg/sec depending on the trial. One plausible explanation of this difference is that each subjects assigns weighting to sensory modalities in an individual way. The emphasis of one particular sense may even change for an individual during the course of a days testing. Labelling subject M a vestibular subject may explain the weak OKN and the enhanced response due to linear acceleration. Similarly, subject N represents visual subjects who respond better to the optokinetic
stimulus and are less sensitive to the vestibular stimulation. Categorizing individuals as being visually or vestibularly dependent does not imply any sort of deficiency. Nor does it suggest that the subject is dependent on only one sensory input. These labels indicate a preference for a particular type of sensory information. The strength of this preference may vary between different experimental protocols. This preference for visual or vestibular information is also likely to change as a result of spaceflight.

This characterization also serves as a post hoc explanation of the difference between subjects M and N in terms of postflight changes. Subject M had a significant change in the amplitude of modulation as a result of spaceflight when trials to the left and right were grouped together. Subject N did not exhibit any significant changes in the amplitude. If subject N is regarded as visually dependent, then it is consistent for changes in the quality of vestibular information to have little affect on his responses, relative to the changes of subject M.

Subject N in experiment 2 showed a consistent asymmetry in the response depending on the direction of the windowshade. This may be due to the fact that trials to the right were usually run before trials to the left. The left trials and right trials were not actually mirror images of one another, since the sled always started at the right end of the track. This suggests a visual rather than vestibular habituation or asymmetry. The other possible explanation for this response is a hidden asymmetry in the otoliths. The central nervous system is fairly plastic and can easily adapt to irregularities in sensory inputs, and develop compensations for abnormal inputs. The CNS adapts slowly to unusual situations such as a rotating room. This central compensation works well during most every day situations. However in a strange environment the compensation may be discarded as the CNS attempts to develop a new compensation for the particular situation. This may explain the sudden appearance of a large asymmetry in the eye movements of some subjects.

One other important finding was the significant decrease in the amplitude of modulation for subject M following a nine day spaceflight. This was previously explained by labelling M as a vestibular subject. Exposure to weightlessness produces peculiar output from the vestibular end organs. Subjects may unconsciously reduce the weighting of vestibular information in the CNS. This would diminish the response to vestibular stimuli and would lead to a reduction in the amplitude of modulated OKN. This predicted change is in the opposite direction to the change predicted by the tilt-translation reinterpretation hypothesis.
The tilt-translation hypothesis states that otolith information is typically classified as either tilt or translation by the CNS. In a 1 g environment, inclination of the head will stimulate the otoliths. This information is used with visual cues and proprioceptive cues to determine the extent of head tilt. In a zero g environment there is no otolith information regarding head tilt. This may initially lead to sensory conflict and nausea during the first days of spaceflight. It is predicted that after several days all otolith information will be interpreted as translation rather than tilt. Finally, this hypothesis predicts larger responses to vestibular stimuli postflight since it will all be regarded as translation and not as tilt. The demonstrated reduction in the amplitude of modulation postflight appears to negate this theory.

Buizza et. al. concluded that the ratio of slow cumulative eye position to the peak displacement of the sled was constant. They estimated this constant, K, had a value of 0.05 radians / meter. Calculated values of K for 0.25 Hz. trials in this thesis agreed with the values in Buizza. This is not surprising since all of their data was collected at 0.20 Hz. However, substantially higher values of K were found at 0.50 and 1.00 Hz. Values of K based on the all-cycles method in Experiment 1 were 0.047, 0.122 and 0.312 respectively from low to high frequency. This change in K is nearly one order of magnitude for a four fold increase in frequency. Because of sled dynamics the peak displacement is actually lower than calculated at higher frequencies, so the value of K would be even larger. The concept of K was clearly inappropriate for the data contained in this thesis.

There is not a better predictive measure currently in use. Previous research on the Linear Vestibular Ocular Reflex (LVOR) found a mean response of 15 deg/sec per g. The values in Experiment 1 ranged from 21 deg/sec per g at low frequencies to 30 deg/sec per g at 1.00 Hz. If the limitations due to sled dynamics are considered, the high frequency response is roughly 33 deg/sec per g. Clearly the ratio of SPV amplitude to acceleration level is not constant for this experimental protocol. A simple approximation that might hold for future experiments is that the modulation of SPV divided by the square root of the jerk is nearly constant. Using the data from experiment 1 and denoting m/s^3 as J, the values were 3.89, 3.45 and 2.84 deg/sec per J^0.5. This prediction is not substantially more accurate than either of the previous methods.
IX  Conclusions

Two experiments were conducted to verify the existence of modulated optokinetic nystagmus, and to extend the understanding of such a phenomenon. It is quite clear that modulated OKN is a reproducible response to the presentation of simultaneous visual and vestibular stimuli. Both experiments used windowshade speeds of 60 deg/sec and sled frequencies of 0.25, 0.50, or 1.00 Hz, with a nominal peak acceleration of 0.50 G. All subjects had modulation that increased significantly with the stimulus frequency. The phase lag also increased with increasing frequency. Some modulation was also observed during the dynamic calibrations due to inherent imperfections in the visual pursuit system. In experiment 1, at 0.25 Hz., the amplitude of modulation of the SPV using the cycle-by-cycle method was typically around 10 deg/sec with a 45 deg phase lag. At 1.00 Hz, the amplitude increased to 15 deg/sec and the phase lag had increased to 75 deg. The amplitudes in Experiment 2 were larger than in Experiment 1.

Based on the results discussed above, it is quite clear that vestibular inputs and visual inputs can be combined by the Central Nervous System to produce complex eye movements. In this case, modulation of optokinetic nystagmus by sinusoidal linear acceleration can be demonstrated statistically. This interaction may be difficult to observe in the raw eye position due to the presence of numerous saccades. However, examination of the Slow Phase Velocity (SPV) clearly reveals the modulation of the eye velocity. Like any biological signal, this response varies noticeably from subject to subject. As shown in Experiment 2, these values are not consistent over time.

Several problems such as habituation and asymmetries were found in this thesis. Further work needs to extend these findings into a wider range of frequencies and acceleration levels.

9.0 Suggestions for Future Research

There are several suggestions of improvements to this thesis. Three suggestions can be made regarding the Optokinetic Stimulator. The first suggestion is to consider using rotating stimulator on the sled, and limiting the subject's peripheral view of the device. In some ways, this seems counter-intuitive to the idea of enhancing LVOR. Obviously a planar optokinetic stimulator can not produce a stimulus of constant angular
velocity. As mentioned before, the angular speed diminishes as $\frac{1}{\sin(\theta)}$, where $\theta$ is measured from straight ahead. So the speed is accurate to within 5.0% if $\theta < 17.7$ degrees. Normal eye movements did not exceed 20 degrees, so no attempt was made to compensate for this nonlinearity. Subjects in other OKN experiments have reported circularvection while using a linear OKN stimulator, so the nonlinearity is not obvious to these subjects.

Other investigators, including Buizza, have used a projection system for eliciting optokinetic nystagmus. However, projected images tend to elicit weaker OKN than moving displays. For this very reason, we have been using moving displays in the Man-Vehicle lab, rather than projection displays. Weaker OKN may actually be advantageous if it ensures that the subject has a short focal distance. Projection images have constant angular velocity rather than constant linear velocity.

Another possible application of a projector setup is to use patterns other than parallel lines. A field of dots moving across a circular field of view would remove many of the strong vertical clues and may enhance the hilltop illusion.

Eye position data should be taken using scleral search coils, sampled at 200 Hz or greater. The data from the search coils and the EOG data was not compared quantitatively, but the coil data appeared to be much cleaner and require less manipulation to calculate the velocity. OS filters should be employed to improve the root signal of the position signal and reduce noise without rounding the corners. A coordinate system should be chosen before beginning data collection, ideally chose a system that agrees with one of the previously established conventions. The programs written by Merfeld could be converted and implemented on a Macintosh, and will provide more accurate estimates of the euler angles for the eye. There are still some remaining questions about the accuracy of AATM for use with this type of data. Until these scaling issues are resolved, NysA may be the easiest way to obtain the SPV.

Better modelling of this data is only possible by stimulating the subject across a broader range of frequencies. Both experiments tested subjects at 0.5 g and a 0.25 Hz and 1.00 Hz. Experiment 1 also contained a 0.5 g 0.50 Hz profile. The actual acceleration of the sled should be measured to assess the reduction in acceleration at higher frequencies. As mentioned before, one of the principal constraints was the length of the sled. By running experiments at lower g levels, it should be possible to test at frequencies on the order of 0.15 Hz. A 0.2 g profile at 0.15 Hz will require a track length of 2.20 meters. Although the sled is capable of profiles in excess of 2.0 Hz, the noise associated with eye movements at that frequency may interfere with the analysis.
However it is important to test at frequencies greater than 1.0 Hz, despite the possible noise problem. The otolith response should still be valid at that range so LVOR type eye movements should be present. Higher frequencies are essential to developing a more accurate transfer function. One other caution about the high frequency runs is that the sled will have a very small amplitude if the same peak acceleration is used for the low frequency runs. If modulation is in fact due to the amplitude of the displacement then the eye movements will be quite weak. However if the amplitude of the modulation is nearly proportional to the jerk as observed earlier in this work, then these runs should produce substantial modulation of the slow phase velocity.

One final topic of consideration or cause for concern is the issue of habituation. The data presented from Experiment 2 shows a trend that suggests the eye movements become progressively weaker over the course of the experiment. This trend may be the cause of some of the left/right asymmetries that were observed. Future experiments should attempt to differentiate between short term and long term habituation. Any significant reduction in response that occurs over the long term is a vital consideration in the design and development of future Spacelab experiments. If the scleral search coils are used then the experiment is quite limited in duration. Nonetheless, it may be possible to better identify the causes of habituation while preventing any peculiar findings.

Modulated OKN is a repeatable response in most subjects. Visually dependent subjects seem to respond differently than vestibularly dependent subjects. By testing a larger number of subjects across a broader frequency range it should be possible to determine a more accurate transfer function than the simple model proposed earlier. The apparent inverse relationship between OKN strength and amplitude of modulation also deserves attention.
References

Aidley, DJ, *Physiology of Excitable Cells*


Battin, RH (1987) *An Introduction to the Mathematics and Methods of Astrodynamics*, AIAA Education Series

Bles W (1991) Correspondence with L. R. Young


Meiry, JL (1965) Human Perception of Linear Motion - A Mathematical Model of the Otoliths. (uncertain source)


Werne, S (1991) University of Sydney, Personal communication.

Young, LR Chapter 42 *Handbook of Physiology*.

Young, LR Cross Coupling between Effects of Linear and Angular Acceleration on Vestibular Nystagmus. *Bibliotheca Ophthalmolgica*, 1972, vol 82, p. 116-121
APPENDIX A : Additional Results from Experiments 1 and 2.

This appendix contains results and data tables from Experiments 1 and 2. Representative tables were presented in the Results section. However, due to limited spaces, the non crucial tables were relegated to the nether appendix region. In other words, the data from Experiment 2 was too bountiful to be included in the main text. Tables A1 through A7 contain data for subject M, for each of the seven baseline data collections. Tables A8 through A14 contain the comparable values for subject N. All tables contain values from the all-cycles method and the cycle-by-cycle method.
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<td>7.27</td>
<td>64.88</td>
<td>11.09</td>
<td>84.80</td>
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Table A.1 Experiment 2: Subject M: Preflight BDC #1 (L-150) Horizontal eye movements: Upper half of table shows values from the all-cycle method. Lower half of table shows values from the cycle-by-cycle method. Bias, amplitude, residual, and phase lag are calculated for each method. Note that there were no dynamic calibrations during BDC #1. Outliers are defined as cycles with an amplitude less than 1.0 standard deviation below the mean of cycle-by-cycle method. † Values are omitted from the †After Removing Outliers‘ column if no outliers were present. Phase lags are denoted by positive values.
### Table A.2

**Experiment 2: Subject M: Preflight BDC #2 (L-90) Horizontal eye movements**: Upper half of table shows values from the all-cycle method. Lower half of table shows values from the cycle-by-cycle method. Bias, amplitude, residual, and phase lag are calculated for each method. *Values for phase lag are not tabulated during dynamic calibrations due to lack of a reference signal. Outliers are defined as cycles with an amplitude less than 1.0 standard deviation below the mean of cycle-by-cycle method. †Values are omitted from the 'After Removing Outliers' column if no outliers were present. Phase lags are denoted by positive values.

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Table A.3 Experiment 2: Subject M: Preflight BDC #3 (L-45) Horizontal eye movements: Upper half of table shows values from the all-cycle method. Lower half of table shows values from the cycle-by-cycle method. Bias, amplitude, residual, and phase lag are calculated for each method. * Values for phase lag are not tabulated during dynamic calibrations due to lack of a reference signal. Outliers are defined as cycles with an amplitude less than 1.0 standard deviation below the mean of cycle-by-cycle method. † Values are omitted from the 'After Removing Outliers' column if no outliers were present. Phase lags are denoted by positive values.
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Table A.4 Experiment 2: Subject M: Preflight BDC #4 (L-15) Horizontal eye movements: Upper half of table shows values from the all-cycle method. Lower half of table shows values from the cycle-by-cycle method. Bias, amplitude, residual, and phase lag are calculated for each method. * Values for phase lag are not tabulated during dynamic calibrations due to lack of a reference signal. Outliers are defined as cycles with an amplitude less than 1.0 standard deviation below the mean of cycle-by-cycle method. † Values are omitted from the 'After Removing Outliers' column if no outliers were present. Phase lags are denoted by positive values.
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Table A.5 Experiment 2: Subject M: Postflight BDC #5 (R+0) Horizontal eye movements: Note that protocol was incomplete on R+0 due to severe time constraints. Upper half of table shows values from the all-cycle method. Lower half of table shows values from the cycle-by-cycle method. Bias, amplitude, residual, and phase lag are calculated for each method. * Values for phase lag are not tabulated during dynamic calibrations due to lack of a reference signal. Outliers are defined as cycles with an amplitude less than 1.0 standard deviation below the mean of cycle-by-cycle method. † Values are omitted from the 'After Removing Outliers' column if no outliers were present. Phase lags are denoted by positive values.
Table A.6: Experiment 2: Subject M: Postflight BDC #6 (R+2) Horizontal eye movements. Upper half of table shows values from the all-cycle method. Lower half of table shows values from the cycle-by-cycle method. Bias, amplitude, residual, and phase lag are calculated for each method. * Values for phase lag are not tabulated during dynamic calibrations due to lack of a reference signal. Outliers are defined as cycles with an amplitude less than 1.0 standard deviation below the mean of cycle-by-cycle method. † Values are omitted from the 'After Removing Outliers' column if no outliers were present. Phase lags are denoted by positive values.
### Table A.7 Experiment 2: Subject M: Postflight BDC #7 (R+7) Horizontal eye movements: Upper half of table shows values from the all-cycle method. Lower half of table shows values from the cycle-by-cycle method. Bias, amplitude, residual, and phase lag are calculated for each method. * Values for phase lag are not tabulated during dynamic calibrations due to lack of a reference signal. Outliers are defined as cycles with an amplitude less than 1.0 standard deviation below the mean of cycle-by-cycle method. † Values are omitted from the 'After Removing Outliers' column if no outliers were present. Phase lags are denoted by positive values.

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Table A.8 Experiment 2: Subject N: Preflight BDC #1 (L-150) Horizontal eye movements: Upper half of table shows values from the all-cycle method. Lower half of table shows values from the cycle-by-cycle method. Bias, amplitude, residual, and phase lag are calculated for each method. There were no dynamic calibrations performed during BDC #1. Outliers are defined as cycles with an amplitude less than 1.0 standard deviation below the mean of cycle-by-cycle method. † Values are omitted from the 'After Removing Outliers' column if no outliers were present. Phase lags are denoted by positive values.
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Table A.9 Experiment 2: Subject N: Preflight BDC #2 (L-90) Horizontal eye movements: Upper half of table shows values from the all-cycle method. Lower half of table shows values from the cycle-by-cycle method. Bias, amplitude, residual, and phase lag are calculated for each method. * Values for phase lag are not tabulated during dynamic calibrations due to lack of a reference signal. Outliers are defined as cycles with an amplitude less than 1.0 standard deviation below the mean of cycle-by-cycle method. † Values are omitted from the 'After Removing Outliers' column if no outliers were present. Phase lags are denoted by positive values.
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<td>99.57</td>
<td>18</td>
<td>39.86</td>
<td>11.07</td>
<td>34.0±8.3</td>
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</table>

Table A.10 Experiment 2: Subject N: Preflight BDC #3 (L-75) Horizontal eye movements: Upper half of table shows values from the all-cycle method. Lower half of table shows values from the cycle-by-cycle method. Bias, amplitude, residual, and phase lag are calculated for each method. * Values for phase lag are not tabulated during dynamic calibrations due to lack of a reference signal. Outliers are defined as cycles with an amplitude less than 1.0 standard deviation below the mean of cycle-by-cycle method. † Values are omitted from the 'After Removing Outliers' column if no outliers were present. Phase lags are denoted by positive values.
Before Removing Outliers

<table>
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<tr>
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<td>-60</td>
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<td>-20.88</td>
<td>11.09</td>
<td>4.80</td>
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<td>60</td>
<td>36.10</td>
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<td>26.10</td>
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</tr>
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<td>60</td>
<td>7.33</td>
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<td>0.70</td>
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<td>35.16</td>
<td>10.06</td>
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<td>LYN429</td>
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<td>60</td>
<td>7.67</td>
<td>32.15</td>
<td>11.06</td>
<td>103.17</td>
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Table A.11 Experiment 2: Subject N: Preflight BDC #4 (L-15) Horizontal eye movements: Upper half of table shows values from the all-cycle method. Lower half of table shows values from the cycle-by-cycle method. Bias, amplitude, residual, and phase lag are calculated for each method. * Values for phase lag are not tabulated during dynamic calibrations due to lack of a reference signal. Outliers are defined as cycles with an amplitude less than 1.0 standard deviation below the mean of cycle-by-cycle method. † Values are omitted from the 'After Removing Outliers' column if no outliers were present. Phase lags are denoted by positive values.
<table>
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<tr>
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<td>-60</td>
<td>-23.63</td>
<td>44.18</td>
<td>3.02</td>
<td>-32.94</td>
<td>Strong nyst. &amp; modul.</td>
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<td>LYN503</td>
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<td>-35.68</td>
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<td>34.42</td>
<td></td>
</tr>
<tr>
<td>LYN504</td>
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<td>-24.55</td>
<td>10.53</td>
<td>1.36</td>
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<td>7.48</td>
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<tr>
<td>LYN506</td>
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<td>60</td>
<td>32.11</td>
<td>30.93</td>
<td>9.33</td>
<td>91.58</td>
<td>Noisy heog</td>
</tr>
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</table>

**Table A.12** Experiment 2: Subject N: Postflight BDC #5 (R+0) Note that a complete protocol was not performed during BDC #5 due to excessive time constraints. Horizontal eye movements: Upper half of table shows values from the all-cycle method. Lower half of table shows values from the cycle-by-cycle method. Bias, amplitude, residual, and phase lag are calculated for each method. * Values for phase lag are not tabulated during dynamic calibrations due to lack of a reference signal. Outliers are defined as cycles with an amplitude less than 1.0 standard deviation below the mean of cycle-by-cycle method. † Values are omitted from the 'After Removing Outliers' column if no outliers were present. Phase lags are denoted by positive values.
<table>
<thead>
<tr>
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<td>5</td>
<td>-60</td>
<td>-18.10</td>
<td>35.72</td>
<td>6.13</td>
<td>38.28</td>
<td>BAD: Blinking</td>
</tr>
<tr>
<td>LYN618</td>
<td>1.00</td>
<td>20</td>
<td>-60</td>
<td>-23.39</td>
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<td>15.91</td>
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</tr>
<tr>
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<td>9.44</td>
<td>96.16</td>
<td></td>
</tr>
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<td>-27.72</td>
<td>12.58</td>
<td>4.05</td>
<td>*</td>
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<tr>
<td>LYN621</td>
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<td>60</td>
<td>36.77</td>
<td>23.21</td>
<td>10.42</td>
<td>48.71</td>
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</table>

*Table A.13 Experiment 2: Subject N: Postflight BDC #2 (R+2) Horizontal eye movements: Upper half of table shows values from the all-cycle method. Lower half of table shows values from the cycle-by-cycle method. Bias, amplitude, residual, and phase lag are calculated for each method. * Values for phase lag are not tabulated during dynamic calibrations due to lack of a reference signal. Outliers are defined as cycles with an amplitude less than 1.0 standard deviation below the mean of cycle-by-cycle method. † Values are omitted from the 'After Removing Outliers' column if no outliers were present. Phase lags are denoted by positive values.*
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<td>-60</td>
<td>-18.82</td>
<td>21.93</td>
<td>12.38</td>
<td>81.64</td>
<td>BAD: Sled crash at 22 sec.</td>
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<td>-60</td>
<td>-47.21</td>
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<td>20</td>
<td>-60</td>
<td>-47.60</td>
<td>25.18</td>
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<td>96.91</td>
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</tr>
<tr>
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<td>-36.88</td>
<td>10.35</td>
<td>3.57</td>
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</tr>
<tr>
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<td>60</td>
<td>41.60</td>
<td>21.43</td>
<td>10.19</td>
<td>35.14</td>
<td>Brief bursts of noise</td>
</tr>
<tr>
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<td>34.22</td>
<td>22.61</td>
<td>15.76</td>
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<td>Lost the earpiece</td>
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<td>-27.65</td>
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<td>58.02</td>
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<td>-38.45</td>
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<td>18.90</td>
<td>87.01</td>
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</tr>
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<td>12.26</td>
<td>13.12</td>
<td>2.87</td>
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<tr>
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<td>60</td>
<td>8.96</td>
<td>22.89</td>
<td>5.85</td>
<td>75.23</td>
<td>&quot;Weaker OKN than before&quot;</td>
</tr>
<tr>
<td>LY728</td>
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<td>60</td>
<td>39.81</td>
<td>22.07</td>
<td>11.71</td>
<td>71.80</td>
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<tr>
<td>LY716</td>
<td>0.25</td>
<td>4</td>
<td>-60</td>
<td>-18.82</td>
<td>18.36</td>
<td>13.9±5.6</td>
<td>79.00</td>
<td>3</td>
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<td>17.70</td>
<td>16.0±4.6</td>
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<td>17.86</td>
<td>10.9±3.1</td>
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<tr>
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<td>-47.60</td>
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<td>18.4±11.6</td>
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<td>5.1±2.1</td>
<td>*</td>
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<tr>
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<td>17.71</td>
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<td>18.7±7.3</td>
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<td>13.53</td>
<td>20.5±6.2</td>
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<td>15.4±6.0</td>
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<td>17.3±4.9</td>
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<tr>
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<td>20</td>
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<td>-38.45</td>
<td>17.70</td>
<td>21.4±13.6</td>
<td>90.34</td>
<td>18</td>
<td>-38.64</td>
<td>17.74</td>
<td>23.3±13.0</td>
<td>89.11</td>
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<tr>
<td>LY726</td>
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<td>4</td>
<td>9.74</td>
<td>20.84</td>
<td>8.6±3.0</td>
<td>73.68</td>
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</tr>
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<td>22.95</td>
<td>7.4±3.7</td>
<td>89.13</td>
<td>4</td>
<td>9.74</td>
<td>20.84</td>
<td>8.6±3.0</td>
<td>73.68</td>
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<td>13.79</td>
<td>16.0±8.4</td>
<td>62.78</td>
<td>18</td>
<td>40.59</td>
<td>13.83</td>
<td>17.0±8.2</td>
<td>68.20</td>
<td></td>
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</tbody>
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Table A.14 Experiment 2: Subject N: Postflight BDC #7 (R+7) Horizontal eye movements: Upper half of table shows values from the all-cycle method. Lower half of table shows values from the cycle-by-cycle method. Bias, amplitude, residual, and phase lag are calculated for each method. * Values for phase lag are not tabulated during dynamic calibrations due to lack of a reference signal. Outliers are defined as cycles with an amplitude less than 1.0 standard deviation below the mean of cycle-by-cycle method. † Values are omitted from the 'After Removing Outliers' column if no outliers were present. Phase lags are denoted by positive values.
APPENDIX B : Additional Equipment

This appendix contains supplemental information about some of the equipment used during this thesis. There is a brief summary of the differences between the two windowshades, most of which were due to the different focal distances. There is also an introduction to the new SLED program that is now used to control the MVL LabSled. As the first practical user of this new system, I had the privilege of exploring new territory and ironing out minor bugs.

Windowshade

Both experiments utilized remarkably similar windowshades. This was not a coincidence. Both were originally designed by Dr. Dan M. Merfeld. They both had the many of the same characteristics, including the following.

Belt: 'Continuous loop T-07 Beta-Lon' conveyor belt.
Paint: Krylon spray paint 1602 and **
Pattern: 50 alternating black and yellow stripes each roughly 3.5 cm wide.
Speed Control: Closed loop analog feedback control.
Speed: Nominally 60 degrees per second.
Size: 86 cm. wide by 174 cm. in circumference (34 in. x 68.5 in.)

Experiment 1 (MIT)

Focal Distance: 63 cm (25 in.). At this distance each stripe subtends 3.2° and the shade subtends 68° by 68°
Speed calibration: The belt was timed for 10 revolutions at 26.2 ± 0.5 seconds.
Calibration: At 315 cm (125 in.), there were marks at ± 10 degrees (56 cm. = 22 in.) in both the horizontal and vertical directions.

Experiment 2 (SLS-1)

Focal Distance: 45 cm (18 in.). At this distance each stripe subtends 4.4° and the shade subtends 87° by 87°
Speed calibration: The belt was timed for 10 revolutions at 36.9 ± 0.5 seconds.
Calibration: At 45 cm, there were marks for horizontal calibrations at ± 15 and ± 20 degrees. For vertical calibrations there were marks at ± 10 degrees and ± 20 degrees.
The new SLED program

Since this program is rather new, it will be discussed at some length here in order to better understand the program's advantages and peculiarities. The new cart program resides on a dedicated 386 machine equipped with both analog to digital (A/D) and digital to analog (D/A) capabilities. The executable version of the code is compiled 'C++' code. The source code will remain on the machine to permit future modifications as needed. The executable code (to be called SLED) can be run by simply typing s while in the DOS shell. SLED is a menu driven routine that allows the user to create a series of velocity commands that are sent as a reference signal to a Pulse Width Modulated controller that drives the sled. The PWM controller had previously wreaked havoc with EOG signals, but an analog controller would not suffice. The PWM controller was not an issue while using the coils. As with the old program, the A/D boards are used to monitor various sled parameters, such as the sled's acceleration, velocity, and position. This is necessary, since the subject's safety is paramount. Based on the sled's dynamics, a safety envelope was previously calculated by Arrott. Elementary physics reveals that

\[
2 - V_f^2 = \frac{v_0^2 - v_e^2}{2*a_d} \Rightarrow a_{\text{crit}} = \frac{v_0^2 - v_f^2}{2*d} < 1.0 \text{ g}
\]

where \(V_f\) is the final velocity, \(a_d\) is the deceleration, and \(d\) is the distance to the end of the track you are approaching. Since the sled can safely decelerate at roughly 1.0 g, the program checks that \(a_{\text{crit}} < 1.0 \text{ g}\). Upon violating the envelope, an emergency slowdown is initiated by the computer to decelerate the sled at more than 1.0 g. In fact there are several layers in the sled safety system.

One drawback of the idea of the sled safety envelope is the reliability of the various inputs. Unfortunately, acceleration is typically a rather noisy signal, due to mechanical vibration. However, acceleration is not specifically considered in the safety envelope equation since the sled motor has only a limited output torque. The velocity is obtained from the sled tachometer and is a fairly reliable signal. Finally the position signal is needed to determine whether or not the sled is operating within the safe region. The position potentiometer tends to drift slowly over time. Because of this, the position signals are unreliable, and can not provide a guaranteed stop in an unsafe situation. Furthermore, a faulty signal could cause the computer to begin deceleration when the sled was actually within the envelope. At either end of the track there are reinforced
endstops which would assuredly stop the sled but in a rather unpleasant manner. Limit switches were installed several centimeters before the sled could contact the endstops. When these switches are interrupted, the power to the sled is disconnected and the brake is engaged. If the sled passed far beyond the limit switches the pillow blocks would hit several bungee cords which would also prevent hitting the endstops. This also produces a somewhat violent stop, approximately 4 g of deceleration. So as a final precaution, both the operator and the subject have emergency stop ('kill') switches. A recent modification to the sled operators abort switch initiates a 'soft abort' by the computer, which is a controlled deceleration.

As mentioned earlier, the SLED program controls the sled, an auxiliary device, and the data computer. It uses the D/A boards for these three purposes. The primary purpose is to output a sled velocity command to the motor controller. This signal is based on a precomputed profile designed by the sled user, and verified to be inside the safety envelope. SLED only stores one cycle of any given run but is capable of sequentially repeating that cycle for many minutes. The second purpose of the D/A boards is to control the auxiliary device, if such a device is used. For this particular experiment, the auxiliary device was the optokinetic stimulator, or windowshade. One important limitation that was discovered during this work is the finite output current of the D/A boards, which are limited to roughly 10 milli Amperes. This should be enough to drive a high impedance controller. However, the particular motor controller used for this experiment draws a remarkable high current of 100 milliamperes at a voltage of 1.5 Volts. To overcome this obstacle, Jim Costello built a unity gain power amplifier to supply the needed voltage. Such a device may be needed in other situations, depending on the impedance of the auxiliary device. It was later discovered that the controller was poorly wired, but the power amplifier was still used for consistency and to prevent later complications. Finally, the tertiary purpose of the D/A boards is to trigger the data collection computer at the beginning of each run.

The SLED program allows the user to create a variety of motion commands which are tested to satisfy safety criteria. Motion commands can be divided into three categories: trajectories, profiles, and protocols. Protocols are the most general of these three since they are composed of profiles, which in turn are composed of trajectories. SLED is capable of controlling both the linear acceleration sled, and an auxiliary channel, using its two D/A channels. During Experiment 1, an Optokinetic Stimulator ( 'Windowshade') was the auxiliary device. Currently, SLED can generate either a sinusoidal disturbance or a constant velocity signal on either channel. Clearly,
the total time of the constant velocity signal can be a problem when controlling the sled, since the tracks are of finite length. However, this is not the case when controlling a rotating auxiliary device, such as the windowshade. SLED checks to make sure that the commands it sends out are safe. Similarly, when running sinusoidal profiles, the cart's motion is limited by the track length. So SLED checks that the frequency and the acceleration satisfy the following relationship.

\[ L \leq \frac{acc}{\omega^2} \quad \text{or} \quad L \leq \frac{G}{4.02 \times f^2} \]

Where \( G \) is the acceleration in units of G and \( f \) is the frequency in Hz instead of radians / second and \( L \) in meters. Note that when creating a sinusoidal trajectory, the SLED program recommends ramping up through several half cycles, the default being two half cycles. Thus the first half cycle has one-third the amplitude and the second half cycle has two-thirds the amplitude of the primary stimulus. Dr. Merfeld has shown that by ramping profiles in this way, all sinusoidal profiles begin and end in the center of the track. This is a useful option since it reduces the time needed to position if all profiles begin and end in the same place. Secondly, it ensures a relatively gentle transition into the profile. Later modifications to the system will permit other trajectories such as ramps, square waves, steps, and sum of sines like on the old CART program.

The next level of motion command allows the user to link a sled trajectory with an auxiliary trajectory to get a profile. The user can determine the length of each trajectory independently, as well as specify a time delay on one or both channels if needed. By padding the delay periods, the user can ensure that both channels will operate for the same amount of time. SLED will send out a pulse at the beginning of the delay phase of each run which is used to trigger the data collection computer. Thus a long delay period can effectively be used to pretrigger the data computer.

Finally, you can link together a series of profiles to create a protocol file. Protocol files are generally used to run an experiment. After creating a protocol file with all the needed profiles, the experimenter can then run through the profiles in order as the experiment progresses. Profiles are generally stored in the same order as they were created.
APPENDIX C: MatLab Scripts

MatLab was used extensively during this thesis. In fact, it may not have been possible without MatLab. However, I still think that the error messages are utterly useless and needlessly annoying. Numerous amateur scripts were written by the author to accomplish rapid data processing. Not all of these scripts worked. At first glance it may seem that I wrote a vast number of scripts. I did. This only proves that I am an amateur. I anticipate that someone out there can produce the same results with half as much code and without leading to the unnecessary demise of so many innocent trees. The casual observer will notice lots of stupid variable names. However, I make no apologies. They meant something to me at the time. Typical default names belong to my cats and dogs. The scripts that relied on borrowed code generally worked better than the scripts I thought up on my own. The survivors are listed below with a brief description of their purpose. The scripts are listed in alphabetical order, and the printouts are arranged similarly.

bode jc
Used to calculate the transfer function in Experiment 1. Utilizes a nonlinear parameter estimation function in MatLab called fmins.

circle_stats
Based on Mardia (1972). Calculates and displays various parameters for the directional data (ie. the phases).

circle_MARDIA_2.3 Subroutine called by circle_stats.
circle_MARDIA_2.5 Subroutine called by circle_stats.
circle_MARDIA_2.6 (You guessed it.) Subroutine called by circle_stats.
clear_specs jc
A simple script, it reduces extraneous variables.

DR_OKN
The final program to find grand means for all trials in Experiment 2. It examines all (or some) trials at a given frequency. It also calculates pre and postflight values for comparison.

edit_alg_dual
Subroutine called by edit_spv_dual to do all the real work.

edit_spv_dual
Used for manually editing two or three axes simultaneously. This script is a derivative of edit_spv. It also allows the user to save intermediate edited files.

file_specs jc
This script stores all the important file names used in NysA and in jc_AATM. Permits the user to make global changes without hunting through hundreds of scripts for a particular variable.
fun1 . . fun5  These scripts contain various generic transfer functions used in the attempt to fit a nonlinear transfer function.

jc_power  Used for displaying final plots of amplitude and phase for Experiment 2.

jc_prove_freq  This was used to verify that the stimulus frequency provided the best fit to the data, effectively served as a comb filter.

jc_sines  Allows batch processing of several files at once, both H and V channels. This script also saves various parameters for use in later processing. Several variables in the header block allow the user to set options such as plotting, statistics, and the all-cycles method.

pick_a_point  This function determines which element of a vector is closest to the given value. Sort of like the find function, but will work with inexact values.

T_test  Contains a table to permit independent t-tests.

vector  Finds the mean direction of a vector (in radians) by calculating the resultant. Not a breathtaking scientific function. However it gives a more valid concept of the mean direction than mean(theta) does.
bode_jc

% This program fits a bode plot to the data
% Originally written by HUGEGLAW 0 (Glenn W. Law)
% Reworked in Nov 1991 by Jock R. I. Christie
% This programs calls various 'functions' ironically
% titled fun1 . . fun5. The script 'fmins' does a
% nonlinear optimization, based on the transfer
% function and a cost function stored in fun1

freq_stim = [0.25; 0.50; 1.00] * 2 * pi; % Thinking in radians / second
i = sqrt(-1); % As i always should be.
tol = 0.0001; % Set tolerance for use with fmins
show_graphs = 0; % = 0 suppresses intermediate graphs
data_path = 'Macintosh_HD:BIG_T:RESULTS_TABLES:';

% Load data from converted Excel (Text) files.
in_file = input('Enter the input file name. ','s');
in_file = 'BODE_A_B';
eval(['load ',data_path,in_file])
eval(['in_mat = ',in_file,';'])

data_type = menu('Select the data type.','All cycles at once', 'Cycle by cycle with outliers', 'Cycle by cycle without outliers');
    data_type = 2;
if data_type == 2
    data_label = 'All Cycles at once';
    plot_col = 8;
elseif data_type == 3
    data_label = 'Cycle by cycle with outliers';
    plot_col = 13;
else
    data_label = 'Cycle by cycle without outliers';
    plot_col = 4;
end

FREQ = in_mat(:,2) * 2 * pi;
BIAS = in_mat(:,plot_col);
RES = in_mat(:,plot_col + 1);
AMP = in_mat(:,plot_col + 2);
PHI = -in_mat(:,plot_col + 3)*pi/180;

x = FREQ;
xi = x*i;
y = AMP;
z = PHI;
Data = x;
Data(:,2) = y;
Data(:,3) = z;
% Find avg and Sd of gain and phase for all freq
avg_gain = [];
std_gain = [];
avg_phi = [];
std_phi = [];
for loop = 1:length(freq_stim)
    avg_gain = [avg_gain; mean(AMP(find(FREQ == freq_stim(loop))))];
    std_gain = [std_gain; std(AMP(find(FREQ == freq_stim(loop))))];
    avg_phi = [avg_phi; mean(PHI(find(FREQ == freq_stim(loop))))];
    std_phi = [std_phi; std(PHI(find(FREQ == freq_stim(loop))))];
end

if show_graphs
    loglog(FREQ, AMP, 'x')
    hold on
    loglog(freq_stim, avg_gain, 'ow');
    hold off
    errorbar_loglog(freq_stim, avg_gain, std_gain);
    title('Log-log plot of Amplitude vs. frequency');
xlabel('Frequency (rad/sec)');
ylabel('Amplitude of Modulation (deg/sec)');
%prts;
pause(5)
end
fprintf(['The following analysis is for ',data_label,'
]);

function_code = menu('Select the curve fit type.','fun1', 'fun2', 'fun3', 'fun4', 'fun5');

% The coefficient for K are reasonable accurate first guesses.
if (function_code == 1)
    k = [11.08; 0.0085];
    p = 2.007;
    [k, count] = fmins('fun1',k, tol);
elseif (function_code == 2)
    k = [1.8; 4.72];
    p = 1.008;
    [k, count] = fmins('fun2',k, tol);
elseif (function_code == 3)
    k = [14.51, 2.31];
    p = 0.04;
    [k, count] = fmins('fun3',k, tol);
elseif (function_code == 4)
    k = [200];
    p = 0.04;
    [k, count] = fmins('fun4',k, tol);
elseif (function_code == 5)
    k = [6.1, 0.41, 0.42];
    p = 0.79;
    [k, count] = fmins('fun5',k, tol);
end
p = fmin('funp1', min(freq_stim)/2,max(freq_stim)*2);
res_amp = norm(A-AMP)/sqrt(length(x));
res_phi = norm(B-PHI)/sqrt(length(x));
res_phi2 = norm(C-PHI)/sqrt(length(x));

clc
hold off
loglog(x,y,'o', x, A, '-g')
pause(1)
plot(x,z,'o',x, B, 'g', x, C, '-b', x, B+C, '*w')
xlabel('Frequency (rad/sec)');
ylabel('SPV modulation - PHASE (rad)');
title('Raw data = o, after amplitude = (green), final = *(black)');
pause(5)
prtsc;

fprintf(\nAnalyzing transfer function # %1.0\n', function_code);
fprintf('After %3.0f iterations, res_amp = %2.4f deg/sec.
', count, res_amp);
fprintf('Initially res_phi = %2.3f rad
After adding a phase lag, res_phi = %2.3f rad.
', res_phi, res_phi2);
disp([k',p]);

%Generate Bode Plot for Gain

l = logspace(0,1,100);
[mag1,phi1] = bode(NUM,DEN,1);
subplot(211)
axis([0,1,10,30]);
semilogx(l,20*log10(mag1),'r', freq_stim,20*log10(avg_gain),'o')
errorbar_semixdB(freq_stim, avg_gain, std_gain);
xlabel('Log of Frequency (rad/sec)');
ylabel('SPV modulation (dB)');
title(['Transfer function # ',int2str(function_code),', Bode fit for Subjects A & B']);

%Generate Bode Plot for Phase

[mag2,phi2] = bode(NUM,DEN,1);
phi3 = phi2 + (180/pi)*atan(-l/p);
subplot(212)
axis([0,1,-150,150]);
semilogx(l,phi2,'--r',l,phi3,'--b',freq_stim,avg_phi*(180/pi),'o')
errorbar_semix(freq_stim, avg_phi*(180/pi), std_phi*(180/pi));
xlabel('Log of Frequency (rad/sec)');
ylabel('Lag in SPV modulation (deg)');
title(['Transfer function # ',int2str(function_code),', Bode fit for Subjects A & B']);
prtsc;
function [mu, kappa, RR, sigma] = circle_stats(theta)
% CIRCLE_STATS CIRCLE_STATS(THETA) estimates the mean
% and the standard deviation of a column vector THETA,
% which is given in radians.

% Based on Mardia (1972) Statistics of Directional Data.

1 = 1;  % l = 360/fraction of used circle. ie. if 0<theta<180 then l = 2;
N = 2;  % N determines the maximum number of moments.
prob = [0.100; 0.050; 0.010; 0.001];

[row, col] = size(theta);
if (row == 1);
    theta = theta';
    [row, col] = size(theta);
end

C_bar = mean(cos(1 * theta*[1:N]));
S_bar = mean(sin(1 * theta*[1:N]));
R_bar = sqrt(C_bar.^2 + S_bar.^2);
RR = R_bar(1);

x_zero = atan2(C_bar,S_bar)- 2*pi*round((sign(atan2(C_bar,S_bar))- 1+eps)/2);
mu = x_zero(1);
S_nought = 1 - R_bar(1);
sigma = sqrt(-2*log(RR));

kappa = circle_MARDIA_2_3(RR);  % To find concentration factor (k)
delta = circle_MARDIA_2_6(kappa);  % This calculates the conf. int.
z = circle_MARDIA_2_5(row);  % Statistics to test significance of R.

p = max(find( (z <= R_bar(1)*ones(1,length(z))) == 1));
if isempty(p)
    fprintf(\nR = %1.3f and is not significant.', R_bar(1));
else
    fprintf(\nR = %1.3f and is significant at the %1.3f level.', R_bar(1), prob(p));
    fprintf(\nThe concentration factor (kappa) = %2.2f, kappa);
    fprintf(\nThe mean phase is %3.1f +/- %3.1f (1.0 STD).', 180*mu/pi, 180*sigma/pi);
end

% Revised from DELTA to SIGMA in August 1991 JC
function kappa = circle_MARDIA_2_3(R)
% Function circle_MARDIA_2_3(R) yields an estimated value for
% kappa based on the estimated value of R(hat)
% Values taken from Mardia (1972) Appendix 2.3 p. 298
if (R < 0.40)
    kappa = (R(1)/6) * (12 + 6*R(1)^2 + 5*(1)^4);
elseif (R > 0.80)
    i = 1-R;
    kappa = (2*i - i^2 - i^3)^(-1);
else
    i(1,:) = [0.40, 0.87408];
    i(2,:) = [0.42, 0.92720];
    i(3,:) = [0.44, 0.98207];
    i(4,:) = [0.46, 1.03889];
    i(5,:) = [0.48, 1.09788];
    i(6,:) = [0.50, 1.15932];
    i(7,:) = [0.52, 1.22350];
    i(8,:) = [0.54, 1.29077];
    i(9,:) = [0.56, 1.36156];
    i(10,:) = [0.58, 1.43635];
    i(11,:) = [0.60, 1.51574];
    i(12,:) = [0.62, 1.60044];
    i(13,:) = [0.64, 1.69134];
    i(14,:) = [0.66, 1.78953];
    i(15,:) = [0.68, 1.89637];
    i(16,:) = [0.70, 2.01363];
    i(17,:) = [0.72, 2.14359];
    i(18,:) = [0.74, 2.28930];
    i(19,:) = [0.76, 2.45490];
    i(20,:) = [0.78, 2.64613];
    i(21,:) = [0.80, 2.87129];
    i(22,:) = [0.82, 3.14262];
    i(23,:) = [0.84, 3.47901];
    i(24,:) = [0.86, 3.91072];
    i(25,:) = [0.88, 4.48876];
    i(26,:) = [0.90, 5.3047 ];
    j = find(i(:,1) == (round(50*R)/50));
    kappa = i(j,2);
else
    t = abs(i(:,1) - R);
    if min(t) == 0
        p = find(t == min(t));
        kappa = i(p,1);
    else
        p = min(find(t == min(t)));
        if (R < i(p,1))
            p = p-1;
        end
        kappa = i(p,2) + (R-i(p,1)) * (i(p+1,2)-i(p,2)) / (i(p+1,1)-i(p,1));
    end
end
function z = circle_MARDIA_2_5(n)
% circle_MARDIA_2_5(DOF) determines the 90% 95% 99% and 99.9% (?)
% critical values of Rayleigh test for a given degree of freedom.
% Values from Mardia (1972) Statistics of Directional Data p. 300
% Courtesy of Jock R. I. Christie August 1991

% Note the following values are not all exact. Feel free to update

r(4,:) = [ 4, 0.752, 0.839, 0.978, 1.001];
% Note values for n = 4 calculated by JC on 14 October 1991
% Using Mardia on p. 135 These are approximations.
r(5,:) = [ 5, 0.677, 0.754, 0.879, 0.991];
r(6,:) = [ 6, 0.618, 0.690, 0.825, 0.940];
r(7,:) = [ 7, 0.572, 0.642, 0.771, 0.891];
r(8,:) = [ 8, 0.535, 0.602, 0.725, 0.847];
r(9,:) = [ 9, 0.504, 0.569, 0.687, 0.808];
r(10,:) = [10, 0.478, 0.540, 0.655, 0.775];
r(11,:) = [11, 0.456, 0.516, 0.627, 0.743];
r(12,:) = [12, 0.437, 0.494, 0.602, 0.716];
r(13,:) = [13, 0.420, 0.475, 0.580, 0.692];
r(14,:) = [14, 0.405, 0.458, 0.560, 0.669];
r(15,:) = [15, 0.391, 0.443, 0.542, 0.649];
r(16,:) = [16, 0.379, 0.429, 0.525, 0.630];
r(17,:) = [17, 0.367, 0.417, 0.510, 0.613];
r(18,:) = [18, 0.357, 0.405, 0.496, 0.597];
r(19,:) = [19, 0.348, 0.394, 0.484, 0.583];
r(20,:) = [20, 0.339, 0.385, 0.472, 0.569];
r(21,:) = [21, 0.331, 0.375, 0.461, 0.556];
r(22,:) = [22, 0.323, 0.367, 0.451, 0.544];
r(23,:) = [23, 0.316, 0.359, 0.441, 0.533];
r(24,:) = [24, 0.309, 0.351, 0.432, 0.522];
r(25,:) = [25, 0.303, 0.344, 0.423, 0.512];
r(26,:) = [26, 0.277, 0.315, 0.387, 0.470];
r(27,:) = [27, 0.256, 0.292, 0.359, 0.436];
r(28,:) = [28, 0.240, 0.273, 0.336, 0.409];
r(29,:) = [29, 0.226, 0.257, 0.318, 0.386];
r(30,:) = [30, 0.214, 0.244, 0.301, 0.367];
r(31,:) = [100, 0.15, 0.17, 0.21, 0.26];

if (n < 4)
    fprintf('Insufficient samples (n < 4) for complete analysis.
');
    z = [inf, inf, inf, inf];
elseif (n >= 5) & (n <= 100)
    t = abs(r(:,1) - n);
    p = min(find(t == min(t)));
    if min(t) == 0
        z = r(p,2:5);
    else
        if (n < r(p,1))
            p = p-1;
        end
        z = r(p,2:5) + (n-r(p,1)) * (r(p+1,2:5)-r(p,2:5)) / (r(p+1,1)-r(p,1));
    end
else
    chi_2_2 = [4.605, 5.991, 9.210, 13.816];
end
\[ z = \sqrt{\frac{\chi^2}{2n}}; \quad \text{% Note this comes out even for } n = 102.3 \ 103.7 \ 104.4 \ 102.2 \]
end
function delta = circle_MARDIA_2_6(kappa)
% circle_MARDIA_2_6(kappa) determines the 90% 95% 99% and 99.9% 
% estimates for the confidence interval based on Kappa.
% Values from Mardia (1972) Statistics of Directional Data p. 301
% Delta is in radians. Jock R. I. Christie August 1991

% Note the following values are not all exact. Feel free to update
% Note that Mardia uses a funky definition of delta. Corrected
% in below. Values are 1) kappa 2) 90% 3) 95% 4) 99%

k(1,:) = [ 0.0, 5.7, 2.9, 0.6, 0.1];
k(2,:) = [ 0.5, 30.8, 15.7, 3.2, 0.3];
k(3,:) = [ 1.0, 53.5, 29.6, 6.2, 0.6];
k(4,:) = [ 1.5, 79.6, 53.1, 13.1, 1.3];
k(5,:) = [ 2.0, 98.8, 77.3, 28.0, 3.0];
k(6,:) = [ 2.5, 111.0, 94.1, 50.7, 7.2];
k(7,:) = [ 3.0, 119.1, 105.1, 70.9, 16.9];
k(8,:) = [ 3.5, 124.9, 112.7, 84.8, 34.9];
k(9,:) = [ 4.0, 129.2, 118.3, 94.3, 54.5];
k(10,:) = [ 4.5, 132.6, 122.7, 101.2, 68.8];
k(11,:) = [ 5.0, 135.4, 126.2, 106.6, 78.8];
k(12,:) = [ 6.0, 139.7, 131.5, 114.5, 92.0];
k(13,:) = [ 7.0, 143.0, 135.5, 120.3, 100.7];
k(14,:) = [ 8.0, 145.6, 138.7, 124.7, 107.1];
k(15,:) = [ 9.0, 147.7, 141.2, 128.2, 112.1];
k(16,:) = [10.0, 149.4, 143.4, 131.2, 116.2];
k(17,:) = [10.5, 150.2, 144.3, 132.5, 118.0];
k(18,:) = [11.0, 150.9, 145.2, 133.7, 119.6];
k(19,:) = [11.5, 151.6, 146.0, 134.8, 121.1];
k(20,:) = [12.0, 152.2, 146.7, 135.8, 122.5];
k(21,:) = [12.5, 152.8, 147.5, 136.8, 123.8];
k(22,:) = [13.0, 153.4, 148.1, 137.7, 125.0];
k(23,:) = [14.0, 154.4, 149.3, 139.3, 127.2];
k(24,:) = [15.0, 155.3, 150.4, 140.8, 129.2];
k(25,:) = [20.0, 158.7, 154.5, 146.3, 136.5];
k(26,:) = [30.0, 162.7, 159.3, 152.7, 144.9];
k(27,:) = [40.0, 165.0, 162.1, 156.4, 149.7];
k(28,:) = [50.0, 166.6, 164.0, 159.0, 153.0];
k(29,:) = [100.0, 170.6, 168.7, 165.2, 161.1];
N_alpha = [1.645, 1.960, 2.576, 3.291];

t = abs(k(:,1) - kappa);
p = min(find(t == min(t)));
if min(t) == 0
    delta = pi - k(p,2:5)*pi/180;
else
    if (kappa < 100)
        if (kappa < k(p,1))
            p = p-1;
        end
        delta = k(p,2:5) + (kappa-k(p,1)) * (k(p+1,2:5)-k(p,2:5))/(k(p+1,1) - k(p,1));
    else
        delta = N_alpha/sqrt(kappa);
    end
end
end
% clear_specs jc

% This simply clears out all of the file_specs declarations,
% except for the data_path. This minimizes programmer's
% anacin consumption.

clear Pos1_Var Pos2_Var Pos3_Var Pos1_File Pos2_File Pos3_File
clear Cal1_Var Cal2_Var Cal3_Var Cal1_File Cal2_File Cal3_File
clear Vel1_Var Vel2_Var Vel3_Var Vel1_File Vel2_File Vel3_File
clear Acc_Var Acc_File zero_A_D folder
clear Okn_scale Okn_Var Okn_File Sled_scale scale_A_D scale_coil

% This still leaves run_code data_path stat_path
% and the other stuff that is needed in jc_AATM
function DR_OKN
% DR_OKN does the last round of statistics for
% the SLS-1 modulated OKN experiment

% Written by Jock R. I. Christie in the wee hours of 15 Nov 1991
% This program utilizes the values stored in MEAN_SPV which are
% obtained from the cycle by cycle method after discarding outliers.
% MEAN_SPV is 4 x 9, one row for each of 4 harmonics.
% The columns represent [freq, amp, std (amp), phi, std(phi), R, kappa, mu, sigma].
% Columns 3 and 4 are in Radians, but Mu and sigma are both in degrees.

axis_num = 2; % 1 is for horizontal etc.
dyn_cal = 0; % Can override frequency selection.
freq_num = 0; % You can chose which frequency to analyze.
freq_stim = [0.25; 1.00]; % Input stimuli
data_path = 'disc40:JC:'; % <--check this!!!
N_harmonics = 4;
p_sig = 0.05; % Determines minimum level of significance..
recycle = 1; % Allows the user to reuse old values.
subject_code = 'LYM'; % Default value
trial_limit = 2; % For limited trials during any test day
x_coord = 0.38; % Used for putting text on the plots

i = sqrt(-1); % Used in shortcuts

if axis_num == 1
    axis_code = 'H:'; axis_label = 'Horizontal';
elseif axis_num == 2
    axis_code = 'V:'; axis_label = 'Vertical';
else
    axis_code = 'T:'; axis_label = 'Torsional';
end

if (subject_code(3) == 'm') || (subject_code(3) == 'M')
    look_at = [116,126; 217,227; 317,327; 422,432; 502,506; 612,622; 717,727];
elseif (subject_code(3) == 'n') || (subject_code(3) == 'N')
    look_at = [115,123; 216,226; 316,327; 418,429; 502,506; 617,622; 716,728];
elseif (subject_code(3) == 'p') || (subject_code(3) == 'P')
    look_at = [122,130; 223,233; 323,333; 420,430; 502,506; 600,600; 716,726];
elseif (subject_code(3) == 's') || (subject_code(3) == 'S')
    look_at = [110,130; 213,233; 313,333; 410,430];
elseif (subject_code(3) == 't') || (subject_code(3) == 'T')
    look_at = [117,125; 214,224; 301,300; 420,430; 503,514; 616,626; 715,719];
else
    fprintf('YOU DOPE - PREPARE TO CRASH !

');
    clear look_at
end

if dyn_cal || (freq_num <= 0)
    dyn_cal = 1;
    freq = min(freq_stim);

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freak = 'DYN';
fprintf(['\nAnalyzing ',axis_label,' SPV Subject ',subject_code(3),'
','subject_code(2)',', Axis  DYNAMIC CALIBRATION.\n']);
box = [0, 8, 0, 20];
else
freq = freq_stim(freq_num);
if freq == 0.25
box = [0, 8, 0, 30];
else
box = [0, 8, 0, 50];
end
freak = num2str(freq);
fprintf(['\nAnalyzing ',axis_label,' SPV Subject ',subjectcode(3),'
','subjectcode(2)',', Axis  %1.2f Hz.\n'], freq);
end
[N_sessions,ij] = size(look_at);
MAT1 = []; % These MATrices used to store the rows of MEAN_SPV
MAT2 = [];
MAT3 = [];
MAT4 = [];
MAT_name = [];
for ij = 1:N_harmonics
    eval(['MEAN_AMP',int2str(ij),' = [];']);
    eval(['STD_AMP',int2str(ij),' = [];']);
end
N_cases = 0;
Days = [];
out_file = [data_path,'O_K_N:',subject_code,'%','freak,'%',',axis_label(1)];
if (recycle&(exist(out_file)==2))
    fprintf(['\nRecycling old values for data code', subject_code]);
eval(['load ',out_file]);
else
    for ij = 1:N_sessions
        folder = [subject_code,int2str(floor(lookat(ij,1)/100)),':',axiscode];
        trial_count = 0;
        for jk = look_at(ij, 1):look_at(ij,2)
            run_code = [subject_code,int2str(jk)];
            if exist([data_path,folder,run_code,'%',',freak','%'])&(trial_count<trial_limit)
                eval(['load ', data_path,folder,run_code,'%','.MEAN1'])
                eval(['TEMP_theta = pi/2 + ',run_code,'%','1.5;']);
                TEMP_theta = (TEMP_theta - 2*pi*sign(TEMP_theta)*(TEMP_theta > pi));
                eval(['clear ',run_code]);
            if exist([data_path,folder,run_code,'%',',MEAN_SPV'])
                eval(['load ', data_path,folder,run_code,'%',',MEAN_SPV'])
                eval(['TEMP = ',run_code,'%'])
                eval(['clear ',run_code]);
                TEMP(:,4) = (TEMP_theta - TEMP(:,4));
                MAT1 = [MAT1; TEMP(1,:)];
                MAT2 = [MAT2; TEMP(2,:)];
                MAT3 = [MAT3; TEMP(3,:)];
            end
        end
    end
end
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MAT4 = [MAT4; TEMP(4,:)];
elseif exist([data_path,folder,run_code,'.SAVE'])
eval(['load ', data_path,folder,run_code,'.SAVE'])
eval(['JUNK = ',run_code,';']);
eval(['clear ',run_code]);
for kl = 1:N_harmonics
    KL = int2str(kl);
    TEMP = (1-dyn_cal)*freq*kl;
    TEMP(2:3) = [mean(JUNK(:,1+2*kl)); std(JUNK(:,1+2*kl))];
    TEMP(4) = vector(JUNK(:,2+2*kl) - TEMP_theta);
    eval(['MAT',KL,' = [MAT',KL,', TEMP];']);
end
end

MAT_name = [MAT_name; run_code];
N_cases = N_cases+1;
trial_count = trial_count+1;
end  % End of if exist([data_path . loop
clear JUNK TEMP
end  % End of for jk
end % End of for ij
end % End of for i = 1:N_sessions loop

% Phase correction
MAT1(:,4) = MAT1(:,4) - 2*pi*sign(MAT1(:,4)).*(MAT1(:,4) > pi);
MAT2(:,4) = MAT2(:,4) - 2*pi*sign(MAT2(:,4)).*(MAT2(:,4) > pi);
MAT3(:,4) = MAT3(:,4) - 2*pi*sign(MAT3(:,4)).*(MAT3(:,4) > pi);
MAT4(:,4) = MAT4(:,4) - 2*pi*sign(MAT4(:,4)).*(MAT4(:,4) > pi);
end

eval(['save ', outfile,' Days MAT1 MAT2 MAT3 MAT4 MAT_name trial_limit
N_cases']);

point_a = find(MAT_name(:,4) <= sprintf('%1.0f',4));
point_p = find(MAT_name(:,4) >= sprintf('%1.0f',5));
for ij = 1:N_harmonics
    IJ = int2str(ij);
    eval(['MEAN_AMP_ANTE(ij) = mean(MAT',IJ,',point_a,2));']);
    eval(['STD_AMP_ANTE(ij) = std(MAT',IJ,',point_a,2));']);
    eval(['MEAN_AMP_POST(ij) = mean(MAT',IJ,',point_p,2));']);
    eval(['STD_AMP_POST(ij) = std(MAT',IJ,',point_p,2));']);
eval(['THETA',IJ,' = MAT',IJ,':(:,4);']);
eval(['MEAN_MAT',IJ,' = mean(MAT',IJ,':(:,2).* (cos(THETA',IJ,') + i*sin(THETA',IJ,'));']);
fprintf('Testing harmonic # %1.0f at %1.2f Hz.',ij, i*j*freq);
if dyn_cal
    fprintf(' during Dynamic Calibration.);
end
fprintf('The mean amplitude preflight (+/- 1.0 std) = %2.2f +/- %2.2f deg/sec.', MEAN_Amp_ANTE(ij), STD_Amp_ANTE(ij));
fprintf('The mean amplitude postflight (+/- 1.0 std) = %2.2f +/- %2.2f deg/sec.
', MEAN_Amp_POST(ij), STD_Amp_POST(ij));
end
clg
hold off
box = [min(Days)-1, max(Days)+1, 0, 5*ceil(0.2*max(MEAN_Amp1 + STD_Amp1))];
axis(box);
plot(Days, MEAN_Amp1, 'w');
plot([4.2 4.2], [box(3:4)], '-.w')
hold on
plot([4.8 4.8], [box(3:4)], '-.w')
hold off
errorbar_plus(Days, MEAN_Amp1, STD_Amp1);
if dyn_cal
    title(['Subject ',subject_code(3),' ',subject_code(2),']

    Dynamic Calibration');
else
    title(['Subject ',subject_code(3),' ',subject_code(2),']

    Frequency = ',sprintf('%1.2f',freq), ' Hz.']);
end
x2 = (4.45-box(1))/(box(2)-box(l));
JUNK = 'FLIGHT';
for ij = 1:length(JUNK)
    text(x2, 0.65-0.04*ij, JUNK(ij),'sc')
end
xlabel(' (Preflight) BDC Session Number

(Postflight)')
ylabel(['Amplitude of ',axis_label,' SPV modulation (deg/sec)']);
prtsc;
fprintf('%n%2.0f Files were loaded for subject ',subject_code,\n
\n', N_cases);
clg
hold off

subplot(221),
polar(THETA1,MAT1(:,2),
x',angle(MEAN_MAT1),abs(MEAN_MAT1),
",ob")
grid
subplot(222),
polar(THETA2,MAT2(:,2),
x',angle(MEAN_MAT2),abs(MEAN_MAT2),
",ob")
grid

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\texttt{subplot(223),
polar(THETA3,MAT3(:,2),'x',angle(MEAN_MAT3),abs(MEAN_MAT3),'ob')
grid
subplot(224),
polar(THETA4,MAT4(:,2),'x',angle(MEAN_MAT4),abs(MEAN_MAT4),'ob')
grid
for ij = 1:4
  eval(['subplot(22',int2str(ij),')']);
title(['freq = ',sprintf('% 1.2f,ij*freq'), ' Hz.']);
end

JUNK = ['Subject code = 'subject_code,' Stimulus = ',num2str(freq),' Hz.'];
%text(0.3, 0.5, JUNK, 'sc');
text(x_coord, 0.55, ['Subject code = ',subject_code,'sc');
if dyn_cal
  text(x_coord, 0.50, 'DYNAMIC CALIBRATION','sc');
else
  text(x_coord, 0.50, ['Stimulus = ',num2str(freq),' Hz.'],'sc');
end
text(x_coord, 0.45, [axis_label,'SPV'],'sc');
[JUNK, prob] = circle_R_crit(N_cases);
ij = max(find(prob >= p_sig));
text(x_coord, 0.40, ['R >= ',num2str(JUNK(ij))],' implies p < '
   ,sprintf('% 1.3f',prob(ij))], 'sc');
text(x_coord, 0.35, ['N of cases = ',int2str(N_cases)], 'sc');
%text(x_coord, 0.35, ['R >= ',num2str(JUNK(2))],' implies p < '
   ,sprintf('% 1.3f',prob(2))], 'sc');
JUNK2 = [' FIRST ';'SECOND ';'THIRD '; 'FOURTH'; 'FIFTH '; 'SIXTH '
   '; 'SEVENTH'];
for ij = 1:4
  fprintf('
\texttt{\textbackslash n\textbackslash nTESTING THE ',JUNK2(ij,:),' HARMONIC at %2.2f HZ.}\texttt{\textbackslash n}'], freq*ij);
  eval(['[z, prob] = T_test(MAT',int2str(ij),',(:,2));']);
  eval(['[mu, kappa, RR, sigma] = circle_stats_a(MAT',int2str(ij),',(:,4));']);
  if RR >= min(JUNK)
    jk = max(find(JUNK <= RR));
    jk = sprintf('% 1.3f,prob(jk));
    text(0.68 - 0.5*rem(ij,2),0.32-0.25*sign(ij-2.5),
   ['R = ',num2str(RR),' (p < ',jk,' ]'), 'sc');
  else
    text(0.70 - 0.5*rem(ij,2),0.32-0.25*sign(ij-2.5),['R = ',num2str(RR),' (ns ]'), 'sc');
  end
end
% Note alternate calculation of R
% crap = cos(THETA1) + i*sin(THETA1);
% R = sqrt(abs(mean(crap)*mean(crap)));

fprintf('\texttt{\textbackslash nData summary for all included trials.\textbackslash n}');
%if dyn_cal, fprintf('\texttt{\textbackslash n\textbackslash nNote that this was a dynamic calibration.\textbackslash n}'); end

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for ij = 1:N_harmonics
    IJ = int2str(ij);
    fprintf('At \%1.2f Hz, the mean amplitude ( +/- 1.0 std. ) = \%2.2f +/- \%2.2f',
        freq, eval(['mean(MAT',IJ,':(:,2))']),eval(['std(MAT',IJ,':(:,2))']));
end

fprintf('

');
pwsc;
function [edited_spv1, edited_spv2, edited_spv3] = 
edit_alg_dual(t,SPV1,SPV2,SPV3,VEL1,VEL2,VEL3,POS1,POS2,POS3,colour)

% EDIT_ALG_DUAL EDIT_ALG_DUAL(t,SPV1,SPV2,SPV3,VEL1, 
% VEL2,VEL3,POS1,POS2,POS3,colour) allows the user to edit both SPV1 and 
% SPV2 simultaneously. SPV3 is also desaccaded, if it exists.
%
% This is the main algorithm for the manual editing of 
% slow phase velocity profiles.
% sample = sampling rate in Hz
% spv   = slow phase eye velocity vector  1 = heog
% vel   = raw eye velocity vector         2 = veog
% pos   = eye position vector            3 = teog
% colour = flag for colour monitor
%
% The user now has the capability of over-riding faulty
% interpolations made by the detection process. The 'diff_list'
% script is called to return a list of regions over which the
% raw velocity and slow phase velocity differ. The format of
% this list is identical to that of 'flag' in the 'heart' script.
%
% If one wishes to re-edit a previously edited SPV profile, then
% the first line can be deleted so that the 'diffs' list contains
% the differences between raw and *edited* SPV profiles.
%
% If the SPV profile is completely different from the raw
% velocity (due to low-pass or order-statistic filtering for
% instance), then the call to 'diff_list' should be removed.
%
% written by D. Balkwill -- 11/27/90
% some portions ruthlessly and shamelessly stripped from
% scripts by B. McGrath and W. Kulecz

% Further clumsy modification by J. Christie and D. Douglass
% July 1991 to permit editing of heog and veog simultaneously.

edited_spv1 = SPV1; % don't overwrite spv
%plot(VEL1 - edited_spv1) % to check variables
% NOTE that diff_list_alt was used due to memory limitations.
diffs1 = diff_list_dual(VEL1,edited_spv1);
num_diffs1 = length(diffs1);
edited_spv2 = SPV2; % don't overwrite spv
diffs2 = diff_list_dual(VEL2,edited_spv2);
num_diffs2 = length(diffs2);
diffs3 = diff_list_dual(VEL3,edited_spv3);

if num_diffs1 == num_diffs2
    if ~isempty(SPV3)
        fprintf('There were %3.0f previous torsional interpolations.
',length(diffs3));
    end
    fprintf('There were %3.0f previous horiz/vert interpolations.
',num_diffs1);
else

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fprintf('This is bad, diffs1 == diffs2.\n');
fprintf('Highest number of detected events:');
disp(max(num_diffs1, num_diffs2))
fprintf('Difference between hor. and ver. data:');
disp(abs(num_diffs1 - num_diffs2))
if ((abs(num_diffs1 - num_diffs2) / max(num_diffs1, num_diffs2)) >= .1)
    fprintf('There is more than a 10 percent difference between')
    fprintf('the horizontal and vertical data.\n')
    ans = input('Do you wish to update your old spv data? (y/n) [default = n] ', 's');
    if (isempty(ans))
        ans = 'n';
    end
    if ((ans ~= 'n') && (ans ~= 'N'))
        if num_diffs1 > num_diffs2
            edited_spv1 = update_spv(spv1, diffs2);
            diffs1 = diffs2;
            num_diffs1 = num_diffs2;
        else
            edited_spv2 = update_spv(spv2, diffs1);
            diffs2 = diffs1;
            num_diffs2 = num_diffs1;
        end
    end
end

highs = [];
num_highs = 0;  % number of regions highlighted
interps = [];
spv_interps1 = [];
spv_interps2 = [];
num_interps1 = 0;  % number of regions interpolated
num_interps2 = 0;

l = length(edited_spv1);
sample = round(1/(t(2) - t(1)));  % assumes t is periodic

% minimum window height to prevent graph from being dominated by noise
rms1 = sqrt(sum(edited_spv1.*edited_spv1)/l);
rms2 = sqrt(sum(edited_spv2.*edited_spv2)/l);
min_height = 3 * [rms1 rms2];
num_pick = 0; % number of points picked
os = 1; % offset of start of current trace, in samples
w = 1 - 1; % width of trace, in samples
redraw = 1; % flag for plotting
mf = 1; % magnification factor
mag_thresh = 1/(sample * 10); % 10 seconds

while (key ~= FINISHED)
    if (redraw == 1)
        df = floor(w/2000);
        if (df < 1)
            df = 1;
        end
        tr = t(os:df:os+w);
        er1 = edited_spv1(os:df:os+w);
        vr1 = VEL1(os:df:os+w);
        pr1 = POS1(os:df:os+w);
        er2 = edited_spv2(os:df:os+w);
        vr2 = VEL2(os:df:os+w);
        pr2 = POS2(os:df:os+w);
    end

    % leave some blank space above and below trace for aesthetics
    mxv = max([er1 er2]); % These had better be column vectors
    if (mxv(1) < 0)
        mx1 = mxv(1) * 0.9;
    else
        mx1 = mxv(1) * 1.1;
    end
    if (mxv(2) < 0)
        mx2 = mxv(2) * 0.9;
    else
        mx2 = mxv(2) * 1.1;
    end

    mnv = min([er1 er2]);
    if (mnv(1) < 0)
        mn1 = mnv(1) * 1.1;
    else
        mn1 = mnv(1) * 0.9;
    end
    if (mnv(2) < 0)
        mn2 = mnv(2) * 1.1;
    else
        mn2 = mnv(2) * 0.9;
    end

end
old = [(mx1 - mn1), (mx2 - mn2)];
if (old(1) < min_height(1))
    mx1 = mx1 + (min_height(1) - old(1))/2;
    mn1 = mx1 - min_height(1);
end
if (old(2) < min_height(2))
    mx2 = mx2 + (min_height(2) - old(2))/2;
    mn2 = mx2 - min_height(2);
end

% ensure that position data appears on plot
pr1 = pr1 - min(pr1) + mnv(1);
pr2 = pr2 - min(pr2) + mnv(2);
mn = min(mn1, mn2);
mx = max(mx1, mx2);

hold off
clg
subplot(211)
axis([tr(1) tr(length(tr)) mn mx]);
subplot(212)
if (colour == 'y')
    if (mf < mag_thresh)
        subplot(211)
        plot(tr,er1,'w')
        subplot(212)
        plot(tr,er2,'w')
        text(.4,0,'black = SPV','sc')
    else
        subplot(211)
        plot(tr,vrl,'r-',tr,prl,'g-',tr,erl,'w')
        title('Horizontal Eye Position and Velocity.');
        subplot(212)
        plot(tr,vr2,'r-',tr,pr2,'g-',tr,er2,'w')
        title('Vertical Eye Position and Velocity.');
        text(.12,0,'black = SPV','sc')
        text(.4,0,'red = raw velocity','sc')
        text(.7,0,'green = eye position','sc')
    end
end

% plot highlighted regions in green, solid
hold on
for i=1:num_highs
    x3 = highs(i,1);
    x4 = highs(i,2);
    subplot(211)
    plot([t(x3),t(x3)],[mn, mx],'g') % Left Side
    plot([t(x4),t(x4)],[mn, mx],'g') % Right Side
    plot([t(x3),t(x4)],[mn, mx],'g') % Diagonal
    subplot(212)
    plot([t(x3),t(x3)],[mn, mx],'g') % Left Side
    plot([t(x4),t(x4)],[mn, mx],'g') % Right Side
end
plot([t(x3),t(x4)], [mn, mx], 'g') % Diagonal
end

% plot picked regions in blue, dash-dotted
for i=1:num_interps1
  % WHAT ABOUT NUM_INTERPS2?
  x3 = interps(i,1);
  x4 = interps(i,2);
  subplot(211)
  plot([t(x3),t(x3)], [mn, mx], 'b-.')
  plot([t(x4),t(x4)], [mn, mx], 'b-.')
  plot([t(x3),t(x4)], [mn, mx], 'b-.')
  plot(t(x3:x4), spv_interps1(1:(x4-x3+1), i), 'b-')
  subplot(212)
  plot([t(x3),t(x3)], [mn, mx], 'b-.')
  plot([t(x4),t(x4)], [mn, mx], 'b-.')
  plot([t(x3),t(x4)], [mn, mx], 'b-.')
  plot(t(x3:x4), spv_interps2(1:(x4-x3+1), i), 'b-')
end

% plot currently picked point in blue, dotted
if (num_pick == 1)
  subplot(211)
  plot([t1, t1], [mn, mx], 'b:')
  subplot(212)
  plot([t1, t1], [mn, mx], 'b:')
end
hold off
else
  if (mf < mag_thresh)
    subplot(211)
    plot(tr, er1)
    text(.4, 0, 'solid = SPV', 'sc')
    subplot(212)
    plot(tr, er2)
    text(.4, 0, 'solid = SPV', 'sc')
  else
    subplot(211)
    plot(tr, vr1, 'r', tr, pr1, 'r--', tr, er1)
    subplot(212)
    plot(tr, vr2, 'r', tr, pr2, 'r--', tr, er2)
    text(.4, 0, 'dotted = raw velocity', 'sc')
    text(.7, 0, 'dashed = eye position', 'sc')
  end
end

% plot highlighted regions in dashed
hold on
for i=1:num_highs
  x3 = highs(i,1);
  x4 = highs(i,2);
  subplot(211)
plot([t(x3),t(x3)],[mn, mx],':'--')
plot([t(x4),t(x4)],[mn, mx],':'--')
plot([t(x3),t(x4)],[mn, mx],':'--')

subplot(212)
plot([t(x3),t(x3)],[mn, mx],':'--')
plot([t(x4),t(x4)],[mn, mx],':'--')
plot([t(x3),t(x4)],[mn, mx],':'--')

end

% plot picked regions in dash-dotted
for i=1:num_interps1
    % WHAT ABOUT NUM_INTERPS2?
x3 = interps(i,1);
x4 = interps(i,2);
 subplot(211)
    plot([t(x3),t(x3)],[mn, mx],':-')
    plot([t(x4),t(x4)],[mn, mx],':-')
    plot([t(x3),t(x4)],[mn, mx],':-')
    plot(t(x3:x4),spv_interps1(1:(x4-x3+1),i),':-')
 subplot(211)
    plot([t(x3),t(x3)],[mn, mx],':-')
    plot([t(x4),t(x4)],[mn, mx],':-')
    plot([t(x3),t(x4)],[mn, mx],':-')
    plot(t(x3:x4),spv_interps2(1:(x4-x3+1),i),':-')
end

% plot currently picked point in dotted
if (num_pick == 1)
    subplot(211)
    plot([tl,tl],[mn, mx],':-')
    subplot(212)
    plot([tl,tl],[mn, mx],':-')
end
hold off
end

subplot(211)
text(.8,.96,['MAG = ',int2str(round(mf)),' X'],'sc')
redraw = 0;
end

[x,y,key] = ginput(1);

if (key == ZOOM_IN) % increase magnification factor
    old=mf;
    mf=min(old*2,max(old,floor(l/100))); % Max change is 2x
    if mf==old % maximum magnification of 100X
        redraw=0;
    else
        redraw=1;
        w=floor(l/mf);
    end
end
elseif (key == FAST_ZOOM_IN)  % fast two-point zoom

% first point of region to zoom into
[t3,y,key] = ginput(1);
if ((key == DELETE_1) & (key == DELETE_2))

% bounds check on first point of region
if (t3 < tr(1))
t3 = tr(1);
elseif (t3 > tr(length(tr)))
t3 = tr(length(tr));
end
x3 = 1 + round(t3 * sample);
t3 = (x3 - 1)/sample;

% display first point
hold on
if (colour == 'y')
subplot(211)
plot([t3,t3],[mn, mx],'r:');
subplot(212)
plot([t3,t3],[mn, mx],'r:');
else
subplot(211)
plot([t3,t3],[mn, mx],':');
subplot(212)
plot([t3,t3],[mn, mx],':');
end
hold off
redraw = 1;

% second point of region to zoom into
[t4,y,key] = ginput(1);

% allow user to abort zoom via delete key
if ((key == DELETE_1) & (key == DELETE_2))

% bounds check on second point of region
if (t4 < tr(1))
t4 = tr(1);
elseif (t4 > tr(length(tr)))
t4 = tr(length(tr));
end
x4 = 1 + round(t4 * sample);
t4 = (x4 - 1)/sample;

% display second point
hold on
if (colour == 'y')
subplot(211)
plot([t4,t4],[mn, mx],'r:');
subplot(212)
end

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plot([t4,t4],[mn, mx],'r:');

else
    subplot(211)
    plot([t4,t4],[mn, mx],'r:');
    subplot(212)
    plot([t4,t4],[mn, mx],'r:');
end

hold off

% swap order of points if needed
if (x4 < x3)
    old = x4;
    x4 = x3;
    x3 = old;
end

% calculate new magnification parameters
if (x3 ~= x4)
    os = x3;
    w = x4 - x3;
    mf = 1/w;
end
end

elseif (key==ZOOM_OUT) % decrease magnification

if (mf == 1) % already completely zoomed out
    redraw = 0;
else
    redraw=1;
    old=mf;
    mf=max(floor(old/2),1);
    w=floor(l/mf);
    if (w >= 1)
        w = 1 - 1;
    end
    if ((os+w)>l)
        os=floor(max(1,1-w));
    end
end

elseif ((key == COMPLETE_PLOT_1) I (key == COMPLETE_PLOT_2) I (key == FAST_ZOOM_OUT)) % display entire plot

os = 1;
mf = 1;
w = 1 - 1;
redraw = 1;

elseif (key==PAN_RIGHT) % increase offset by quarter-screen

old=os;
os = floor(max(1, min(1 - w, os + 0.25 * w)));  
if old == os  % already panned to end
   redraw = 0;
else
   redraw = 1;
end

elseif (key == PAN_LEFT)  % decrease offset by quarter-screen

   old = os;
   os = floor(max(1, os - 0.25 * w));
   if os == old  % already panned to beginning
      redraw = 0;
   else
      redraw = 1;
   end

elseif (key == SCROLL_RIGHT)  % jump display one screenful right

   old = os;
   os = floor(max(1, min(os + w, l - w)));
   if os == old  % already panned to end
      redraw = 0;
   else
      redraw = 1;
   end

elseif (key == SCROLL_LEFT)  % jump display one screenful left

   old = os;
   os = floor(max(1, os - w));
   if old == os  % already panned to beginning
      redraw = 0;
   else
      redraw = 1;
   end

elseif (key == ACCEPT)  % accept fast phase interpolations

   if (num_pick == 0)
      for i = 1:num_interps1
         % WHAT ABOUT NUM_INTERPS2?
         % substitute new values into edited SPV
         x1 = interps(i, 1);
         x2 = interps(i, 2);
         edited_spv1(x1:x2) = spv_interps1(1:(x2 - x1 + 1), i);
         edited_spv2(x1:x2) = spv_interps2(1:(x2 - x1 + 1), i);

         % add region to list of differences  Due SPV1 first.
         if (num_diffs1 == 0)  % add to beginning
            diffs1 = [x1 x2];
         elseif (x2 < diffs1(1, 1))  % add to beginning
            diffs1 = [[x1 x2] ; diffs1];
      end
   end

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elseif (x1 > diffs1(num_diffs1,2)) % add to end
diffs1 = [ diffs1 ; [x1 x2] ];
else
  for j=1:num_diffs1
    if (diffs1(j,1) > x2)
      break;
    end
  end
diffs1 = [diffs1(1:j-1,:) ; [x1 x2] ; diffs1(j:num_diffs1,:) ];
end
num_diffs1 = num_diffs1 + 1;
if (rem(num_diffs1,20) == 0)
  fprintf('There are currently %3.0f interpolations.
',num_diffs1);
end

% Do the same thing now for SPV2
if (num_diffs2 == 0) % add to beginning
  diffs2 = [x1 x2];
elseif (x2 < diffs2(1,1)) % add to beginning
  diffs2 = [[x1 x2] ; diffs2];
elseif (x1 > diffs2(num_diffs2,2)) % add to end
  diffs2 = [diffs2 ; [x1 x2] ];
else
  for j=1:num_diffs2
    if (diffs2(j,1) > x2)
      break;
    end
  end
diffs2 = [diffs2(1:j-1,:) ; [x1 x2] ; diffs2(j:num_diffs2,:) ];
end
num_diffs2 = num_diffs2 + 1;
end

% reset appropriate values
num_interps1 = 0;
num_interps2 = 0;
clear interps spv_interps1 spv_interps2
interps = [ ];
spv_interps1 = [ ];
spv_interps2 = [ ];
num_pick = 0;
redraw = 1;
end

elseif ((key==RE_INTERP_1) | (key==RE_INTERP_2))
  % Added by JC in August 1991
  for i=1:num_highs
    x3 = highs(i,1);
    x4 = highs(i,2);
    % Do first order interpolation
    pick_t = t(x3:x4);
slope1 = (edited_spv1(x4) - edited_spv1(x3)) / (x4 - x3);
slope2 = (edited_spv2(x4) - edited_spv2(x3)) / (x4 - x3);
end
\[
edited_{\text{spv1}}(x_3:x_4) = \text{edited}_{\text{spv1}}(x_3) + ([0:x_4-x_3]' \times \text{slope1});
\]
\[
edited_{\text{spv2}}(x_3:x_4) = \text{edited}_{\text{spv2}}(x_3) + ([0:x_4-x_3]' \times \text{slope2});
\]
end
num_highs = 0;
clear highs
highs = [];
redraw = 1;

elseif ((key==\text{DELETE}_1) \lor (key==\text{DELETE}_2))

if (num_pick > 0)  \% wipe out currently picked point
    num_pick = 0;
    redraw = 1;
elseif (num_highs > 0) \% wipe out highlit regions
    for i=1:num_highs
        x3 = highs(i,1);
        x4 = highs(i,2);
        \% copy raw velocity values back in
        edited_{\text{spv1}}(x3:x_4) = \text{VEL1}(x_3:x_4);
        edited_{\text{spv2}}(x_3:x_4) = \text{VEL2}(x_3:x_4);
        index = \text{InList}(x_3,\text{diffs1});
        diffs1 = \text{DeleteRow}(\text{index},\text{diffs1});
        diffs2 = \text{DeleteRow}(\text{index},\text{diffs2});
    end
    num_diffs1 = num_diffs1 - num_highs;
    num_diffs2 = num_diffs2 - num_highs;
    num_highs = 0;
clear highs
    highs = [];
    redraw = 1;
elseif (num_interps1 > 0) \% wipe out last interpolation
    \% \text{WHAT} \text{ABOUT NUM_INTERPS2}?
    redraw = 1;
    num_interps1 = num_interps1 - 1;
    num_interps2 = num_interps2 - 1;
    interps = interps(1:num_interps1,:);
    \% \text{WHAT} \text{ABOUT NUM_INTERPS2}?
    spv_interps1 = spv_interps1(:,1:num_interps1);
    spv_interps2 = spv_interps2(:,1:num_interps2);
end

elseif (key==\text{1}) \lor (key==\text{2}) \lor (key==\text{3}) \% up to three-button mouse input

if (num_pick == 0) \% this is the first picked point

    \% bounds check on picked point
    if (x < \text{tr}(1))
        x = \text{tr}(1);
    elseif (x > \text{tr}(\text{length(tr)}))
        x = \text{tr}(\text{length(tr)});
    end

    \% convert time value to sample number
x1 = 1 + round(x * sample);

% see if point is in a selected region
% % % % Potential Problem here if diffs1 ~= diffs2.
index1 = InList(x1,diffs1);
if (index1 > 0)
  index2 = InList(x1,highs);
  if (index2 > 0) % de-highlight region
    num_highs = num_highs - 1;
    highs = DeleteRow(index2,highs);
    redraw = 1;
  else % highlight region for future deletion
    x1 = diffs1(index1,1);
    x2 = diffs1(index1,2);
    t1 = (x1 - 1)/sample;
    t2 = (x2 - 1)/sample;
    num_highs = num_highs + 1;
    highs(num_highs,:) = [x1 x2];
    if (colour == 'y')
      hold on
      subplot(211)
      plot([t1 t1],[mn mx],'g');
      plot([t2 t2],[mn mx],'g');
      plot([t1 t2],[mn mx],'g');
      subplot(212)
      plot([t1 t1],[mn mx],'g');
      plot([t2 t2],[mn mx],'g');
      plot([t1 t2],[mn mx],'g');
    else
      hold on
      subplot(211)
      plot([t1 t1],[mn mx],'-');
      plot([t2 t2],[mn mx],'-');
      plot([t1 t2],[mn mx],'-');
      subplot(212)
      plot([t1 t1],[mn mx],'-');
      plot([t2 t2],[mn mx],'-');
      plot([t1 t2],[mn mx],'-');
    end
  end
else % point is not already in a selected region
% display as first point of region being selected
  t1 = (x1 - 1)/sample;
  num_pick = 1;
  hold on
  if (colour == 'y')
    subplot(211)
    plot([t1 t1],[mn mx],'b:');
    subplot(212)
    plot([t1 t1],[mn mx],'b:');
  else
    subplot(211)
    plot([t1 t1],[mn mx],':');
  end
end
else % point is not already in a selected region
% display as first point of region being selected
  t1 = (x1 - 1)/sample;
  num_pick = 1;
  hold on
  if (colour == 'y')
    subplot(211)
    plot([t1 t1],[mn mx],'b:');
    subplot(212)
    plot([t1 t1],[mn mx],'b:');
  else
    subplot(211)
    plot([t1 t1],[mn mx],':');
  end
end

elseif (num_pick == 1)  % second picked point

  % bounds check on picked point
  if (x < tr(1))
    x = tr(1);
  elseif (x > tr(length(tr)))
    x = tr(length(tr));
  end

  % convert time value to sample number
  x2 = 1 + round(x * sample);
  t2 = (x2 - 1)/sample;

  if (x2 == x1)  % cannot have interval of zero width
    num_pick = 0;
    redraw = 1;
  else
    if (x2 < x1)  % order picked points
      oldx = x1;
      x1 = x2;
      x2 = oldx;
    end
    num_pick = 0;
    hold on
    if (colour == 'y')
      subplot(211)
      plot([t2,t2],[mn, mx],'b:');
      subplot(212)
      plot([t2,t2],[mn, mx],'b:');
    else
      subplot(211)
      plot([t2,t2],[mn, mx],'-.');
      subplot(212)
      plot([t2,t2],[mn, mx],'-.');
    end
  end

  % interpolate linearly across picked interval
  slope1 = (edited_spvl(x2) - edited_spvl(x1)) / (x2 - x1);
  slope2 = (edited_spv2(x2) - edited_spv2(x1)) / (x2 - x1);
  pick_spvl = edited_spvl(x1) + (0:x2-x1)' * slope1;
  pick_spv2 = edited_spv2(x1) + (0:x2-x1)' * slope2;
  pick_l = length(pick_spv1);
  pick_t = t(x1:x2);
  if (colour == 'y')
    subplot(211)
    plot(pick_t,pick_spv1,'b-');
    subplot(212)
    plot(pick_t,pick_spv2,'b-');
else
    subplot(211)
    plot(pick_t,pick_spv1,'-.');
    subplot(212)
    plot(pick_t,pick_spv2,'-.');
end
hold off

% add region to list of interpolated regions, and
% add interpolated vector to its list, padding the
% list of interpolated vectors with zeros as needed
num_interps1 = num_interps1 + 1;
interps = [interps ; [x1 x2]];
[mm,nn] = size(spv_interps1);
if (pick_l < mm)
    pick_spv1 = [pick_spv1 ; zeros(mm-pick_l,1)];
elseif (pick_l > mm)
    if (nn > 0)
        spv_interps1 = [spv_interps1 ; zeros(pick_l-mm,nn)];
    end
end
spv_interps1 = [spv_interps1 pick_spv1];

num_interps2 = num_interps2 + 1;
[mm,nn] = size(spv_interps2);
if (pick_l < mm)
    pick_spv2 = [pick_spv2 ; zeros(mm-pick_l,1)];
elseif (pick_l > mm)
    if (nn > 0)
        spv_interps2 = [spv_interps2 ; zeros(pick_l-mm,nn)];
    end
end
spv_interps2 = [spv_interps2 pick_spv2];
end
%
end  % manual editing complete

if ~isempty(VEL3) % ie. vel3 exists
    text(0.4,0.5,'WAIT - Processing Torsion','sc')
diffs3 = diffs1;
num_diffs3 = length(diffs3);
edited_spv3 = SPV3; % don't overwrite spv
for k = 1:num_diffs3
    x1 = diffs3(k,1);
    x2 = diffs3(k,2);
slope3 = (edited_spv3(x2) - edited_spv3(x1)) / (x2-x1);
edited_spv3(x1:x2) = edited_spv3(x1) + ([0:x2-x1]'*slope3);
end
diffs3 = diff_list_dual(VEL3(edited_spv3);
if (length(diffs3) < length(diffs1))
    fprintf('nThere were only %3.0f torsional interpolations.
','length(diffs3));
end

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else
    edited_spv3 = [];
end

ave_len = mean(diffs1(:,2)-diffs1(:,1))*max(t)/length(t);
fprintf('There are %3.0f interpolations after editing.
The average duration is %1.3f seconds.
',num_diffs1, ave_len);

clg;
hold off;
return;
% edit_spv dual
% EDIT_SPV_DUAL allows user to edit two dimensions simultaneously.
% The commands are very similar to those used in edit_spv
% Maximum vector length is 10,000 points. Clear all junk before.
% It will load all available axes automatically.
% The user has the option to save intermediate files, and then
% resume editing. This algorithm works best when all axes are edited together.
% See also EDIT_ALG_DUAL

% (if it works!!) JC & DD July 1991

% This script is used for manual editing of a slow phase
% velocity profile. The user specifies a run code and an axis
% number, and the corresponding eye position, velocity, and
% slow phase velocity are loaded from the data_path. The eye
% position is then corrected to degrees (relative, not absolute)
% so that all displayed data will be in deg or deg/sec.
%
% The 'edit_alg_dual' script is then called to perform the actual
% editing process -- this is simply the interface between the
% basic algorithm and the NysA format.
%
% Finally, the user is giving the option of saving the edited
% SPV profile, or aborting so as not to overwrite previously
% saved data. It is also possible to save after editing
% and return to edit the rest of the file without reloading.
%
% D. Balkwill -- 11/27/90
% D. Douglass -- 7/3/91
% J. Christie -- 7/9/91

if (exist('nysa_path') ~= 1)
    nysa_path = get_path;
    %nysa_path = 'JC_DATA:NYSA:scripts:';
end

eval(['load ',nysa_path,'bookkeeping:vel_filter.mat']);
eval(['load ',nysa_path,'bookkeeping:colour']);
file_specs jc

run_code = [folder(1),'01l'];
name = input(['Enter exp. code [ default = ', run_code, ' ] '],'s');
if (~isempty(name))
    run_code(1:4) = CAPS(name);
end

clear Acc_Var Acc_File folder name scale_coil zero_A_D
clear Cal1_Var Cal1_File Cal2_Var Cal2_File Cal3_Var Cal3_File
clear Okn_File_raw Okn_File_out Okn_scale Okn_Var
clear Sled_File_raw Sled_File_out Sled_scale Sled_Var

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axis_flag = 0;
in_file = file_name(Pos1_File,run_code);
if (exist([data_path,in_file]) == 2) % This auto loads axis 1, if possible.
    axis_flag = axis_flag + 1;
    fprintf(\n'Loading '); fprintf(Pos1_Var); fprintf(' ');
    eval(['load ',data_path,in_file]);
    switch_h
        eval(['POS1 = ',Pos1_Var,';']);
        eval(['clear ',Pos1_Var]);
    clear in_file Pos1_var
    in_file = file_name(Vel1_File,run_code);
    eval(['load ',data_path,in_file]);
    eval(['VEL1 = ',Vel1_Var,';']);
    eval(['clear ',Vel1_Var]);
    clear in_file
    in_file = file_name(Edited1_File,run_code); % Y/3 or Z/4
    if (exist([data_path,in_file]) == 2)
        fnew = input(\n'Do you want to use edited SPV1? [ default = y ] ','s');
        if (isempty(fnew))
            fnew = 'y';
        end
        if ((fnew == 'y') | (fnew == 'Y'))
            eval(['load ',data_path,in_file]);
            eval(['SPV1 = ',Edited1_Var,';']);
            eval(['clear ',Edited1_Var]);
        else
            clear in_file
            in_file = file_name(SPV1_File,run_code);
            eval(['load ',data_path,in_file]);
            eval(['SPV1 = ',SPV1_Var,';']);
            eval(['clear ',SPV1_Var]);
            clear in_file
        end % Added by JC and DD July 1991 to be smart
    else
        clear in_file
        in_file = file_name(SPV1_File,run_code);
        eval(['load ',data_path,in_file]);
        eval(['SPV1 = ',SPV1_Var,';']);
        eval(['clear ',SPV1_Var]);
        clear in_file
    end

x = POS1;
filtzero;
cal_factor1 = (max(VEL1) - min(VEL1)) / (max(x) - min(x));
cal_factor1 = (cal_factor1 + std(VEL1)/std(x))/2;
POS1 = POS1 * cal_factor1;
clear x in_file Pos1_File Vel1_Var Vel1_File SPV1_Var SPV1_File
end
end

in_file = file_name(Pos2_File,run_code);
if (exist([data_path,in_file]) == 2)  % This auto loads axis 2, if possible.
    axis_flag = axis_flag + 2;
    fprintf('Loading '); fprintf(Pos2_Var); fprintf(' ');
    eval(['load ',data_path,in_file]);
    switch_v
        eval(['POS2 = ',Pos2_Var, '; ']);
        eval(['clear ',Pos2_Var]);
    end
    in_file = file_name(Vel2_File,run_code);
    eval(['load ',data_path,in_file]);
    eval(['VEL2 = ',Vel2_Var, '; ']);
    eval(['clear ',Vel2_Var]);
end

if (exist([data_path,in_file]) == 2)
    fnew = input('Do you want to use edited SPV2 ? [ default = y ] ', 's');
    if (isempty(fnew))
        fnew = 'y';
    end
    if ((fnew == 'y') | (fnew == 'Y'))
        eval(['load ',data_path,in_file]);
        eval(['SPV2 = ',Edited2_Var, '; ']);
        eval(['clear ',Edited2_Var]);
    else
        clear in_file
        in_file = file_name(SPV2_File,run_code);
        eval(['load ',data_path,in_file]);
        eval(['SPV2 = ',SPV2_Var, '; ']);
        eval(['clear ',SPV2_Var]);
    end  % Added by JC and DD July 1991 to be smart
else
    clear in_file
    in_file = file_name(SPV2_File,run_code);
    eval(['load ',data_path,in_file]);
    eval(['SPV2 = ',SPV2_Var, '; ']);
    eval(['clear ',SPV2_Var]);
end

x = POS2;
filtzero;
cal_factor2 = (max(VEL2) - min(VEL2)) / (max(x) - min(x));
cal_factor2 = (cal_factor2 + std(VEL2)/std(x))/2;
POS2 = POS2 * cal_factor2;
clear x in_file Pos2_File Vel2_Var Vel2_File SPV2_Var SPV2_File
end

in_file = file_name(Pos3_File,run_code);
if (exist([data_path,in_file]) == 2)  % This auto loads axis 3, if possible.
    axis_flag = axis_flag + 4;
    fprintf('Loading '); fprintf(Pos3_Var); fprintf(' ');
    eval(['load ',data_path,in_file]);
end
eval(['POS3 = ',Pos3_Var,';']);
eval(['clear ',Pos3_Var]);
clear in_file
in_file = file_name(Vel3_File,run_code);
eval(['load ',data_path,in_file]);
eval(['VEL3 = ',Vel3_Var,';']);
eval(['clear ',Vel3_Var]);
clear in_file
in_file = file_name(Edited3_File,run_code); % Y/3 or Z/4
if (exist([data_path,in_file]) == 2)
  \% fnew = input('Do you want to use edited SPV3 ? [ default = y ] ',s);
  if (isempty(fnew))
    fnew = 'y';
  end
  if ((fnew == 'y') | (fnew == 'Y'))
    Name_Var = 'Edited3_Var';
    eval(['load ',data_path,in_file]);
    eval(['SPV3 = ',Edited3_Var,';']);
    eval(['clear ',Edited3_Var]);
  else
    clear in_file
    in_file = file_name(SPV3_File,run_code);
    eval(['load ',data_path,in_file]);
    eval(['SPV3 = ',SPV3_Var,';']);
    eval(['clear ',SPV3_Var]);
  clear in_file
end  \% Added by JC and DD July 1991 to be smart
else
  clear in_file
  in_file = file_name(SPV3_File,run_code);
  eval(['load ',data_path,in_file]);
  eval(['SPV3 = ',SPV3_Var,';']);
  eval(['clear ',SPV3_Var]);
  clear in_file
end

x = POS3;
filtzero;
cal_factor3 = (max(VEL3) - min(VEL3)) / (max(x) - min(x));
cal_factor3 = (cal_factor3 + std(VEL3)/std(x))/2;
POS3 = POS3 * cal_factor3;
clear x in_file Pos3_File Vel3_Var Vel3_File SPV3_Var SPV3_File
else  \% This loads blanks to permit use of edit_alg_sls
  POS3 = [];  
  VEL3 = [];  
  SPV3 = [];  
end

clear A B x cal_factor1 cal_factor2 cal_factor3 Name_Var fnew
fprintf('Loading complete.

');
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l = length(SPV1);
if (length(SPV1) == length(SPV2))
    fprintf('Roh Roh ! length(SPV1) ~ = length(SPV2)\n');
end
continue = 'y';
t = [0:(l-1)]/sample;

if ((axis_flag == 1)||(axis_flag == 2)||(axis_flag == 4))
    dn = int2str(round(log(2*axis_flag)/log(2)));
    while (continue == 'y')
        eval(['edited_spv',dn, ' = editalg(t,SPV',dn,',VEL',dn,',POS',dn,',colour);']);
        clear POS1 POS2 POS3 VEL1 VEL2 VEL3
        hold off
        clg
        subplot(111);
        axis([1 2 3 4]);
        eval(['plot(t,SPV',dn,','r');']);
        hold on
        eval(['plot(t,edited_spv',dn,','w');']);
        hold off
        xlabel('Time (sec)');
        ylabel('Slow Phase Velocity (deg/sec)');
        eval(['title("Edited Pos',int2str(dn),'_Var");'run_code,''])
        text(.2,0,'red = Raw SPV','sc')
        text(.7,0,'black = Edited SPV','sc')
        yn = input('Do you wish to save this edition? (y/n) [ default = y ] ','s');
        if (isempty(yn))
            yn = 'y'; % defaults to yes.
        end
        if ((yn ~= 'n') & (yn ~= 'N'))
            var = eval(['Edited',dn, '_Var']);
            eval(['var,= edited_spv',int2str(dn),';']);
            eval(['out_file = file_name(Edited',dn,',_File,run_code);'],$');
            fprintf('Ability to save files is incapacitated right now.$n');
            eval(['save ',data_path,out_file,' ',var]);
            %JC eval(['save ',nysa_path,'Data_Out:edited_spv',int2str(dn),',var]);
        end
        eval(['SPV',int2str(dn), '= edited_spv',int2str(dn),';'])
        eval(['clear edited_spv',int2str(dn)]);
    end
end

elseif ((axis_flag == 3)||(axis_flag == 7))
    clear t
    POS3 = []; % This is done to save memory, since it is never plotted anyhow.
    hold off
    clg

end
subplot(111);  
while (continue == 'y')|(continue == 'Y')  
    [edited_spv1, edited_spv2, edited_spv3] = edit_alg_dual([0:(1-1)]/sample,SPV1,SPV2,SPV3,VEL1,VEL2,VEL3,POS1,POS2,POS3,colour);  
    for dn = 1:round(2 + (axis_flag -3)/4),  
        eval(['plot([0:(1-1)]/sample,SPV',int2str(dn),',"r");']);  
        hold on  
        eval(['plot([0:(1-1)]/sample,edited_spv',int2str(dn),',"w");']);  
        hold off  
        xlabel('Time (sec)');  
        ylabel('Slow Phase Velocity (deg/sec)');  
        eval(['title("Edited ',eval(['Pos',int2str(dn),'_Var']), ', in black. -- Run #',',prefix, run_code,"")']);  
        text(.2,0,'red = Raw SPV','sc')  
        text(.7,0,'black = Edited SPV','sc')  
        yn = input('Do you wish to save this edition? [ default = y ] ','s');  
        if (isempty(yn))  
            yn = 'y';  
        end  
        if (((yn ~= 'n') & (yn ~= 'N')))  
            var = eval(['Edited',int2str(dn),'_Var']);  
            eval(['var,= edited_spv',int2str(dn),',']);  
            eval(['out_file = file_name(Edited',int2str(dn),',_File,run_code);']);  
            eval(['save ,nysa_path,Data_Out:edited_spv',int2str(dn),',var]);  
            eval(['clear ,var]);  
        end  
        eval(['SPV',int2str(dn),' = edited_spv',int2str(dn),',']);  
        eval(['clear edited_spv',int2str(dn)]);  
    end  
    continue = input('Do you wish to continue editing? [ default = y ] ','s');  
    if isempty(continue)  
        continue = 'y';  
    end  
    clear dn out_file var yn  
end  
% End of While continue loop  

clear POS1 POS2 POS3 VEL1 VEL2 VEL3 SPV1 SPV2 SPV3  

elseif ((axis_flag == 5)|(axis_flag == 6))  
    dn = int2str(axis_flag - 4);  
    % eval(['[edited_spv',int2str(dn),', edited_spv3] =  
    edit_alg_with_tor(t,SPV',dn,',SPV3,VEL',dn,',VEL3,POS',dn,',POS3,colour);']);  
    clear POS1 POS2 POS3 VEL1 VEL2 VEL3 SPV1 SPV2 SPV3  
    % perhaps we need to use int2str(dn) above?  
    fprintf('
Option %1.1f is not supported at this time.
',axis_flag);  
else  
    fprintf('
Option %1.1f is not supported at this time.
',axis_flag);  
end  

clear nysa_path dn dim pos vel spv edited_spv t sample run_code
clear accept_flag ans var mn mx l data_path latest in_file out_file colour
clear axis_flag yn continue prefix stat_path

clear Edited1_File edited_spv1 Edited1_Var Edited2_File
clear edited_spv2 Edited2_Var Edited3_File edited_spv3 Edited3_Var
% clear SPV1 SPV2 SPV3 Pos1_Var Pos2_Var Pos3_Var

% file_specs_jc
% contains names of raw data files and enclosed variable names
% D. Balkwill 9/13/90
% amended over the course of Summer '91 D. Douglass and J. Christie

prefix = 'LYN';
folder = 'LYN3:';
data_path = ['Macintosh_HD:THINKC:',folder];  % <---check this!!
stat_path = ['Macintosh_HD:THINKC:',folder,'STATS:'];  % <---check this!!

% For all three channels with coils
% 10 deg = 2 Volts and 20 Volts = 4096 units.
% So scale Coil = 100/4096 =0.024414 deg/unit by default

scale_coil = 0.024414;
Sled_scale = 0.00253517;  %JC JULY 91 % (meters/sec) / (A/D unit)
Okn_scale = (60/0.140) * (10/2048);  % (deg/sec) / (A/D unit)
zero_A_D = 2048;

eval(['Pos1_File = [prefix,"#C3.POS"]';])  % Y/3 or Z/4
eval(['Pos2_File = [prefix,"#C4.POS"]';])
eval(['Pos3_File = [prefix,"#C5.POS"]';])
eval(['Cal1_File = [prefix,"#C3.POS"]';])  % Y/3 or Z/4
eval(['Cal2_File = [prefix,"#C4.POS"]';])
eval(['Cal3_File = [prefix,"#C5.POS"]';])
eval(['Vel1_File = [prefix,"#C3.VEL"]';])  % Y/3 or Z/4
eval(['Vel2_File = [prefix,"#C4.VEL"]';])
eval(['Vel3_File = [prefix,"#C5.VEL"]';])
eval(['SPV1_File = [prefix,"#C3.aspvh"]';])  % Y/3 or Z/4
eval(['SPV2_File = [prefix,"#C4.aspvv"]';])
eval(['SPV3_File = [prefix,"#C5.aspvt"]';])
eval(['Edited1_File = [prefix,"#C3.NEW2"]';])  % Y/3 or Z/4
eval(['Edited2_File = [prefix,"#C4.NEW2"]';])
eval(['Edited3_File = [prefix,"#C5.NEW2"]';])
eval(['Sled_File = [prefix,"#C2.MAT"]';])
eval(['Okn_File = [prefix,"#C1.MAT"]';])
eval(['Acc_File = [prefix,"#.acc"]';])  % Y/Z

Sled_Var = 'sled';
Okn_Var = 'shade';
Pos1_Var = 'theta1';  % h-Y axis, v-Z axis
Pos2_Var = 'theta2';
Pos3_Var = 'theta3';
Cal1_Var = 'theta1'; % h-Y axis, v-Z axis
Cal2_Var = 'theta2';
Cal3_Var = 'theta3';
Vel1_Var = 'h_vel'; % 1-Y axis, 2-Z axis
Vel2_Var = 'v_vel';
Vel3_Var = 'v_vel';
SPV1_Var = 'aspvh'; % 1-Y axis, 2-Z axis
SPV2_Var = 'aspvv';
SPV3_Var = 'aspvt';
Edited1_Var = 'h_vel_slo2'; % 1-Y axis, 2-Z axis
Edited2_Var = 'v_vel_slo2';
Edited3_Var = 't_vel_slo2';
Acc_Var = 'm_acc';

if (data_path(length(data_path)) ~=':') % adds: if missing
    data_path = [data_path,':'];
end
if (stat_path(length(stat_path)) ~=':') % adds: if missing
    stat_path = [stat_path,':'];
end
function f = fun1(k)

% GLAW first, then Jock R. I. Christie 09 Nov 91
% fits the gain function: \( g = k \cdot \sqrt{(wc/w^2 + 1)} \)
% for OCR & CEP

x = Data(:,1);
x_i = x*i;
y = Data(:,2);

NUM = [k(1), k(1)*k(2)]; DEN = [1, 0]; % << Check this
A = abs(polyval(NUM,xi)./polyval(DEN,xi));
B = angle(polyval(NUM,xi)./polyval(DEN,xi));

% f is kind of like a standard deviation for all points
f = norm(A-y)/sqrt(length(x));

fprintf('std dev = %.4f
',f);
% Statements to plot progress of fitting:
if show_graphs
    clg
    loglog(x,A,x,y,'o')
    text(.15,.85,['k = ' num2str(k(1)) ' w = ' num2str(k(2))],'sc')
    text(.15,.8,'std dev = ' num2str(f),'sc')
end

function f = fun2(k)

% GLAW first, then Jock R. I. Christie 09 Nov 91
% fits the gain function: \( g = k \cdot \sqrt{(w^2 + w^2)} \)
% for SPV

x = Data(:,1);
x_i = x*i;
y = Data(:,2);

NUM = [k(1), k(1)*k(2)]; DEN = [0,1]; % << Check this
A = abs(polyval(NUM,xi)./polyval(DEN,xi));
B = angle(polyval(NUM,xi)./polyval(DEN,xi));

% f is kind of like a standard deviation for all points
f = norm(A-y)/sqrt(length(x));

fprintf('std dev = %.4f
',f);
% Statements to plot progress of fitting:
if show_graphs
    clg
    loglog(x,A,x,y,'o')
    text(.15,.85,['k = ' num2str(k(1)) ' w = ' num2str(k(2))],'sc')
    text(.15,.8,'std dev = ' num2str(f),'sc')
end
end
function \( f = \text{fun3}(k) \)
% Jock R. I. Christie 09 Nov 91
% fits the gain function: \( g = \frac{\text{abs}(s / (wc + s))}{\text{ie } g = s/\sqrt{s^2 + k^2}} \)
% for SPV
\[
x = \text{Data}(:,1);
x_i = x*\text{i};
y = \text{Data}(:,2);
\]
\[
\text{NUM} = [k(1), 0]; \text{DEN} = [1,k(2)]; \quad \% \text{<< Check this}
A = \text{abs(polyval(NUM,xi)./polyval(DEN,xi))};
B = \text{angle(polyval(NUM,xi)./polyval(DEN,xi))};
\]
% \( f \) is kind of like a standard deviation for all points
\[
f = \text{norm}(A-y)/\sqrt{\text{length}(x)};
\]
%fprintf('std dev = %1.4f
',f);
% Statements to plot progress of fitting:
if show_graphs
    clg
    loglog(x,A,x,y,'o')
    text(.15,.85,['k = ' num2str(k(1)) ' '],'sc')
    text(.15,.8,['std dev = 'num2str(f)],'sc')
end

function \( f = \text{fun4}(k) \)
% Jock R. I. Christie 09 Nov 91
% fits the gain function: \( g = \text{abs}(k / ((10s+1)*(0.66s+1))) \)
% as transfer function from acceleration to SPV
% Based on Meiry etc.
\[
x = \text{Data}(:,1);
x_i = x*\text{i};
y = \text{Data}(:,2);
\]
\[
\text{NUM} = [k(1), 0]; \text{DEN} = [6.6, 10.66, 1]; \quad \% \text{<< Check this}
A = \text{abs(polyval(NUM,xi)./polyval(DEN,xi))};
B = \text{angle(polyval(NUM,xi)./polyval(DEN,xi))};
\]
% \( f \) is kind of like a standard deviation for all points
\[
f = \text{norm}(A-y)/\sqrt{\text{length}(x)};
\]
%fprintf('std dev = %1.4f
',f);
% Statements to plot progress of fitting:
if show_graphs
    clg
    loglog(x,A,x,y,'o')
    text(.15,.85,['k = ' num2str(k(1)) ' '],'sc')
    text(.15,.8,['std dev = 'num2str(f)],'sc')
end
function \texttt{f = fun5(k)}

% Jock R. I. Christie 09 Nov 91
% fits the gain function: \( g = \frac{\text{abs}(k(1)s+k(2))/(ks+1)} \)
% as transfer function from acceleration to SPV
% Based on Meiry etc.

\begin{verbatim}
\begin{verbatim}
x = Data(:,1);
i = x**i;
y = Data(:,2);

NUM = [k(1), k(2)]; DEN = [k(3), 1]; % << Check this
A = abs(polyval(NUM,xi)./polyval(DEN,xi));
B = angle(polyval(NUM,xi)./polyval(DEN,xi));

\% f is kind of like a standard deviation for all points
f = norm(A-y)/sqrt(length(x));
\end{verbatim}
\end{verbatim}

\end{verbatim}

function \texttt{f = funpl(p)}

% GLAW first, then Jock R. I. Christie 10 Nov 91
% fits the phase function: phase = atan\[-(w/wd)\]
% for OCR & CEP
\begin{verbatim}
\begin{verbatim}
x = Data(:,1);
i = x**i;
z = Data(:,3);
C = atan(-x/p);

\% f is kind of like a standard deviation for all points
f = norm(C-(z-B))/sqrt(length(x));
\end{verbatim}
\end{verbatim}

\end{verbatim}
% JC_POWER
% Written hastily by Jock R. I. Christie to make plots

axis_num = 1; % 1 loads the horizontal data
box = [0 80 120];  % sets limits of graphing window for amplitude
boxP = [box(1:2), -200, 200]; % sets limits of graphing window for phase
data_path = 'Macintosh_HD:stats:'; % <---check this!!!
data_path = 'disc40:JC:'; % <---check this!!!
freq_stim = [0.25; 1.00]; % Input stimuli
N_harmonics = 4; % Number of harmonics in original test.
subject_code = 'LYM'; % Default subject code
trial_limit = 2; % For limited trials during any test day
x_coord = 0.65; % Used for putting text on the plots
i = sqrt(-1); % Allows quicker calculations.

if axis_num == 1
    axis_code = 'H:';  axis_label = 'Horizontal';
elseif axis_num == 2
    axis_code = 'V:';  axis_label = 'Vertical';
else
    axis_code = 'T:';  axis_label = 'Torsional';
end

for ij = 1:N_harmonics
    IJ = int2str(ij);
    eval(['clear MEAN_AMP',IJ,' STD_AMP',IJ,' MEAN_PHI',IJ,' STD_PHI',IJ,' PHI',IJ]);
end
for ij = 1:length(freq_stim)
clear Days MAT1 MAT2 MAT3 MAT4 MAT_name trial_limit N_cases
freq = freq_stim(ij);
in_file = [data_path,'O_K_N:','subject_code',num2str(freq),',axis_label(1)];
eval(['load ', in_file]);
nn(ij), mm(ij) = size(MAT_name);
for kl = 1:N_harmonics
    KL = int2str(kl);
eval(['PHI',KL,' = MAT',KL,':(:,4) - 2*pi*sign(MAT',KL,':(:,4)).* (abs(MAT',KL,':(:,4)) > pi)];
end
for jk = 1:length(Days)
    pointy = find(MAT_name(:,4) == sprintf('%1.0f',Days(jk)));
    for kl = 1:N_harmonics
        KL = int2str(kl);
eval(['MEAN_AMP',KL,':(jk,ij) = mean(MAT',KL,':(pointy,2));']);
eval(['STD_AMP',KL,':(jk,ij) = std(MAT',KL,':(pointy,2));']);
eval(['MEAN_PHI',KL,':(jk,ij) = (180/pi)*mean(PHI',KL,':(pointy));']);
eval(['STD_PHI',KL,':(jk,ij) = (180/pi)*std(PHI',KL,':(pointy));']);
end
end
end  % End of ij loop
clc
hold off
axis(box);
for ij = 1:length(freq_stim)
    errorbar_shift(Days, MEAN_AMP1(:,ij), STD_AMP1(:,ij), 0.2*(ij-1.5));
end
title(['Subject ',subject_code(3),' ',subjectcode(2),' Axis Both 0.25 and 1.00 Hz.']);
x2 = (4.6-box(1))/(box(2)-box(1));
JUNK = 'FLIGHT';
for ij = 1:length(JUNK)
    text(x2, 0.85-0.04*ij, JUNK(ij),'sc')
end
xlabel(' (Preflight) BDC Session Number (Postflight)')
ylabel(['Amplitude of ',axis_code(1),' SPV modulation (deg)']);
text(x_coord, 0.75, ['0.25 Hertz (N = ',sprintf('%2.0f,nn(1)),' samples)']);
text(x_coord, 0.80, ['1.00 Hertz (N = ',sprintf('%2.0f,nn(2)),' samples)']);
prtsc;

clc
hold off
axis(boxP);
for ij = 1:length(freqstim)
    errorbar_shift(Days, MEAN_PHI1(:,ij), STD_PHI1(:,ij), 0.2*(ij-1.5));
end
title(['Subject ',subject_code(3),' ',subjectcode(2),' Axis Both 0.25 and 1.00 Hz.']);
x2 = (4.6-boxP(1))/(boxP(2)-boxP(1));
JUNK = 'FLIGHT';
for ij = 1:length(JUNK)
    text(x2, 0.85-0.04*ij, JUNK(ij),'sc')
end
xlabel(' (Preflight) BDC Session Number (Postflight)')
ylabel(['Phase Lag of ',axis_code(1),' SPV modulation (deg/sec)']);
text(x_coord, 0.75, ['0.25 Hertz (N = ', sprintf('%2.0f,nn(1)),' samples)']);
text(x_coord, 0.80, ['1.00 Hertz (N = ', sprintf('%2.0f,nn(2)),' samples)']);
prtsc;
% function [amp, freq_test, noise] = jc_prove_freq(SPV)
% This function is used to prove that the stimulus
% frequencies do in fact yield the largest response
% when analyzed at those frequencies

box = [0;50;0;20];
data_path = 'jc_wants_2_leave:JCB';
freq = 0.25;
freq_test = [0.01; 0.05; 0.10; 0.15; 0.20; 0.21; 0.22; 0.23; 0.24; 0.25; 0.26; 0.27; 0.28;
0.29; 0.30; 0.35; 0.40; 0.45; 0.50; 0.55; 0.60; 0.65; 0.70; 0.75; 0.80; 0.85; 0.90; 0.95;
1.00]*freq / 0.25;
box = [0;max(freq_test);0;20];
discard = 4.0;
old_start = 2000;
sample = 200;
start = old_start + sample*discard;
show_plots = 0;
T_run = 32; %24;
total_ticks = (T_run-discard)*sample;
run_code = 'JCB007'; %'LYN317';

eval(['load ',data_path,run_code,'C3.NEW']);

for i = 1:length(freq_test);
    fprintf('%1.2f,freq_test(i));
    step = sample/freq_test(i);
    t = sample*floor((T_run-discard)*freq_test(i));
    if t < freq_test(i)  t = sample*(T_run-discard);
    else  t = t/freq_test(i);
    end
    S = sin(freq_test(i)*2*pi*[0:t/sample]';
    C = cos(freq_test(i)*2*pi*[0:t/sample]';
    temp = ([S C ones(S)]*SPV(start:start+t));
    amp(i) = sqrt(temp(1)^2 + temp(2)^2);
    phi(i) = atan2(temp(2),temp(1));
    fit = temp(3) + (amp(i)*sin(freq_test(i)*2*pi*[0:t/sample + phi(i)]));
    if show_plots
        plot((start:start+t)/sample, SPV(start:start+t),[start:start+t]/sample, fit, 'b')
        title(['Frequency = ',num2str(freq_test(i)), ' Hz.']);
    end
    noise(i) = rms((SPV(start:start+t)-fit) - mean(SPV(start:start+t) - fit));
end

clg
hold off
axis(box);
plot(freq_test,noise, '-w');
title(['Run Code = ',run_code,' Stimulus = ',sprintf('%1.2f',freq), ' Hz.']);
xlabel('Frequency [Hz]');
ylabel('Residual noise (deg/sec)');
% jc_sines
% Created by Jock Christie 10 October 90 and still evolving
% Note that any use without my express written or verbal consent
% constitutes flagrant plagiarism and violation of copyright laws.

% Used in analysis of windowshade OKN to filter, plot, and
% calculate gain and phase of the relevant data.

% Data comes from 386 via maclink and JC_COILS_convert.
% This yields 1) shade 2) sled 3) heog 4) veog 5) teog

% Enable diary logfile to record the days events

\begin{verbatim}
ALT = 1; % 1 Enables the all-cycles method
bias_flag = 0; % bias_flag = 1; will calculate pos/neg bias.
discard = 4.0; % Number of seconds to discard at start of trial
EDV = 0; % set EDV = 1 for edited values, else it loads SPV
eye_vel_sign = [-1, 1]; % = +/- 1 to correct for sign conventions.
freq_stim = [0.25, 0.50, 1.00]; % Should be in ascending order.
G_level = 0.5; % Maximum sinusoidal G level.
N = 4; % Allows user to chose the number of harmonics.
old_start = 2.0; % Estimated time at which stimulus starts.
pick = 'n'; % 'y' allows user to manually select starting point.
run_code = 118; % This is used only for example purposes.
sample = 200; % Sampling rate in hertz
STATS = 'y'; % 'y' produces statistics about the phase and amp.
STD_DEV = 1.0; % determines the number of std below mean to discard.
stim_offset = 2048; % This is the zero value for the A/D board.
stim_scale = 0.0062332; % Calculated by JC and DMM for use with the Labsled.
top = 100; % Used for plotting.
T_run = 24.0; % Duration of data to be analyzed in seconds.
wolfie = 'y'; % 'y' is used to plot the curve fits.
\end{verbatim}

file_specsjc % This is not the most efficient way, but it guarantees
clear_specsjc % compatibility with NysA

first_code = input(['Enter first code [ default = ', int2str(run_code), ', ' ' ] ']);
if (isempty(first_code))
    first_code = run_code;
end
last_code = input(['Enter final code [ default = ',int2str(first_code+1), ', ' ' ] ']);
if (isempty(last_code))
    last_code = first_code+1;
end

for eta = first_code:last_code
    fprintf('**
    eta_code = sprintf('%g',eta);
    run_code = [prefix, eta_code];
    eval(['load ',data_path,file_name(Sled_File,eta_code)));
    eval(['stim = stim_scale*(',Sled_Var,','-stim_offset);']);
end

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eval(['clear ', 'Sled_Var']);

file_len = length(stim);
total_ticks = T_run*sample;

if ((pick == 'y') && (pick == 'Y'))
    hold off
    clg
    plot((1:file_len/2)/sample, stim(1:file_len/2))
    hold on
    plot((1:file_len/2)/sample, ones(file_len/2,1)*mean(stim(1:200)),'b')
    hold off
    xlabel('Time in seconds.');
    fprintf('
Click at the point where the stimulus starts
');
    [xx, yy] = ginput(1);
    start = round(xx*sample);
else
    start = round(old_start*sample);
end

NNN = 2^floor(log(min(length(stim)-start,total_ticks))/log(2));
v = stim(start:start+NNN-1) - mean(stim(start:start+NNN-1));
[AMP, b] = max(2*abs(fft(v, NNN))/NNN);
guess = sample*(b-1)/NNN;
if (AMP < 0.25) && (guess > 2*max(freq_stim))
    dyn_cal = 1;
    AMP = 0;
    known_freq = min(freq_stim);
    stepp = sample/known_freq;
    title_string = ['File code = ', run_code, ' Dynamic Calibration '];
else
    dyn_cal = 0;
    known_freq = freq_stim(pick_a_freq(freq_stim, guess));
    stepp = sample/known_freq;
    start = zero_cross(stim, start + stepp) - stepp;  % Avoids transients.
    title_string = ['File code = ', run_code, ',', num2str(G_level), ' G
', num2str(known_freq), ' Hz '];
end
clear b guess NNN v
start = start + discard*sample;
num_steps = round((total_ticks - discard*sample)/stepp);  % Should be 6 or 24
% Revised by JC and LM 26 April 1991 Should be 5 or 20

for psi = 1:2
    if psi == 1
        STAT_PATH = [stat_path,'H:'];
        axis_label = 'Horizontal';
    elseif psi == 2
        STAT_PATH = [stat_path,'V'];
        axis_label = 'Vertical';
    elseif psi == 3
        STAT_PATH = [stat_path,'T:'];
        axis_label = 'Torsional';
end
eval(['filespv = file_name(Edited',int2str(psi),'_File,eta_code);']);
if (EDV) & (exist([data_path,filespv]) == 2)
    EDV_flag = 1;
    fprintf(['Loading ',axis_label,' EDV.
']);
    spv_name = eval(['Edited',int2str(psi),'_Var']);
    eval(['load ',data_path,filespv]);
    eval(['SPV = eye_vel_sign(psi)*',eval(spv_name),';']);
    eval(['clear ',eval(spv_name)]);
else
    fprintf(['Loading ',axis_label,' SPV.
']);
    EDV_flag = 0; % This is if .EDV file missing.
    eval(['filespv = file_name(SPV',int2str(psi),'_File,eta_code);']);
    eval(['load ',data_path,filespv]);
    eval(['SPV = eye_vel_sign(psi)*',eval(['SPV',int2str(psi),'_Var']),';']);
    eval(['clear ',eval(['SPV',int2str(psi),'_Var'])]);
end
clear filespv name spv_name

sum_error = 0;
coeff_stim = zeros(1,2*N+2); % Matrix of coeff. for each cycle
coeff_spv = zeros(1,2*N+2); % Ditto (may need space for two freq.
time = [0:(stepp - 1)]/stepp;
K = ones(time);
% Note, All terms must be orthogonal, so drift was removed in March 1991 JC
% Second order Harmonics added 26 April 1991 JC
% Fourth order Harmonics added 06 July 1991 JC
for i = 1:N
    S = [S, sin(2*i*pi*time)];
    C = [C, cos(2*i*pi*time)];
end
linear_part = zeros(file_len,1); % Used to calculate residues.
curves = zeros(file_len,N);
pointer = start;
final_cycle = num_steps;
for loop = 1:num_steps,
    if ((pointer+stepp > file_len)
        (sqrt(2)*rms(stim(pointer+1:min(file_len,pointer+stepp))) < (0.75 * AMP))
        final_cycle = loop - 1; % ie. aborting due to sled crash.
        fprintf('
Aborting after cycle %2.0f out of %2.0f 
',final_cycle ,num_steps);
        break
    end
    tempstim = ([S C]stim(pointer+1:pointer+stepp));
    coeff_stim(loop,1) = loop; % Loads coefficients into Sled Matrix
    coeff_stim(loop,2) = (K*stim(pointer+1:pointer+stepp));
    coeff_stim(loop,3:2:(2*N+1)) =
    sqrt(tempstim(1:N).^2+temp_stim(N+1:2*N).^2);
    coeff_stim(loop,4:2:(2*N+2)) = atan2(temp_stim(N+1:2*N),temp_stim(1:N));
    temp_spv = ([S C]SPV(pointer+1:pointer+stepp));
end
coeff_spv(loop,1) = loop; % Loads coefficients into Spv Matrix
coeff_spv(loop,2) = (K*SPV(pointer+1:pointer+stepp));
coeff_spv(loop,3:2:(2*N+1)) = sqrt(temp_spv(1:N).^2+temp_spv(N+1:2*N).^2);
coeff_spv(loop,4:2:(2*N+2)) = atan2(temp_spv(N+1:2*N),temp_spv(1:N));

linear_part(pointer+1:pointer+stepp) = coeff_spv(loop,2)*K;
curves(pointer+1:pointer+stepp:) = sin((2*pi*time*[1:N]) +
(ones(stepp,1)*coeff_spv(loop,4:2:(2*N+2))))*diag(coeff_spv(loop,3:2:(2*N+1)));

pointer = pointer + stepp; % increment for next round
end

K S C temp_stim temp_spv time

last_pt = start + final_cycle*stepp; % Point at which sled motion ends

% This section repositions the branch cut to 2*pi.
coeff_stim(:,4:2:2*N+2) = coeff_stim(:,4:2:2*N+2) -
2*pi*round((sign(coeff_stim(:,4:2:2*N+2))-1+eps)/2);

coeff_spv(:,4:2:2*N+2) = coeff_spv(:,4:2:2*N+2) -
2*pi*round((sign(coeff_spv(:,4:2:2*N+2))-1+eps)/2);

% meatloaf = [(SPV(1:old_start)-mean(SPV(1:old_start))]; % The leftover part
% meatloaf = [meatloaf; (SPV(last_pt+1:file_len) - mean(SPV(last_pt+1:file_len))];
% To remove bias during static phase.
correction = linear_part + sum(curves');

rms_kinetic = rms(SPV(start+1:pointer) - correction(start+1:pointer));
RMSS = rms(SPV(start+1:pointer) - mean(coeff_spv(:,2)));

% This is to find a composite correction with all cycles together
if ALT

% meatloaf = [[(S C) SPV(start+1:pointer)];
corr_alt(1) = 0; % Loads coefficients into Spv Matrix
corr_alt(2) = DC;
clear DC S C
curves_alt = zeros(file_len,N);
corr_alt(4:2:2*N+2) = atan2(temp_alt(N+1:2*N),temp_alt(1:N));
corr_alt(3:2:2*N+1) = sqrt(temp_alt(1:N).^2+temp_alt(N+1:2*N).^2);
corr_alt(4:2:2*N+2) = corr_alt(4:2:2*N+2) -
2*pi*round((sign(corr_alt(4:2:2*N+2))-1+eps)/2);
curves_alt(start+1:pointer,:) = sin((2*pi*time*[1:N]) +
(ones(final_cycle*stepp,1)*corr_alt(4:2:2*N+2)))*diag(corr_alt(3:2:2*N+1));
correction_alt = linear_part + sum(curves_alt');
rms_alt = rms(\text{SPV}(start+1:pointer) - correction\_alt(start+1:pointer));
clear curves\_alt linear\_alt temp\_alt time
end

fprintf(['\n',\text{title\_string},\n']);
junk = find(coeffs\_spv(:,3) <= (mean(coeffs\_spv(:,3)) - STD\_DEV*std(coeffs\_spv(:,3))));
if isempty(junk)
    coeffs\_spv\_save = coeffs\_spv;
    coeffs\_stim\_save = coeffs\_stim;
    rms\_remainder = rms\_kinetic;
    fprintf(\nNot discarding any cycles. All within bounds.\n');
else
    coeffs\_spv\_save = coeffs\_spv(1:junk(1)-1,:);
    coeffs\_stim\_save = coeffs\_stim(1:junk(1)-1,:);
    remainder = \text{SPV}(start+1:start+(junk(1)-1)*stepp) - correction(start+[1:(junk(1)-1)*stepp]);
    fprintf(\nDiscarding cycles with amp. less than 1.1f std below the mean.\n', STD\_DEV);
    fprintf(\nDiscarding cycle # %2.0f ', junk(1));
    for i = 1:length(junk)-1
        fprintf(\n%2.0f ', junk(i+1));
        coeffs\_spv\_save = [coeffs\_spv\_save; coeffs\_spv(junk(i)+1:junk(i+1)-1,:)];
        coeffs\_stim\_save = [coeffs\_stim\_save; coeffs\_stim(junk(i)+1:junk(i+1)-1,:)];
        remainder = [remainder; (SPV(start+1:start+(junk(1)-1)*stepp) - correction(start+[1:(junk(1)-1)*stepp]));
    end
    coeffs\_spv\_save = [coeffs\_spv\_save; coeffs\_spv(junk(length(junk))+1:final\_cycle,:)];
    coeffs\_stim\_save = [coeffs\_stim\_save; coeffs\_stim(junk(length(junk))+1:final\_cycle,:)];
    remainder = [remainder; (SPV(start+1:start+(length(junk))*stepp:pointer) - correction(start+1:start+(length(junk))*stepp:pointer))];
    rms\_remainder = rms(remainder);
end

MEAN\_SPV = [];
for i = 1:N,
    eval(['MEAN',num2str(i),',(1:2,1) = [1; 2];']);
    eval(['MEAN',num2str(i),',(1:2,2) = (1-dyn\_cal)*[known\_freq; known\_freq];']);
    eval(['MEAN',num2str(i),',(1,3:4) = [mean(coeffs\_stim(:,',num2str(1+2*i),'));
    std(coeffs\_stim(:,',num2str(1+2*i),'))];
    eval(['MEAN',num2str(i),',(1,5:6) = [vector(coeffs\_stim(:,',num2str(2+2*i),'));
    std(coeffs\_stim(:,',num2str(2+2*i),'))]);
    eval(['MEAN',num2str(i),',2:3) = [mean(coeffs\_spv(:,',num2str(1+2*i),'));
    std(coeffs\_spv(:,',num2str(1+2*i),'))]);
    eval(['MEAN',num2str(i),',2:5) = [vector(coeffs\_spv(:,',num2str(2+2*i),'));
    std(coeffs\_spv(:,',num2str(2+2*i),'))]);
    eval(['MEAN',num2str(i),',2:save(1:2,1) = [1; 2];']);
    eval(['MEAN',num2str(i),',2:save(1:2,2) = (1-dyn\_cal)*[known\_freq; known\_freq];']);
end

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eval(['MEAN', num2str(i), '_save(1,3:4) = [mean(coeff_stim_save(:,', num2str(1 + 2 * i),')) std(coeff_stim_save(:,', num2str(1 + 2 * i),'))];']);

eval(['MEAN', num2str(i), '_save(1,5:6) = [vector(coeff_stim_save(:,', num2str(2 + 2 * i),')) std(coeff_stim_save(:,', num2str(2 + 2 * i),'))];']);

eval(['MEAN', num2str(i), '_save(2,3:4) = [mean(coeff_spv_save(:,', num2str(1 + 2 * i),')) std(coeff_spv_save(:,', num2str(1 + 2 * i),'))];']);

eval(['MEAN', num2str(i), '_save(2,5:6) = [vector(coeff_spv_save(:,', num2str(2 + 2 * i),')) std(coeff_spv_save(:,', num2str(2 + 2 * i),'))];']);

eval(['MEAN_SPV = [MEAN_SPV;
MEAN', num2str(i), '_save(2,2:6)*diag([i, 1, 1, 1, 1, 1])];']);

eval(['MEAN', num2str(i), '_save(2,2:6)*diag([i, 1, 1, 1, 1, 1])]);
end

%fprintf(' Stim cycle # bias amp phase 2amp 2phase
')
%disp(coeff_stim(:,1:6)*diag([1, 1, 1, (180/pi), 1, (180/pi)]));

fprintf(' Eye cycle bias amp phase 2amp 2phase
')
disp(coeff_spv(:,1:6)*diag([1, 1, 1, (180/pi), 1, (180/pi)]));

fprintf(' STIM / SPV Hz. Amp Amp phase phase
')
disp(MEAN1*diag([1, 1, 1, 1, (180/pi), (180/pi)]));

if (STATS == 'y') || (STATS == 'Y')
    JUNK = [' FIRST ';'SECOND '; 'THIRD '; 'FOURTH'; 'FIFTH '; 'SIXTH
'; 'SEVENTH'];
    for i = 1:min(N, N)
        fprintf('n
TESTING THE ',JUNK(i,:),' HARMONIC at %2.2f HERTZ.'],
known_freq[i]);
        [z, prob] = T_test(coeff_spv_save(:,1+2*i));
        [mu, kappa, RR, sigma] = circle_stats(coeff_spv_save(:,2+2*i));
        MEAN_SPV(i,6:9) = [RR, kappa, (180/pi)*mu, (180/pi)*sigma];
    end
end

if bias_flag
    [pos, neg] = find_bias(SPV(start:last_pt));
    fprintf('The positive bias = %3.3f deg./sec. 
The negative bias = %3.3f deg./sec.
', pos, neg);
else
    neg = 0;
    pos = 0;
end

if length(junk) == 1
    fprintf(' Mean values after discarding 1 cycle
');
    disp(MEAN1_save*diag([1, 1, 1, 1, (180/pi), (180/pi)]));
else if length(junk) >= 2
    fprintf(' Mean values after discarding %2.0f cycles.
',length(junk));
    disp(MEAN1_save*diag([1, 1, 1, 1, (180/pi), (180/pi)]));
end

if (biasflag)
    [pos, neg] = find_bias(SPV(start:last_pt));
    fprintf('The positive bias = %3.3f deg./sec. 
The negative bias = %3.3f deg./sec.
', pos, neg);
else
    neg = 0;
    pos = 0;
end
GAIN = MEAN1_save(2,3)/G_level;
PHASE = (MEAN1(1,5)-MEAN1(2,5)) * (180/pi) + 90;
PHASE_save = (MEAN1_save(1,5)-MEAN1_save(2,5)) * (180/pi) + 90;
if (abs(PHASE_save) > 180)
    PHASE_save = PHASE_save - 360*sign(PHASE_save);
end
if (abs(PHASE) > 180)
    PHASE = PHASE - 360*sign(PHASE);
end
if dyn_cal
    fprintf('
The modulation of the SPV has a peak of %2.2f deg/sec.
', MEAN1(2,3));
else
    fprintf('
Estimated Gain = %3.3f (deg/sec) /g
Estimated Phase Lag = %3.3f degrees. (Formerly %3.3f degrees)
', GAIN, PHASE_save, PHASE);
end
fprintf('The bias = %2.2f deg/sec initially
The bias = %2.2f deg/sec after discarding.
', mean(coeff_spv(:,2)), mean(coeff_spv_save(:,2)));
    fprintf('The RMS error associated with the %1.0f part curve fit is %2.2f deg. / sec.
', N, rms_kinetic);
    fprintf('The RMS error for the curve fit after discarding is %2.2f deg. / sec.
', rms_remainder);
    fprintf('The RMS error associated with the stationary phase is %2.2f deg. /
sec.
', rms_static);
if ALT
    fprintf('The RMS error associated with the alternate curve is %2.2f deg. / sec.
', rms_alt);
    fprintf('Alternate curve fit
 cycle # bias amp phase 2amp 2phase
');
    disp(coeff_alt(1:6)*diag([1, 1, 1, (180/pi), 1, (180/pi)]));
    GAIN_ALT = coeff_alt(3)/G_level;
    PHASE_ALT = (vector(coeff_stim_save(:,4))-coeff_alt(4)) * (180/pi) + 90;
    if (abs(PHASE_ALT) > 180)
        PHASE_ALT = PHASE_ALT - 360*sign(PHASE_ALT);
    end
    fprintf('Using Alternate fitting.
 Estimated Gain = %3.3f (deg/sec) /g
Estimated Phase Lag = %3.3f degrees.
', GAIN_ALT, PHASE_ALT);
end
fprintf('Data Summary
 Offset Residual Amp Phase Lag RMS
');
disp([coeffalt(2), rms_alt, coeff_alt(3), PHASE_ALT, RMSS]);
end % End of if ALT
paste = [final_cycle, mean(coeff_spv(:,2)), rms_kinetic, MEAN1(2,3:4), PHASE; final_cycle-length(junk), mean(coeff_spv_save(:,2)), rms_remainder, MEAN1_save(2,3:4), PHASE_save];
fprintf('Data Summary (Before)
 Cycles Bias Residual Amp +/-std Phase Lag
');
disp(paste(1,:));
fprintf('Data Summary (After)
 Cycles Bias Residual Amp +/-std Phase Lag
');
disp(paste(1,:));
disp(paste(2,:));

TITLE_STRING = [title_string, ' ; axis_label,' SPV in red Curve fit in black.'];
if ((wolfie == 'y')(wolfie == 'Y'))
    clg
    hold off
    axis([0 file_len/sample -top top]);
    plot((1:file_len)/sample,SPV,'r')
    hold on
    plot([start start] / sample, [-top top], 'g-.');
    plot([old_start:last_pt] / sample, 5*stim([old_start:last_pt]), 'g')
    time= [0:(stepp - 1)];
    for i = 1:(final_cycle-length(junk))
        plot((start+1+(coeff_spv_save(i,1)-1)*stepp + time)/sample,
            correction(start+1+(coeff_spv_save(i,1)-1)*stepp + time),'w');
    end
    clear time
    if ALT
        % plot((1:file_len)/sample,correction_alt,'w')
    end
    hold off
    xlabel('Time in seconds.);
    ylabel('SPV (deg/sec)');
    title(TITLE_STRING);
    prtsc;
end % End of loop to display residue

eval(['save ',STAT_PATH,run_code,'.STIM coeff_stim /ascii /tabs ']);
eval(['save ',STAT_PATH,run_code,'.MEAN1 MEAN1 /ascii /tabs ']);
eval(['save ',STAT_PATH,run_code,'.MEAN_SPV MEANSPV /ascii /tabs ']);
if EDV_flag
    eval(['save ',STAT_PATH,run_code,'.EDV coeff_spv /ascii /tabs ']);
else
    eval(['save ',STAT_PATH,run_code,'.SPV coeff_spv /ascii /tabs ']);
end
eval(['save ',STAT_PATH,run_code,'.SAVE coeff_spv_save /ascii /tabs ']);
if ALT
    eval(['save ',STAT_PATH,run_code,'.ALT coeff_alt /ascii /tabs ']);
eval(['save ',STAT_PATH,run_code,'.STAT coeffstim coeffspv MEAN1 neg run_code pos start coeff_alt']);
    paste = [coeff_alt(2), rms_alt, coeff_alt(3), PHASE_ALT, RMSS, 0; paste];
else
    eval(['save ',STAT_PATH,run_code,'.STAT coeff_stim coeff_spv MEAN1 neg run_code pos start']);
end
eval(['save ',STAT_PATH,run_code,'.PASTE paste /ascii /tabs ']);
if dyn_cal
eval(['save ',STAT_PATH,run_code,'.DYN coeff_stim coeff_spv MEAN1 neg run_code pos start coeff_alt']);
else
    eval(['save ',STAT_PATH,run_code,'.FREQ knownfreq']);
    % eval(['if (known_freq == freq_stim(',int2str(i),'))']);
    eval(['save ',STAT_PATH,run_code,',',num2str(known_freq),' coeff_stim coeff_spv MEAN1 neg run_code pos start coeff_alt']);
end
%
Polar_edit(coeff_spv(:,4:-1:3))
clear GAIN GAIN_ALT JUNK MEAN_SPV MEAN1 MEAN1_save
clear MEAN2 MEAN2_save MEAN3 MEAN3_save MEAN4 MEAN4_save
clear PHASE PHASE_ALT PHASE_save RMSS
clear coeff_alt coeff_stim coeff_stim_save coeff_spv coeff_spv_save
clear i loop neg paste pointer pos remainder
clear rms_alt rms_kinetic rms_remainder rms_static
clear STAT_PATH sum_error z

clear correction correction_alt SPV TITLE_STRING
clear sigma junk kappa mu prob RR
end % End of psi loop

clear AMP EDV_flag dyn_cal file_len final_cycle known_freq last_pt
clear num_steps start stepp stim title_string total_ticks
end % End of eta loop

clear axis_label eta_code psi
clear bias_flag discard eye_vel_sign freq_stim old_start
clear pick run_code sample stim_scale stim_offset top wolfie
clear ALT EDV G_level N STATS STD_DEV T_run

clear data_path eta first_code last_code stat_path prefix
clear Edited1_Var Edited2_Var Edited3_Var Sled_File Sled_Var
clear Edited1_File Edited2_File Edited3_File
clear SPV1_Var SPV2_Var SPV3_Var SPV1_File SPV2_File SPV3_File

[ Finally the end of jc_sines ]
function p = pick_a_point(in_vector, value)

% This function determines which element of the
% vector is closest to the given value.
% This function does not assume that the vector is in order (ie. sorted)
% Written by Jock R. I. Christie July 1991

flag = 1;
Vector = sort(in_vector);
len = length(Vector);
temp = abs(Vector - value);
range = max(abs(Vector))/min(abs(Vector));
if (range < 2.0)
    fprintf('This is a tight vector\n');
end

% Screens for really high or really low values, and complains.
if (value > max(Vector)*2.0)(value < min(Vector)/2.0)
    fprintf('The value of %3.3f is out of range.\n',value);
    flag = 0;
end

while flag
    if abs(value - Vector(1)) < abs(value - Vector(2))
        t = 1;
    elseif abs(value - Vector(len)) < abs(value - Vector(len-1))
        t = len;
    else
        t = find(temp == min(temp));
    end
    flag = 0;
    if length(t) > 1
        fprintf('Error condition: Could not properly assign value.\n');
    end
end
p = find(in_vector == Vector(t));
function [z, prob] = T_test(arg, show)
% T_TEST T_TEST(ARG, SHOW) determines whether arg is statistically
% different from zero at the 90% 95% 99% and 99.9% levels
% SHOW = 'n' or SHOW = 'N' suppresses display statements.
% T_TEST returns a vector full of t-scores at the levels of probability
% specified in the prob vector
% NOTE: These values for 2 sided test. See CRC (1983) p.547
prob = [0.100; 0.050; 0.010; 0.001];

[n, col] = size(arg);
if (n == 1);
    arg = arg';
    [n, col] = size(arg);
end
if ~exist('show')
    show = 'y';
end

  t(1,:) = [ 1, 6.314, 12.706, 63.657, 636.619];
  t(2,:) = [ 2, 2.920, 4.303, 9.925, 31.598];
  t(3,:) = [ 3, 2.353, 3.182, 5.841, 12.924];
  t(4,:) = [ 4, 2.132, 2.776, 4.604, 8.610];
  t(5,:) = [ 5, 2.015, 2.571, 4.032, 6.869];
  t(6,:) = [ 6, 1.943, 2.447, 3.707, 5.959];
  t(7,:) = [ 7, 1.895, 2.365, 3.499, 5.408];
  t(8,:) = [ 8, 1.860, 2.306, 3.355, 5.041];
  t(9,:) = [ 9, 1.833, 2.262, 3.250, 4.781];
  t(10,:) = [10, 1.812, 2.228, 3.169, 4.587];
  t(11,:) = [11, 1.796, 2.201, 3.106, 4.437];
  t(12,:) = [12, 1.782, 2.179, 3.055, 4.318];
  t(13,:) = [13, 1.771, 2.160, 3.012, 4.221];
  t(14,:) = [14, 1.761, 2.145, 2.977, 4.140];
  t(15,:) = [15, 1.753, 2.131, 2.947, 4.073];
  t(16,:) = [16, 1.746, 2.120, 2.921, 4.015];
  t(17,:) = [17, 1.740, 2.110, 2.898, 3.965];
  t(18,:) = [18, 1.734, 2.101, 2.878, 3.922];
  t(19,:) = [19, 1.729, 2.093, 2.861, 3.883];
  t(20,:) = [20, 1.725, 2.086, 2.845, 3.850];
  t(21,:) = [21, 1.721, 2.080, 2.831, 3.819];
  t(22,:) = [22, 1.717, 2.074, 2.819, 3.792];
  t(23,:) = [23, 1.714, 2.069, 2.807, 3.767];
  t(24,:) = [24, 1.711, 2.064, 2.797, 3.745];
  t(25,:) = [25, 1.708, 2.060, 2.787, 3.725];
  t(26,:) = [26, 1.706, 2.056, 2.779, 3.707];
  t(27,:) = [27, 1.703, 2.052, 2.771, 3.690];
  t(28,:) = [28, 1.701, 2.048, 2.763, 3.674];
  t(29,:) = [29, 1.699, 2.045, 2.756, 3.659];
  t(30,:) = [30, 1.697, 2.042, 2.750, 3.646];
  t(31,:) = [30, 1.684, 2.021, 2.704, 3.551];
  t(32,:) = [30, 1.671, 2.000, 2.660, 3.460];
\[ t(33,:) = [120, 1.658, 1.980, 2.617, 3.373]; \]
\[ t_{\text{inf}} = [1.645, 1.960, 2.576, 3.291]; \]

if \( n < 1 \)
   fprintf(\nSorry you lose. Not enough Data.\n');
elseif (n >= 1) & (n <= 30)
   \( z = t(n,2:5); \)
elseif (n > 30) & (n <= 120)
   \( r = \text{abs}(t(:,1) - n); \)
   \( p = \text{min}(\text{find}(r == \text{min}(r))); \)
   if \( \text{min}(r) == 0 \)
      \( z = t(p,2:5); \)
   else
      if \( n < t(p,1) \)
         \( p = p-1; \)
      end
      \( z = t(p,2:5)' + (n-t(p,1)) * (t(p+1,2:5)' - t(p,2:5)') / (t(p+1,1) - t(p,1)); \)
   end
else
   \( z = t_{\text{inf}}; \)
endif

if (show ~= 'n') & (show ~= 'N')
   \( p = \text{max}(\text{find}( (z <= \text{abs}((\text{mean}(\text{arg})/\text{std}(\text{arg}))) == 1)); \)
   \% I think that the abs() makes this two sided ??
   \% /\text{std()}/ is not good if n=1 then std(arg) = 0
   if isempty(p)
      fprintf(\nThe amplitude <= %2.2f and is not significant.', mean(arg));
   else
      fprintf(\nThe amplitude is significant at the %1.3f level.', prob(p));
      fprintf(\nThe mean amplitude = %2.2f +/- %2.2f', mean(arg), std(arg)*z(p));
   end
endif
function z = vector(in_dat)
% FUNCTION VECTOR(ANGLES) takes the input vector
% of angles and determines the angle of the resultant
z = atan2(mean(sin(in_dat)),mean(cos(in_dat)));

function z = zero_cross(vector,guess)
% ZERO_CROSS ZERO_CROSS(VECTOR,GUESS) is designed to find
% accurate zero crossing based on decent guess.
% This function assumes that vector does cross through zero.


n = 12;
[row, col] = size(vector);
if (row == 1)
    vector = vector';
end
len = length(vector);

if (n <= guess)&&(len-n >= guess)
    coeff = [ones(2*n+1,1) (1:2*n+1)']*vector(guess-n:guess+n);
    delta = round(coeff(1)/coeff(2));
    z = guess - n - 1 - delta;
else
    small = max(1, guess - n);
    big = min(len, guess + n);
    z = find(min(abs(vector(small:big))))
end
Appendix D Human Use Forms.

This appendix contains a copy of the human use form that was submitted to the MIT Committee On the Use of Humans as Experimental Subjects (COUHES) and a copy of the informed consent form used during this experiment. I am including these forms because I have to. I do not intend that in a belligerent fashion. I am grateful that a human use committee exists to keep the scientists from getting to wacked out when they dream up new experiments. But seriously, as I am fond of saying: 'Safety first, comfort second.' This slogan works inside and outside of the lab.

Application Number # 1982

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Committee on the Use of Humans as Experimental Subjects

APPLICATION FOR APPROVAL TO USE HUMANS AS EXPERIMENTAL
SUBJECTS

PART I.

TITLE OF STUDY: Visual Vestibular Interaction

PRINCIPAL INVESTIGATOR: C.M. Oman, L.R. Young Dept. A&A
Room 37-211
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ASSOCIATED INVESTIGATORS: Conrad Wall, Ph.D., Mass Eye and Ear Infirmary

Collaborating Institution(s), if applicable: Mass Eye and Ear Institute
(Please attach copies of approval documents or correspondence from collaborating institution(s) where applicable.)

FINANCIAL SUPPORT: (Research grant title, agency and award number, if any. If not applicable, please indicate how project will be financed.)

NASA Ames Research Center NAG2-445

PURPOSE OF STUDY: (Please provide a concise statement of the background, nature and reasons for the proposed study.)
Human visual-vestibular interaction will be investigated by studying eye movements and perception of self-motion. The experiments will emphasize vertical eye movements and ocular torsion in conjunction with vertical linearvection. Motions which stimulate the utricular or saccular otolith organs will be combined with corresponding wide field motion displays capable of producing optokinetic nystagmus and self-motion illusions. The experiments utilize our linear acceleration sled.

This research concerns human visual vestibular interaction with emphasis on stimulation in the vertical and longitudinal axes. The measurements will be psychophysical estimates of vection and objective measurements of ocular torsion and vertical eye movements. We will utilize our linear "sled" to produce horizontal longitudinal linear acceleration for comparison with horizontal lateral acceleration. Measurements of vertical eye movements for z-axis acceleration, in comparison with lateral eye movements for y-axis acceleration, with and without confirming and conflicting visual wide field stimuli, will be made in conjunction with subjective estimations of self-motion. This set of experiments will permit us to delineate between linear acceleration effects on eye movements and affects on motion perception when the stimulus is primarily along the presumed axis of sensitivity of the saccular otolith organ.

Part II.

EXPERIMENTAL PROTOCOL: Please provide an outline of the actual experiments to be performed, including, where applicable, detailed information as to exact dosages of drugs and chemicals to be used, total quantity of blood samples to be drawn, nature of any special diets, physical or emotional stress, and the appropriate protective measures you are planning to take.

For applications in the social sciences, please provide a detailed description of your proposed study, and include a copy of any questionnaire you plan to incorporate into your project. If your study involves interviews, please submit an outline indicating the types of questions you will include.

If convenient, you may attach photocopies of material from previously submitted proposals, etc.; however, please try to avoid submitting extraneous material, such as grant applications in their entirety.

The ultimate goals of these experiments are to quantitatively describe the transfer functions of both the utricular and saccular otolithic and optokinetic torsion systems and to understand their interactions when suppressive and conflicting visual/motion conditions are produced.

Torsion eye movements will be measured using the magnetic search coil method described below. The coils used to generate the external magnetic field will be mounted on the sled. He will wear either a commercial Skalar lenses or the coil lenses described below. The subject will be secured in the sled by shoulder and lap seatbelts and his head will be held in position by a bite-bar and wood/foam head restraint. Sinusoidal and step profiles will be the motion stimuli.

The proposed experiments on linear visual-vestibular interaction emphasize the differences between Z-axis optokinetic and vestibular responses and the corresponding Y-axis responses. For all of the experiments in the series two kinds of measurements are taken: eye movements along the axis of stimulation and subjective magnitude.
estimation of body velocity. The experiments will begin with simple tests of pure
optokinetic and pure inertial stimuli, in Z and Y axes, followed by interactive
experiments with confirming and conflicting visual and vestibular stimuli.

The principal motion stimulus will be provided by the MIT Sled, a rail mounted linear
acceleration cart designed by Lichtenberg (1979) and modified by Loo (1980) and by
Arrott (1982). In the most closely related work, using measurements of motion
perception and of eye movements, it was employed for the normative studies supporting
our Spacelab-1 pre and post flight vestibular assessments, and in the lateral visual-
vestibular interaction perception experiments (Huang, 1983). The seat can be positioned
to allow X, Y or Z axis motion of the subject along the horizontal rails. The cart is
controlled by a pre-tensioned cable wound around a pulley at one end and a winch at the
other. Power is supplied through a 3.5 hp DC permanent magnet torque motor
controlled by a pulse-width modulated velocity control. Sled motion as well as data
logging is under the control of a microcomputer. An interactive FORTRAN program
provides real time control of cart motion profiles and provides supervisory control and
one level of safety devices (Arrott, 1985). Current motion profiles provide for single
sinusoids, sum of sines, constant accelerations, subthreshold positioning, frequency
sweep, and subject control of cart velocity. The envelope of sled motion is determined
by its length (4.7 m), maximum acceleration (0.8 g) and bandwidth (7 Hz).

Visual stimulus for our visual-vestibular interaction experiments has, in the past, been
provided through a point-light source, moving film strip system which reflected from a
long mirror to a rear projection screen attached to the sled cart (Huang, 1983). In order
to provide a flexible moving field linear display which could be mounted to the cart for z-
axis (subject supine) as well as y-axis acceleration, we recently developed a new
mechanical stimulator. This "window shade" device (Vargas, 1985) provides computer
controlled linear acceleration of a 47.5 x 47.5 cm screen placed 47.5 cm from the
subject, and will be our primary source for optokinetic and linear VVI experiments in
conjunction with the sled. A drawing of the windowshade attachment is enclosed.

Eye movements will be measured both by means of the coil system and/or standard
electro-oculography, using our own dc-coupled, high input impedance amplifiers and
pregelled infant EOG electrodes. We record EOG binocularly for horizontal eye
movements and have determined that, for normal subjects, vergence eye movements and
lack of conjugate gaze is not a problem. By using pre-experiment time for dark
adaptation and electrode stabilization, we can achieve stable recordings requiring only
pre and post-test calibration. Three distinct types of lateral or vertical eye movements are
encountered during linear body acceleration in the dark, as opposed to the simple OKN
seen for field motion. The eye movement pattern may be nystagmoid, a smooth
pendular response, or highly irregular. In all cases the EOG records are inspected and
then "desaccaded" by computer (Massoumnia, 1983) to produce the cumulative slow
phase eye position and slow phase velocity (SPV).

The scleral search coil method of measuring eye movements uses two sets of coils. One
or more pairs of transmitter coils surrounds the subject's head and transmit an
electromagnetic field that is designed to be uniform in the area of the subject's eye.
Another set of receiving coils is temporarily attached to the subject's eye via a silastic
rubber annulus and move with the eye. Eye movements are detected and measured by
electrically comparing the received signals to the transmitted signals. Properly selected
combinations of coils allow for measurement of horizontal, vertical, and torsional eye
movement components. The scleral search coil method will be the primary means to
measure ocular torsion and will also be useful in assessing vertical eye movements. The
C&C search coil system will be specifically designed for use with our sled. Phase detector sensors will be provided to measure horizontal, vertical and torsional eye movements simultaneously. The Skalar medical torsion coil annulus may be used. The procedures recommended by Skalar Medical for safe use and installation of the coil annulus will be followed. Care will be taken to limit the time that the annulus is worn by the subject to a maximum of 30 minutes. Since the coils are relatively expensive and can be re-used, they will be disinfected and stored in accordance with the Skalar Medical procedure. This procedure has been approved by the National Institutes of Health and the Center for Disease Control. Subject calibration for this system will be provided by a calibration fixture which comes with the C&C search coil system.

The sequence of visual-vestibular interaction experiments begins with pure visual (optokinetic) stimuli, comparing vertical eye movements and linear-vection to lateral (horizontal) responses for subjects supine and erect. The next step will be pure vestibular experiments on the sled, in darkness, comparing z-axis to y-axis horizontal acceleration conditions. Finally, visual and vestibular conditions will be combined by putting the linear "window shade" on the sled.

For each condition there will be three basic stimulus profiles: steps of constant velocity, sines of constant peak velocity covering the range of frequencies, and pseudorandom sums of 25 sinusoids. Both the eye movement and the subjective velocity measurements will be analyzed using linear systems analysis techniques to extract the gain and phase of the response velocity relative to the stimulus velocity. For the case of vertical motions, particular attention will be paid to up-down asymmetries, which will necessitate separate consideration of upward and downward phases of eye and self-motion velocity indications. For the sines and pseudo-random signals, we use FFT analysis of self velocity and cumulative slow phase velocity to calculate the frequency response, harmonics, and remnant.

For these linear visual-vestibular interaction experiments, we plan to use the same four combinations of stimuli which have proven effective in the development of models for VVI about the angular axes. The first is the countermotion (CON) condition, in which the visual field moves opposite to the sled, at the same speed, so that it represents the fixed laboratory environment and the optokinetic and vestibular drives are consistent. The second condition is the fixed (FIX) visual field, which provides for visual suppression of vestibular nystagmus and inhibition of vection, but which also promotes the oculogravic illusion. The third condition is constant velocity (CV) field motion, independent of the sled motion. The last condition is the dual random input stimulus in which independent pseudorandom inputs of different frequency content are presented to the sled motion drive and to the visual velocity drive to enable calculation of the subject's dual input describing function (DIDF). This technique has proven very valuable when used with closed loop velocity nulling by the subject in yaw (Zacharias and Young, 1981, Huang and Young 1985a), but has been difficult to implement for linear acceleration studies (Hiltner, 1983, Huang, 1983.)

For the static visual stimulation experiments, the subject's head will be fixed by the helmet we also use in the sled experiments or the subject will be provided with a personal biteboard. Following calibration with fixed 15 degree targets the subject will be instructed to stare ahead to generate "stare nystagmus" as opposed to tracking nystagmus. The vertical EOG calibration problem will be dealt with by a separate investigation of each subject in which voluntary fixation and vertical saccades will be monitored by EOG and the coil system and the extent of the correction noted. Pattern movements for constant velocity steps are anticipated to be of 20 second durations at five
speeds in each direction, logarithmically spaced between 1 cm/sec and 1 m/sec. Sines will also be logarithmically spaced between 0.02 Hz and 2.0 Hz, with a peak velocity of 50 cm/sec. The pseudorandom signal will consist of 25 sines between 0.02 Hz and 1.25 Hz. The pure vestibular linear acceleration tests on the sled will follow a similar pattern, limited only by the performance envelope of the device. The sled has been safety rated up to 1.0 g's for subject erect (y-axis) and subject supine (z-axis). The combined visual and vestibular stimuli are conducted on the sled with the moving visual field device attached.

The total number of subjects to be used in each test series depends, of course, on the stability of the measurements and the inter-subject variability. Based upon our experience over the course of many years, we estimate that at least six subjects will be required for each of the subjective estimation tests, but that 10-15 subjects will be required to obtain reliable patterns of linear acceleration induced eye movements. Since so many of the tests involve comparison between conditions, subjects will be selected from within the Laboratory's population of students and staff, who will be willing to commit to a long duration study with numerous retests over the course of several years. Order effects will be taken into account in the experimental design for each comparison, such as y-axis vs. z-axis.

PART III. Please answer all questions and indicate NA where not applicable. Positive answers should be briefly explained, with detailed information included in Part II.

1. How will subjects be obtained? Word-of-mouth
   Number of subjects needed? 20
   Age(s) of subjects? > 18

2. Will subjects receive any payment or other compensation for participation? Yes

3. Will your subjects be studied outside MIT premises? No.
   If so, please indicate location.

4. Will the facilities of the Clinical Research Center be used? No.
   If so, the approval of the CRC Policy Committee is also required.
   For proposed investigations in social sciences, management, and other non-biomedical areas, please continue with question 9.

5. Will drugs be used? No.
   Any Investigational New Drugs (IND)?

6. Will radiation or radioactive materials be employed? No.
   If so, your study must also be approved by the Committee on Radiation Exposure to Human Subjects. Application forms are available from Mr. Francis X. Masse, Radiation Protection Office, 20B-238, x3-2180 or 18-3212.

7. Will special diets be used? If so, please state proposed duration(s).
   No.

8. Will subjects experience physical pain or stress? No.
9. Will a questionnaire be used? No.  
If so, please attach a copy.

10. Are personal interviews involved? No.  
If so, include an explanation in Part II and attach an outline.


12. Does this study involve planned deception of subjects? No.

13. Can information acquired through this investigation adversely affect a subject's relationship with other individuals (e.g. employee-supervisor, patient-physician, student-teacher, coworker, family relationships)? No.

14. Please explain how subject's anonymity will be protected and/or confidentiality of data will be preserved.

   Subjects will be referred to only by codes.

PART IV.

A. Please summarize the risks to the individual subject, and the benefits, if any; include any possible risk of invasion of privacy, embarrassment or exposure of sensitive or confidential data, and explain how you propose to deal with these risks.

   Risks associated with the use of the Skalar search coil system: The subject wears a very small coil that is completely imbedded in a silicon rubber annulus and which is shaped to adhere to the limbus of the eye. There is a 12.5 mm central hole in the annulus so that vision is not occluded. The manufacturer of the annulus has developed procedures for the safe insertion of the coil and also for cleaning, disinfecting and storing the coils. These procedures will be adhered to in the measurement protocol. Personnel who insert the coil will be approved in writing by a collaborating ophthalmologist or doctor of optometry. A 30 minute guideline for maximum wearing of the search coil will be adhered to as mentioned in the manufacturer's procedures.

   Prior to insertion of the annulus, the eye will be briefly anesthetized by 1 or 2 drops of a topical ophthalmic anesthesia such as Novosine (oxybuprocaine 0.4%). The annulus will be removed from the subject's eye in accordance with the recommended procedures. After use, the annulus will be cleaned by thorough rising in a stream of lukewarm water and subsequently disinfected by immersion in fresh 3% hydrogen peroxide for 10 minutes. This procedure is in agreement with a recent guideline based on studies at the National Institutes of Health and the Center for Disease Control. After the immersion, there will be a second thorough rinsing with water and the device will be air dried on tissue paper.

B. Detection and reporting of harmful effects: If applicable here, please describe what follow up efforts will be made to detect harm to subjects, and how this committee will be kept informed.

   The probability of even a minor irritation to the eye is very low. Investigators at other institutions (National Eye Institute, Johns Hopkins University, UCLA) have found it to be less than one percent. All subjects will be examined by an optometrist prior to participating in any experiments involving lenses or annular rings. In case of irritation,
the subject's eye will be patched and treated with an ophthalmologic topical antibiotic and
then re-examined the next day. The Committee will be informed in the event of any such
occurrences. These procedures have been carried out on 50-60 insertions of the lenses
with subjects from Dr. Wall's laboratory with only one case of minor irritation (see
attached protocol from MEEI).

PART V.

INFORMED CONSENT MECHANISMS: The committee is mandated by the DHHS
and Institute regulations to require documentation of informed consent. Under
certain circumstances, the committee may waive documentation. The elements
of such informed consent are:

1. An instruction that the person is free to withdraw his/her consent and to
discontinue participation in the project or activity at any time without prejudice to
the subject.

2. A fair explanation of the procedures to be followed and their purposes, including
identification of any procedures which are experimental.

3. A description of any attendant discomforts and risks reasonably to be expected.

4. A description of any benefits reasonably to be expected.

5. A disclosure of any appropriate alternative procedures that might be
advantageous for the subject.

6. An offer on the part of the investigator to answer any inquiries concerning the
procedures.

7. There shall be no exculpatory language making the subject seem to waive any
rights.

8. The following statement shall appear on all informed consent documents, except
that in certain cases of experiments in the social sciences, management, or other
non-biomedical disciplines, where it is clearly not applicable, it may be omitted.
COUHES, however, reserves the right to request that this paragraph be included.

"In the unlikely event of physical injury resulting from participation in this research, I
understand that medical treatment will be available from the MIT Medical Department,
including first aid, emergency treatment and follow-up care as needed, and that my
insurance carrier may be billed for the cost of such treatment. However, no
compensation can be provided for medical care apart from the foregoing. I further
understand that making such medical treatment available, or providing it, does not imply
that such injury is the investigator's fault. I also understand that by my participation in
this study I am not waiving any of my legal rights. I understand that I may also contact
the Chairman of the Committee on the Use of Humans as Experimental Subjects (MIT,
253-6787), if I feel I have been treated unfairly as a subject." Consent forms in
cooperating institutions must assure that the rights of the subjects are protected at least to
the same degree.
These elements should be clearly stated in a document to be signed by the subject or a legally authorized representative in the case of minors or incompetent individuals. The material presented in such a document must be in clear English, easily understandable to the least educated of subjects. Diagrams or pictures may make such an exposition simpler to comprehend. Where minors are involved as subjects, due consideration should be given to their capability to give consent. The Informed Consent document should be signed by both the subject and parent and guardian wherever possible.

In the case of Questionnaires or Interviews, the Committee may decide that a consent form is not required if the intent is merely to obtain the requested information. However, it must be clear to the subject that:

- Participation is voluntary.
- The subject may decline to answer any questions.
- The subject may decline further participation at any time without prejudice.
- Confidentiality and/or anonymity are assured.

In addition:

- No coercion to participate will be involved. For example, handing out or collecting questionnaires personally may be so interpreted.
- The date collected will be reported in such a way that the identity of individuals is protected.
- Proper measures will be taken to safeguard the data.

Other examples of situations in which informed consent documentation is not required include use of discarded blood, certain psychological studies involving intentional deception or use of stored data. In a case of any deception, debriefing mechanisms must be acceptable before the approval of an application may be completed. The committee expects that the investigators will notify the committee if any hazards develop in excess of those anticipated.

Principal Investigator__________________________Date____________

Department Head_____________________________Date____________

Please return this application with 3 photocopies to COHES Chairman, E23-389, 253-6787
INFORMED CONSENT STATEMENT

You have been asked to participate in an experiment aimed at better understanding the workings of the inner ear and the eyes. Your participation is purely voluntary and you are free to withdraw at any time. In the experiment, you will be seated and strapped into a linear acceleration device (sled) either in the upright or supine position and asked to look straight ahead. The sled may or may not move. You may be asked to look at a moving display and you may be asked to indicate your perception of movement. At the end of the experiment, you may be asked to discuss how you perceived various stages of the experiment.

Please feel free to ask any questions you care to about the experiment. When the sled is moving, you can stop it at any time by pushing the "panic button". If at any time, you experience any discomfort or have any misgivings about continuing the experiment, we ask that you tell us - we will stop the test at any time you like.

Your eye movements will be measured using soft contact lens search coils, the most accurate method available today. The cornea of your eye will be anaesthetized using eye drops. The anaesthetic used is "Opthetic", active ingredient proparacaine HCl. If you have any allergies to this anesthetic, you should withdraw from participation in this experiment. The lens, in which a tiny search coil is embedded, will be applied to your eye. This will be worn for no longer than thirty minutes. Before application and after removal, your eyes will be examined by an optometrist to rule out any possible corneal abrasion. There is a less than one percent chance that the wearing of the soft contact lens may cause a slight corneal abrasion. If this does occur, a prophylactic antibiotic and covering will be applied overnight. Finally, we may also video your eye movements, using a small video camera with a low level light source.

"In the unlikely event of injury resulting from participation in this research, I understand that medical treatment will be available from the MIT Medical Department, including first aid, emergency treatment and follow-up care as needed, and that my insurance carrier may be billed for the cost of such treatment. However, no compensation can be provided for medical care apart from the foregoing. I further understand that making such medical treatment available, or providing it, does not imply that such injury is the investigator's fault. I also understand that by my participation in this study I am not waiving any of my legal rights (for more information, call the Institute's Insurance and Legal Affairs Office at 253-2822). I understand that I may also contact the Chairman of the Committee on the Use of Humans as Experimental Subjects, Dr. H. Walter Jones (MIT E23-389, 253-6787), if I feel I have been treated unfairly as a subject."

I have been informed as to the procedures and purpose of this experiment and agree to participate.

Signed:______________
Date:______________
Witness:______________