AL/CF-TR-1997-0141

UNITED STATES AIR FORCE ARMSTRONG LABORATORY

Visual Scene Effects on the Somatogravic Illusion

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December 1997

19980424 078

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REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	December 1997	Interim - April 1997 to July 1997

4. TITLE AND SUBTITLE
Visual Scene Effects on the Somatogravic Illusion

5. FUNDING NUMBERS
C: F33615-92-C-0018
PE: 62202F
PR: 7184
TA: 60
WU: 01

6. AUTHOR(S)
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Fred H. Previc, Brian Self, and Jeremy Beer

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Armstrong Laboratory
Crew Systems Directorate
Crew Technology Division
2504 Gillingham Drive, Suite 1
Brooks Air Force Base, TX 78235-5104

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AL/CF-TR-1997-0141

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
The somatogravic illusion is a dangerous illusion that is believed to have caused a large number of mishaps in civilian and military aviation over the years. This illusion is usually experienced during forward acceleration, which creates a backward inertial force that combines with gravity to produce a resultant gravitoinertial vector rotated backward from the pilot; hence, the pilot perceives a pitching up of the aircraft. The false climb illusion demonstrates the limitations of the otolith organs in providing accurate information to the brain, when there is insufficient visual information to correct the misinformation; hence, the objective of this research was to determine the relative importance of various visual scene cues in achieving visual dominance over nonvisual orientational inputs. The three orientational cues that were presented in both isolation and in various combinations were perspective splay, texture flow, and a horizon line. All of the visual scene cues were designed to depict level flight in the face of a pitch up somatogravic illusion (SGI). It was hypothesized that some visual cues would be more effective than others in reducing the magnitude of the perceived somatogravic pitch up illusion when compared to the eyes closed SGI condition. No significant differences were observed between the perceived pitch during the eyes closed and any of the other visual conditions. The results suggest that the scenes may have been too basic, not bright enough, or not as realistic as a bright daytime scene.

14. SUBJECT TERMS
Somatogravic Illusion, Spatial Disorientation, Vection,
Advanced Spatial Disorientation Demonstrator (ASDD)

15. NUMBER OF PAGES
30

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

Standard Form 298 (Rev. 2-89) (EG)
Prescribed by ANSI Std. 239.18
Designed using Perform Pro, WHS/DIOR, Oct 94

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PREFACE

KRUG Life Sciences, Incorporated, has provided technical support to accomplish the specific research, development, test, and evaluation (RDT&E) requirements for the Armstrong Laboratory at Brooks AFB, Texas. The KRUG Life Sciences, Incorporated research team provided design support for the down-pointer and profile programming. KRUG Life Sciences personnel performed the experiments and analyzed the data for this specific protocol. In general, the KRUG Life Sciences, Incorporated research teams provide support to on-going RDT&E efforts in response to the requirements designated in Section C, Description/specifications of the Air Force Contract #F33615-92-C-0018. This final report provides the finding of a Somatogravic Illusion protocol implemented with the Brooks AFB Advanced Spatial Disorientation Demonstrator (ASDD).

ACKNOWLEDGMENT

We appreciate the work of Mr. Joseph Campbell, Systems Research Laboratory, Inc. (SRL) in programming the various visual scenes used in the Somatogravic Illusion research protocol. Also, we appreciate the outstanding support provided by Mr. B. J. Frende, Environmental Tectonics Corporation (ETC) in daily maintenance of the ASDD and alignment and convergence of the visual display unit within the ASDD.

VISUAL SCENE EFFECTS ON THE SOMATOGRAVIC ILLUSION

Charles Lessard, Graeme Maidment,
Fred H. Previc, Brian Self, and Jeremy Beer

INTRODUCTION

From January 1990 to November 1995, approximately 30 USAF Class A mishaps were attributed to spatial disorientation, resulting in losses of $470M. These are unacceptable losses and should serve as a challenge for researchers to obtain a greater understanding of the visual cues that allow the pilot to maintain proper spatial orientation during the abnormal acceleratory environment of flight. Hopefully, unraveling the roles and interactions of visual, vestibular, and somatosensory processes in humans may contribute to improved situation awareness, flight safety, and overall mission effectiveness.

The objective of this research was to determine the relative importance of various visual scene cues in achieving "visual dominance" over nonvisual orientational inputs. Three orientational cues that were presented in both isolation and in various combinations: perspective splay (P), texture flow (T), and a horizon line (L). All visual scene cues were designed to depict level flight in the face of a "pitch-up" somatogravic illusion (SGI) that normally occurs during forward linear acceleration. It was hypothesized that some visual cues would be more effective than others in reducing the magnitude of the perceived somatogravic pitch-up illusion when compared to the eyes-closed SGI condition.

BACKGROUND

The somatogravic illusion, first described by Graybiel [6] in connection with its visual manifestation (the Oculogravic illusion), is a very dangerous illusion believed to have caused a large number of mishaps in civilian and military aviation over the years [5]. This illusion is usually experienced during forward acceleration, which creates a backward inertial force that combines with gravity to produce a resultant gravitoinertial vector rotated backward from the pilot; hence, the pilot perceives a pitching-up of the aircraft. If the pilot flies by the "seat-of-the-pants" sensation rather by his or her instruments, the ensuing tendency will be to lower the nose of the aircraft from an already level attitude, leading to a potentially dangerous situation.

The SGI is ordinarily not experienced under good visual conditions, because the visual scene in this instance dominates the pilot's perceived spatial orientation and correctly conveys the actual state of the aircraft (i.e., level but accelerating). However, aircraft acceleration in night-time or otherwise degraded visual conditions in which the horizon and other critical terrain features are not present greatly increases the likelihood of experiencing this illusion [1,2,5]. The visual cues most crucial to "breaking" the SGI (i.e., correctly perceiving a level aircraft attitude) are not known, but three in particular (a visible horizon, perspective, and ground-texture flow) were manipulated in a recent study [8]. It is known from anecdotal evidence that, in the absence of an actual horizon, a "false" horizon such as a night-time shoreline that recedes beneath the aircraft as the latter passes over it can enhance the pitch-up illusion. But what if the pilot has adequate perspective or texture information (i.e., streets, buildings, and lights) from terrain in front of the shore, would these be sufficient to convey accurately the level trajectory of the aircraft? Previous research has shown that perspective lines or grids are very effective in controlling one's altitude [4], and texture flow is also capable of providing altitude, attitude, and heading information [3,11]. The Previc *et al.* study [8] was the first that was intended specifically to manipulate these cues in the context of an actual spatial disorientation illusion.

The problem with the Previc *et al.* study was that even its full-cue daylight scene was unable to "break" the SGI, presumably because of the failure of its low-cost helmet-mounted scene to achieve visual dominance. Consequently, Previc *et al.*'s original experiment was redone and expanded using a visual display that was more likely to establish visual dominance. This requirement was presumed to be met by the visual display system of the Advanced Spatial Disorientation Demonstrator (ASDD), which in a recent evaluation [9] produced a sensation of level flight in 21 of 22 pilots during the "dark-night takeoff" SGI illusion when a runway scene was present.

EXPERIMENTAL METHOD

Subjects: Sixteen subjects participated in the experiment. All subjects had satisfactory uncorrected binocular visual acuity (at least 20/30) and were free of obvious vestibular pathology according to a standard vestibular screening battery. None of the subjects were military pilots. All subjects were naive with regards to the experimental hypothesis.

Facility: This study was conducted in the Advanced Spatial Disorientation Demonstrator (ASDD), a device that is owned by the Flight Physiology Department of the United States Air Force School of Aerospace Medicine (USAFSAM/FP), but which was made available for this research as part of a memorandum of agreement between the USAFSAM and the Armstrong Laboratory. The ASDD is a short-arm (2.46-m) centrifuge that can generate 360 degrees of angular motion in the pitch, roll, and yaw axes of the gondola and has a planetary motion capability that can generate a maximum centrifugal force of +2.2 G at 28 rpm. The ASDD visual display subtends 58-degrees vertically by 114-degrees horizontally, and its nearly collimated optics transmit a graphics image generated by a Silicon Graphics Skywriter 440 VGX computer.

Experimental Procedures: The overall procedures of this experiment were similar to those of Previc *et al.* [7]. A down-pointer was fixed to the inner frame of the gondola so as to hang downward, level to, and approximately 12 inches from the subject's right shoulder. The down-pointer was used by the subject to subjectively indicate his or her perceived down, i.e., the perceived direction of gravity. Movement of the down-pointer forward or aft sent a potentiometer voltage through the ASDD sliprings to a computer. Prior to any subject run, the down-pointer was calibrated in 10-degree increments over the range from 0 to +40 degrees with a fluid-filled protractor. Additionally, the luminance of the display scene was checked and recorded so that the brightness and contrast remained constant throughout the experiment.

Subjects were presented with various scenes depicting level, forward-accelerating flight at a fixed altitude (~300 m) over simulated terrain that consisted of various combinations of three visual cues: a horizon line, a series of perspective lines, and a set of square texture-elements located along the ground plane. These scenes were presented while the ASDD was rotated at a planetary velocity of 14.2 rpm, corresponding to a centrifugal force of 1.15 $+G_z$ and a net shift of the resultant gravitoinertial vector of 30.9 degrees.

The depiction of acceleration in the visual scene (5.66 m/s^2) corresponded to the acceleratory motion required to produce the 1.15 $+G_z$ inertial force. A 40 second delay was necessary to synchronize acceleration of the scene to the acceleration ramp of the ASDD. Prior to presentation of the visual scene, while the gondola was being accelerated (initial planetary arm ramp-up), subjects were instructed to "... look into the distance and silently count the number of red lights in the scene." Small red dots (lights) of one second duration were presented at random intervals and locations in the scene. The fixation task was used primarily to encourage the subjects to focus their attention on the center of the scene and serve as an indicator of subject alertness. If the subject counted less than 50% or more than 150% of the red lights, the run was repeated. The scene was presented for 50 seconds, of which 30 seconds were during the ASDD's planetary ramp-up to 14.2 rpm and the last 20 seconds were at the peak constant velocity. At the constant peak velocity, the subjects received the following instructions: "Find the down-pointer without looking at it."; "Mark where you perceive down is."; and "Say, 'Mark' when you have finished." Marking with the down-pointer was completed during the last 10 seconds of the visual scene and prior to deceleration of the gondola. Once the gondola stopped (homed at zero degrees of pitch), the subject was instructed to close his or her eyes, then to find the down-pointer without looking at it, to mark where he or she perceived down to be, and to say, 'Mark' when finished. This provided a measure of post-SGI zero-pitch perception. The final step in the SGI run was to have the subject follow the operator's instructions of moving the down-pointer forward, backward, then slowly forward until told to stop. In this manner, the down-pointer was returned to true zero pitch for the next SGI run.

In addition to a SGI-baseline (eyes-closed) condition, subjects were presented with the following seven nonconflict scene conditions: 1) horizon line, texture flow, and perspective lines (HTP) together; 2) horizon and perspective (HP) only, 3) texture and perspective (TP) only, 4) horizon and texture (HT) only; 5) horizon (H) alone, 6) perspective (P) alone, and 7) texture (T) alone. The eight conditions were repeated on a second experimental day, but they were presented in the reverse order in which the conditions had been presented to the subject on his or her first day.

Static 0-degree and 30-degrees pitch perceptual measurements with eyes-closed were obtained at the beginning and end of each experimental session. Two down-pointer measurements were recorded. The first measurement was made with the gondola stationary at 0-degrees of pitch, and the second measurement was taken when the gondola cab was at 30 degrees. In the presomatogravic (pre-SGI) pitch-up runs, the ASDD was not rotated in the planetary mode but was rotated only around the lateral (Y) axis at a rate of 2-degrees per second until the gondola reached a +30-degrees (pitch-up) angle. Once the rotation had stopped, the subject received the same instructions as in the SGI trials. Marking with the down-pointer was completed during the last 10 seconds prior to returning the gondola to its resting position (0-degrees of pitch). The post-SGI, pitch-up runs used the same profile as the pre-SGI run, but the 30-degrees pitch perceptual measurement with eyes closed was obtained before the static 0-degree pitch measurement. The static zero degrees of pitch measurement was recorded after the gondola had stopped all motion. Each day's session lasted less than one hour.

The final set of scene runs were included to determine if the illusion of forward motion (vection) is necessary to overcome the pitch-up sensation. Vection is defined as the illusion of self-motion produced by the surrounding visual scene. During this phase the ASDD gondola was not moved. The subject was asked to view the same seven scenes as before and subjectively rate the feeling of vection or the feeling of forward movement that the scene made him or her feel. A scale of "0 to 3" was used with a rating of 3 being used to describe the feeling of forward motion from the scene that was comparable to a maximal vection test pattern. This test pattern consisted of the texture elements that moved from distant points in a plane toward the viewer. For the SGI runs, the texture element started at the lower third of the scene and would get larger as they approached the bottom of the scene. In the maximal vection test pattern, the texture elements were presented in the lower and upper thirds of the viewing scene. This test pattern was presented as often as the subject desired before rating the seven scenes. A scene vection rating of two meant the subject had a moderate feeling of forward motion, but not as strong as the Maximal Vection test pattern. A scene vection rating of one (1) meant the scene only produced a little feeling of forward motion, and a rating of zero (0) meant the scene did not produce any feeling of motion. The seven scenes were repeated in vection rating runs on the second day, but the scenes were presented in the reverse order in which they had been presented to the subject on the first day.

A subthreshhold rotation in pitch to 30-degrees profile with eyes-closed and with the horizon line, texture elements, and perspective lines (HTP) scene was introduced after 7 subjects had completed their two days of trial runs. This profile was introduced to compare results from the somatogravic run with pure otolith stimulus of gravity (as in subthreshhold tilt about the lateral axis) while viewing the same scene.

Data Analysis: The subjects' indicated perceived orientation in space during the final 10 seconds of the visual scene interval was recorded from the down-pointer directly onto a Pentium Personal Computer (PC). A 3 second window of data was digitized at 20 samples per second when the subject said, "Mark" via LabView, National Insturments, Inc., Austin, Texas and written to file on a hard-drive. The data were also recorded manually as a back-up.

RESULTS

Excel Analysis: An Excel spread sheet was used to view the data and obtain some basic descriptive statistics on the measures. The Excel files were used as input for subsequent hypothesis testing. Table 1, from the Excel data files, presents the means and standard deviation for the first day of 0-pitch and +30 degrees pitch-up baseline tests. From Table 1, one notes that the mean value of the Day 1, pre-SGI, 0-pitch baseline (PREBL - second column) is slightly positive (0.21 degrees), whereas, the mean value of the Day 1, post-SGI, 0-pitch baseline (POSTBL - third column) is negative (-4.82). The overall mean for pre- and post-SGI, 0-pitch baselines is -2.31 with a standard deviation (σ) of $\mp$6.18. Table 1 also presents the perceived pitch feeling after the subject is pitched-up 30 degrees. The pre-SGI, +30 degree, baseline mean value (PRE-30 - sixth column) is 22.51 ($\sigma = \mp 6.07$) while the post-SGI, +30 degree, baseline mean value (POST-30 - seventh column) is 27.40 ($\sigma = \mp 13.35$). The overall mean value for the pre- and post-SGI, +30 degree, baseline (eigth column) is 24.95 ($\sigma = \mp 10.83$).

TABLE 1
PRE AND POST ZERO-BASELINE: FIRST DAY

	PITCH =ZERO			*PITCH=+30 DEG*		
Sub #	**PREBL**	**POSTBL**	**MEAN**	**PRE-30**	**POST-30**	**MEAN**
1	3.70	-6.39	**-1.35**	23.57	39.91	**31.74**
2	4.43	-9.10	**-2.34**	18.58	13.58	**16.08**
3	-3.17	-2.23	**-2.70**	23.88	31.27	**27.58**
4	0.68	-23.14	**-11.23**	21.08	12.96	**17.02**
5	-1.29	1.83	**0.27**	20.45	24.51	**22.48**
6	9.94	-11.08	**-0.57**	32.62	57.28	**44.95**
7	-0.98	-10.35	**-5.66**	14.62	12.23	**13.43**
8	1.10	-3.90	**-1.40**	24.09	24.72	**24.40**
9	-0.25	-3.17	**-1.71**	29.81	24.20	**27.01**
10	-1.50	-5.46	**-3.48**	13.79	19.41	**16.60**
11	1.93	5.68	**3.80**	28.46	44.28	**36.37**
12	-5.14	-1.92	**-3.53**	18.89	23.68	**21.28**
13	-1.81	6.40	**2.29**	30.54	49.48	**40.01**
14	-2.54	-0.15	**-1.35**	15.25	17.54	**16.39**
15	-1.19	-11.28	**-6.24**	29.40	29.40	**29.40**
16	-0.57	-2.86	**-1.71**	15.04	13.90	**14.47**
MEAN	**0.21**	**-4.82**	**-2.31**	**22.51**	**27.40**	**24.95**
SD	**3.56**	**7.27**	**6.18**	**6.07**	**13.35**	**10.83**

Figure 1 is a graph of each subject's pre-SGI baseline perceived 0-pitch as measured with the down-pointer on the subject's first and second days of testing. From the bargraphs, the range of the first day's data denoting the subjects' perception of down and error from true down is from -5.14 degrees (tilted forward) to +9.94 degrees (tilted backward) of pitch), with the overall mean almost zero (+0.21 ∓ 3.56 degrees). The range of the resulting second day data is from -8.06 degrees to +3.7 degrees, with the overall mean of -1.43 degrees.

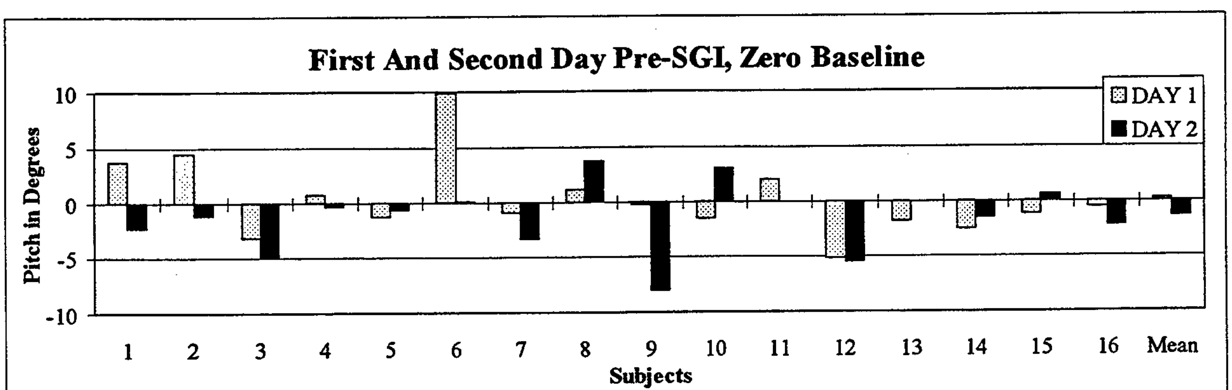

Figure 1. Graph of each subject's down-pointer measurement during Pre-somatogravic, zero-pitch baseline of the first and second day runs.

Table 2 presents the means and standard deviation (σ) for the second day of 0 and +30 degrees baseline tests. From Table 2 it is noted that the mean value of the pre-SGI, 0-pitch, baseline (second column) is -1.43 (σ = ∓3.00), whereas, the mean value of the post-SGI, 0-pitch, baseline (third column) is -8.11 (σ = ∓9.11). The overall mean value for pre- and post-SGI, 0-pitch, baseline is -4.77 (σ = ∓7.48). Table 2 also presents the perceived pitch measurements after the subject is tilted +30 degrees backwards. The pre-SGI, +30 degree, baseline mean value (sixth column) is 24.61 (σ = ∓10.66) while the post-SGI, +30 degree, baseline mean value (seventh column) is 23.24 (σ = ∓15.05). The overall mean value for the pre- and post-SGI, +30 degree, baseline (eigth column) is 23.92 (σ = ∓12.85).

TABLE 2

PRE AND POST ZERO-BASELINE: SECOND DAY

	PITCH =ZERO				*PITCH=+30 DEG*		
Sub #	**PREBL**	**POSTBL**	**MEAN**	**SD**	**PRE-30**	**POST-30**	**MEAN**
1	-2.34	2.76	**0.21**	**3.61**	35.64	24.20	**29.92**
2	-1.19	-7.75	**-4.47**	**4.64**	16.71	13.17	**14.94**
3	-4.94	-0.15	**-2.54**	**3.38**	35.64	55.51	**45.58**
4	-0.36	-13.99	**-7.17**	**9.64**	13.27	3.18	**8.23**
5	-0.67	-7.75	**-4.21**	**5.00**	16.91	9.73	**13.32**
6	0.06	-32.92	**-16.43**	**23.32**	29.61	32.42	**31.01**
7	-3.38	-15.86	**-9.62**	**8.83**	18.79	16.71	**17.75**
8	3.70	-3.06	**0.32**	**4.78**	23.68	19.62	**21.65**
9	-8.06	-13.05	**-10.55**	**3.53**	20.24	22.53	**21.39**
10	2.97	-6.50	**-1.76**	**6.70**	17.54	13.58	**15.56**
11	-0.05	0.99	**0.47**	**0.74**	44.38	45.84	**45.11**
12	-5.46	-7.54	**-6.50**	**1.47**	28.67	16.60	**22.64**
13	-0.05	3.28	**1.62**	**2.35**	43.97	43.03	**43.50**
14	-1.50	-10.03	**-5.77**	**6.03**	11.71	6.92	**9.32**
15	0.58	-15.44	**-7.43**	**11.33**	23.88	34.91	**29.40**
16	-2.23	-2.75	**-2.49**	**0.37**	13.06	13.90	**13.48**
Mean	**-1.43**	**-8.11**	**-4.77**	**7.48**	**24.61**	**23.24**	**23.92**
SD	**3.00**	**9.11**	**7.48**		**10.66**	**15.05**	**12.85**

Figure 2 presents bargraphs of each subject's post-SGI baseline (after completion of all the subject's somatogravic runs) perceived zero-degrees of pitch as measured with the down-pointer on the subject's first and second days of testing. The range of the first day's resulting data is from -23.14 degrees to +6.40 degrees, with an overall first day mean value of -4.82 ∓7.27 degrees. The range of the second day's resulting data varied from -32.92 degrees to +3.28 degrees, with an overall second day mean value of -8.11 ∓9.11 degrees. These results indicate that in general the subjects have greater forward-tilt feeling after completion of all the somatogravic runs as compared to the pre- somatogravic runs.

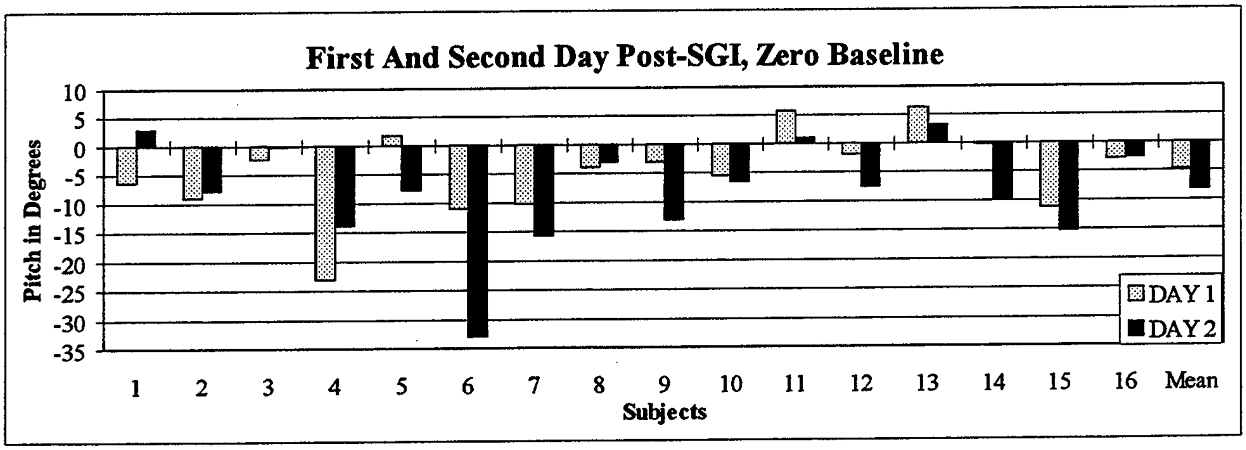

Figure 2. Graph of each subject's down-pointer measurement during Post-somatogravic, zero pitch baseline of the first and second day runs.

Figures 3 and 4 present bargraphs of the first and second day down-pointer measurements after being tilted 30 degrees backward while seated in the cab (gondola) of the ASDD. "Pre-SGI" means the 30 degrees of static pitch-up was run prior to any somatogravic runs where the subjects experience planetary rotation, and "Post-SGI" means the 30 degrees of static pitch-up was completed after all somatogravic runs were finished. The pre-SGI, +30 degree, baseline mean for the first day (Figure 3) is 22.51 ∓6.07 while the pre-SGI, +30 degree, baseline mean for the second day is 24.61 ∓10.66 , and an overall pre mean value for the two days of 23.56. The mean value for the post-SGI, +30 degree, baseline (Figure 4) for the first day is 27.40 ∓13.35 while the post-SGI, +30 degree, baseline mean for the second day is 23.24 ∓15.05, and an overall post mean value for the two days of 25.32. Pre- and post-SGI means and standard deviations for the static 30 degrees of pitch-up are shown in Tables 1 and 2.

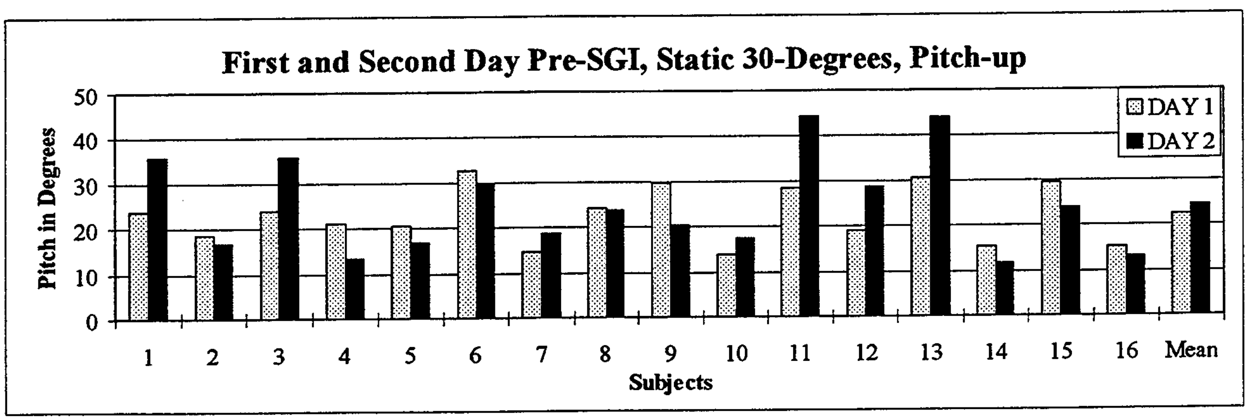

Figure 3. Bargraphs of each subject's down-pointer measurements during Pre-somatogravic (Pre-SGI), static 30 degrees of pitch-up during the first and second day runs.

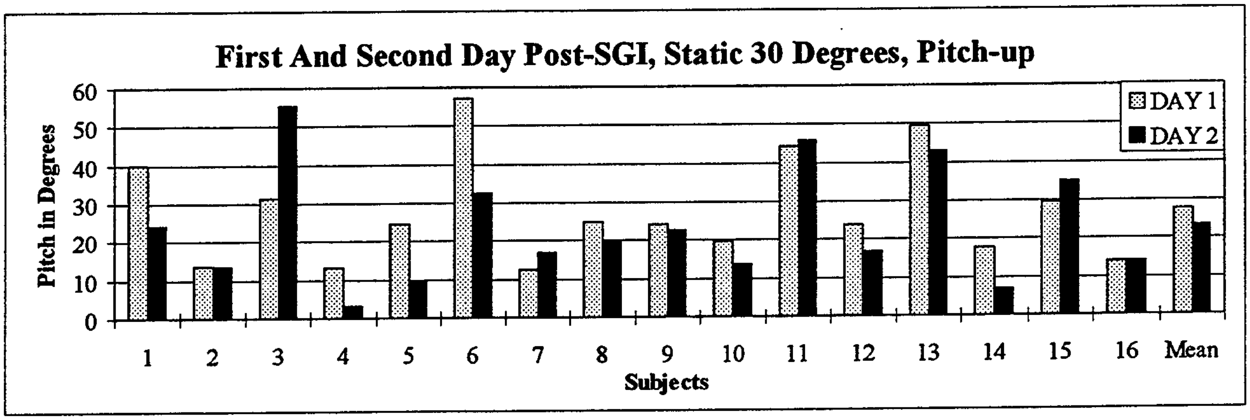

Figure 4. Bargraph of each subject's down-pointer measurements during Post-somatogravic (Post-SGI), static 30 degrees of pitch-up during the first and second day runs.

Tables 3 and 4 present the means and standard deviations for the first and second days of SGI measurements. The mean and standard deviation values for a subject are given in the last two columns; whereas, the mean and standard deviation values for treatment condition are given in the last two rows.

TABLE 3
SOMATOGRAVIC MEASUREMENTS: FIRST DAY

	CONDITION									
Sub #	***EC1***	***H1***	***T1***	***P1***	***HT1***	***HP1***	***TP1***	***HTP1***	***MEAN***	***SD***
1	37.20	27.42	21.08	25.86	25.34	9.84	16.29	12.96	**22.00**	**8.86**
2	9.63	7.34	9.94	11.50	12.96	14.52	10.67	9.32	**10.74**	**2.24**
3	12.96	14.52	24.61	16.91	26.17	24.61	35.12	35.23	**23.77**	**8.59**
4	12.02	1.93	14.52	15.46	15.66	12.96	13.69	21.91	**13.52**	**5.56**
5	14.31	3.28	17.95	14.83	14.94	21.80	5.57	-9.83	**10.36**	**10.18**
6	64.57	31.58	44.07	21.39	26.69	16.29	18.27	14.94	**29.72**	**17.04**
7	4.01	10.36	15.87	22.22	23.88	27.32	23.78	23.99	**18.93**	**8.11**
8	13.17	15.14	11.71	3.70	12.23	12.13	14.10	17.02	**12.40**	**3.94**
9	14.42	25.55	16.39	14.94	17.75	14.31	18.68	15.66	**17.21**	**3.71**
10	12.34	10.57	8.28	13.69	12.44	5.99	10.57	9.01	**10.36**	**2.53**
11	40.74	41.78	48.54	48.34	53.75	37.20	40.01	47.50	**44.73**	**5.61**
12	11.29	13.27	26.07	21.80	19.62	28.25	22.84	24.92	**21.01**	**6.02**
13	43.13	56.24	31.27	16.71	62.69	36.99	61.97	46.36	**44.42**	**15.96**
14	7.03	7.13	6.51	8.07	4.22	15.46	15.77	8.38	**9.07**	**4.23**
15	29.50	27.73	26.38	29.81	26.17	30.44	23.88	29.40	**27.92**	**2.28**
16	15.25	19.20	21.28	17.64	20.55	15.46	12.02	11.92	**16.67**	**3.61**
MEAN	**21.35**	**19.57**	**21.53**	**18.93**	**23.44**	**20.22**	**21.45**	**19.92**	**20.80**	**13.27**
SD	**16.77**	**14.78**	**11.94**	**10.15**	**15.06**	**9.55**	**14.03**	**14.70**	**13.27**	

Subject variability during the first day (Table 3) is noted to be from -9.83 degrees to +64.6 degrees, and the range of the within-subject mean values to be from +9.07 to +44.7. Yet, if the range of the means values are examined by condition (between subjects), the range appears to be fairly consistent from 18.93 to 23.44. The between subject mean values (by conditions) are almost equal (about 2.5 degrees from the grand mean) with a large overall standard deviation ($\sigma = \mp 13.27$). As in Table 3, the subject variability during the second day (Table 4) is large with a range from -2.02 to +70.7 degrees. The range of the mean values by subject is from +2.6 to +50.1, while the range of the mean values by condition is from 19.5 to 24.9.

TABLE 4
SOMATOGRAVIC MEASUREMENTS: SECOND DAY

	CONDITION									
Sub #	***EC2***	***H2***	***T2***	***P2***	***HT2***	***HP2***	***TP2***	***HTP2***	***MEAN***	***SD***
1	10.88	12.23	22.84	0.58	5.05	12.44	16.08	16.29	**12.05**	**6.90**
2	16.08	7.55	7.86	11.29	9.63	7.13	11.19	10.67	**10.18**	**2.91**
3	29.61	50.83	39.08	43.55	55.72	33.77	40.22	47.29	**42.51**	**8.68**
4	5.78	2.35	17.43	15.04	4.64	14.73	9.11	2.45	**8.94**	**6.06**
5	9.21	8.17	1.72	2.97	-0.98	1.41	0.16	-2.02	**2.58**	**4.09**
6	18.06	48.54	17.75	30.02	48.86	27.11	44.28	54.58	**36.15**	**14.67**
7	13.48	20.24	18.58	17.85	13.17	20.03	20.03	12.96	**17.04**	**3.28**
8	13.17	9.63	12.75	12.65	18.89	19.62	12.86	10.46	**13.75**	**3.63**
9	18.68	23.16	21.28	31.27	16.18	23.47	25.76	26.69	**23.31**	**4.74**
10	17.85	15.98	14.00	16.08	15.98	19.20	16.29	15.46	**16.35**	**1.56**
11	45.94	44.07	51.04	45.73	42.72	54.37	45.73	45.63	**46.90**	**3.85**
12	14.83	16.81	25.86	28.57	28.57	27.73	27.73	28.57	**24.83**	**5.66**
13	46.25	38.03	58.53	44.80	46.77	58.01	37.51	70.70	**50.08**	**11.44**
14	10.88	10.15	9.21	3.49	6.09	9.32	1.93	10.77	**7.73**	**3.47**
15	26.07	20.24	23.05	27.11	30.65	28.98	30.34	29.81	**27.03**	**3.75**
16	14.73	18.27	23.57	19.72	20.55	16.18	20.14	18.16	**18.92**	**2.74**
MEAN	**19.47**	**21.64**	**22.79**	**21.92**	**22.66**	**23.34**	**22.46**	**24.91**	**22.40**	**15.40**
SD	**11.95**	**15.36**	**15.17**	**14.69**	**17.69**	**15.42**	**14.30**	**20.23**	**15.40**	

In Figure 5 contains bargraph representations from Tables 3 and 4 of the perceived somatogravic means obtained with the down-pointer measurements during the last 10 seconds of the somatogravic runs during the first and second days of testing. The graphs are between subject mean values for specific SGI scene conditions. The perceived pitch-up grand mean value from the 128 first day runs is +20.8 ($\sigma = \mp 13.27$) while the perceived pitch-up grand mean value from the 128 second day runs is +22.4 ($\sigma = \mp 15.40$).

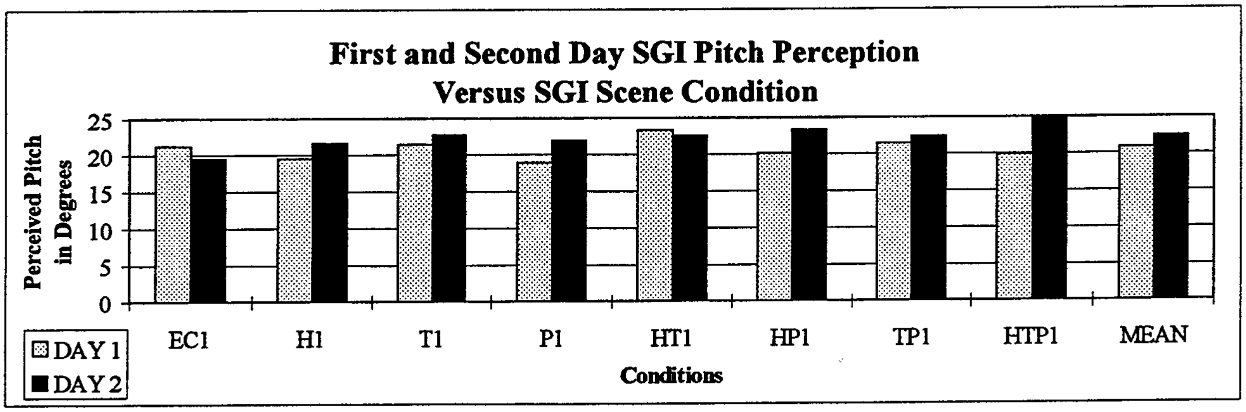

Figure 5. Graph of the first and second day means (N=16) of the somatogravic perceived pitch plotted against the various scene conditions.

When the results of the 256 somatogravic runs are averaged by treatment or scene condition and the averages compared to the theoretical resultant somatogravic vector (calculated to be 30.9 degrees), there is a consistent underestimation of the gravitoinertial vector in all conditions. The test results were verified with a repeated-measures factorial analysis-of-variance (ANOVA) using the general linear model (GLM) procedure. The factorial analysis of the data set from 16 subjects, 8 treatment conditions, and 2 days of somatogravic runs indicated significant main effects differences in "Subjects" and the interaction effects term "Subjects*Day", but no significant differences were found in "Treatment Conditions".

Tables 5 and 6 present the means and standard deviation for the first and second day of setting the down-pointer to zero after each somatogravic run. Recall that after each SGI run, the gondola is stopped and the gimbal brakes are locked to prevent movement. The subject is asked to close his or her eyes and to set the down-pointer where he or she perceives "down" to be. From Table 5 one notes that the mean and standard deviation values for each subject are given in the last two columns; whereas, the mean and standard deviation values for each treatment condition are given in the last two rows. Subject variability in Table 5 is noted to range from -20.44 degrees to +11.19 degrees and in Table 6 from -19.92 to 8.59. For Day 1 the within-subject mean values range from -10.88 to +7.18, while for Day 2 the range is from -12.84 to 4.64. Yet, if the range of the between-subject mean values (by Condition) are examined, the range appears to be fairly consistent for both Day 1 (from -4.86 to -1.49 degrees) and Day 2 (from -6.04 to -2.78). The grand mean value of the 128 observations is -3.11 degrees with the overall standard deviation equal to 6.02. Consistent negative values of the means by condition, observed in Table 5, are also noticed in both Pre- and Post-SGI baseline zero measurements shown in Tables 1 and 2. Looking at Table 6, the second day of postsomatogravic zero measurements, consistent negative values of the between-subject means (by condition) are also observed in Table 6. This may imply that the subjects may actually feel a slight tilting forward perception or that the down-pointer measurement may not accurately reflect the subject's true perception. From Tables 3 and 4, as well as Figures 5 and 6, the observation was made that the subjects had underestimated the somatogravic vector. However, algebraically summing the SGI perceived measurements with the zero measurements would result in a value for the perceived somatogravic vector which would be closer to the theoretical vector.

TABLE 5

POST SOMATOGRAVIC, ZERO MEASUREMENTS: FIRST DAY

	CONDITION									
Sub #	*EC1*	*H1*	*T1*	*P1*	*HT1*	*HP1*	*TP1*	*HTP1*	*MEAN*	*SD*
1	-11.28	-7.95	-8.16	-19.61	-2.65	-7.12	-6.08	-0.25	**-7.89**	**5.84**
2	-5.04	-2.34	-1.92	-6.39	-1.92	-4.00	-2.44	-3.90	**-3.49**	**1.63**
3	-6.39	-3.27	-3.69	0.58	-3.06	-3.90	2.87	-2.02	**-2.36**	**2.87**
4	-5.14	-7.54	-20.44	-7.64	-10.97	-6.39	-8.99	-6.91	**-9.25**	**4.84**
5	2.76	-4.10	1.62	-2.23	-2.54	3.60	6.51	2.03	**0.96**	**3.06**
6	-12.95	-9.10	-6.18	-5.98	-4.10	-15.97	-1.81	-18.25	**-9.29**	**5.88**
7	-5.25	-8.79	-2.54	-4.21	-0.36	0.58	0.06	0.37	**-2.52**	**3.36**
8	0.37	-0.46	-8.27	-2.02	-3.27	3.70	-5.77	-3.58	**-2.41**	**3.72**
9	-4.00	-5.04	-1.81	-7.85	3.60	-2.02	-0.36	0.68	**-2.10**	**3.56**
10	-1.29	3.60	2.35	-0.67	0.89	1.51	0.27	1.31	**0.99**	**1.58**
11	6.61	11.19	2.03	8.59	7.76	10.88	8.69	1.72	**7.18**	**3.60**
12	-7.23	-4.00	-6.71	-5.14	-11.80	-8.99	-5.04	-10.14	**-7.38**	**2.73**
13	0.06	-2.13	8.07	-2.13	9.21	-1.92	0.27	3.39	**1.85**	**4.58**
14	-6.39	-2.75	-2.54	-1.61	-8.47	4.22	-3.79	-1.92	**-2.91**	**3.73**
15	-20.02	-16.38	-12.95	-3.90	-12.22	-2.23	-11.49	-7.85	**-10.88**	**6.01**
16	-2.54	-1.29	-3.90	-2.75	-0.77	2.97	3.28	2.87	**-0.27**	**2.09**
MEAN	**-4.86**	**-3.77**	**-4.06**	**-3.93**	**-2.54**	**-1.57**	**-1.49**	**-2.65**	**-3.11**	**6.02**
SD	**6.36**	**6.04**	**6.66**	**5.72**	**6.28**	**6.36**	**5.38**	**5.76**	**6.02**	

Figure 6 presents bargraphs of the first- and second-day means of the perceived pitch (as measured by the down-pointer) for each SGI scene condition after the ASDD gondola returned to its resting position, i.e., the planetary rotation has stopped and the ASDD gimbal locks are on. The bargraphs (Figure 6) show the range of the treatment condition means to be negative values between -6.04 degrees and -1.49 degrees.

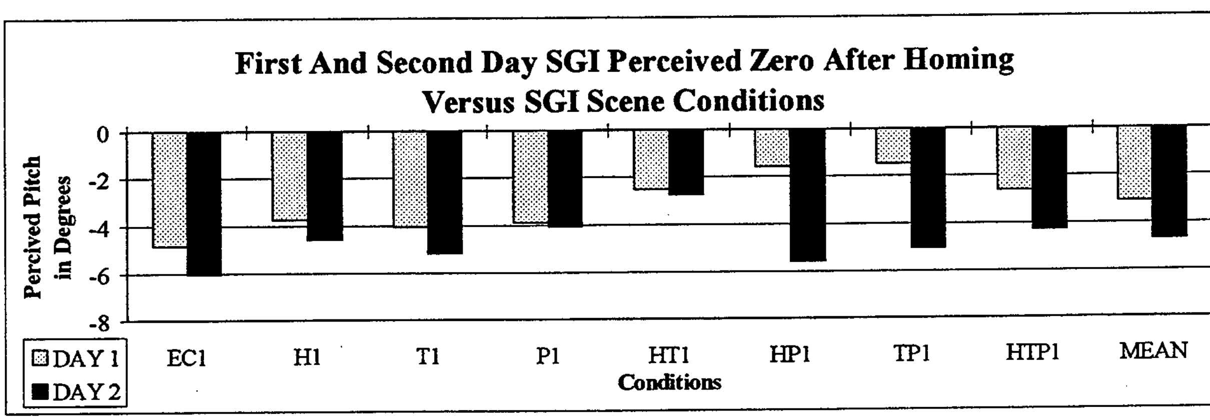

Figure 6. Graph of the first and second day means (N=16) of the perceived zero after homing (Post-SGI run) versus scene condition.

TABLE 6

POST SOMATOGRAVIC, ZERO MEASUREMENTS: SECOND DAY

	CONDITION									
Sub #	***EC2***	***H2***	***T2***	***P2***	***HT2***	***HP2***	***TP2***	***HTP2***	***AVG***	***SD***
1	-10.76	-7.12	-4.10	-8.99	-7.12	-5.66	-0.57	1.62	**-5.34**	**4.17**
2	-12.64	-6.50	-7.43	-3.69	-6.60	-3.90	-9.62	-9.72	**-7.51**	**3.05**
3	-6.08	3.28	0.68	-0.15	7.34	-11.08	2.55	-2.13	**-0.70**	**5.76**
4	-7.54	-10.55	-9.72	-4.00	-10.76	-12.74	-7.95	-14.09	**-9.67**	**3.18**
5	-1.29	-0.36	-2.96	-4.31	-8.58	-3.79	-3.48	-7.43	**-4.03**	**2.80**
6	-13.26	-11.39	-12.74	-9.93	-7.33	-8.99	-12.64	-8.47	**-10.59**	**2.23**
7	-7.95	-11.91	-9.10	-15.76	-10.45	-12.95	-8.68	-14.61	**-11.43**	**2.86**
8	-6.81	-6.71	-8.89	-4.52	-0.67	0.89	-7.02	-4.21	**-4.74**	**3.36**
9	-6.91	0.79	-4.31	0.47	-2.54	-6.60	-7.33	0.06	**-3.30**	**3.46**
10	0.79	-3.06	1.41	-1.29	0.68	-3.17	-7.75	-0.05	**-1.55**	**3.04**
11	1.93	2.24	4.53	8.59	6.51	4.01	5.26	4.01	**4.64**	**2.18**
12	-15.44	-12.12	-6.71	-5.87	-0.05	-10.14	-5.25	0.37	**-6.90**	**5.53**
13	0.27	3.08	0.47	2.76	1.62	1.93	0.06	2.45	**1.58**	**1.18**
14	3.80	-1.40	-3.90	-2.96	-3.48	1.31	-7.43	-2.13	**-2.02**	**3.41**
15	-18.46	-14.51	-19.92	-11.18	-3.90	-11.18	-11.28	-12.32	**-12.84**	**4.97**
16	3.70	2.45	-0.77	-4.83	0.79	-7.43	-0.25	-2.75	**-1.14**	**3.72**
AVG	**-6.04**	**-4.61**	**-5.22**	**-4.10**	**-2.78**	**-5.59**	**-5.09**	**-4.34**	**-4.72**	**5.85**
SD	**6.99**	**6.22**	**6.13**	**5.78**	**5.52**	**5.50**	**5.14**	**6.02**	**5.85**	

The grand mean (Table 5) for the first day runs is -3.11 (6.02), while the grand mean (Table 6) for the second day runs is -4.72 (5.58). On the surface, it would appear that there isn't anything of significant interest; however, a factorial analysis showed significant difference in "Day" (pr > F = 0.0347) as a main effect, and significant interaction effects in the term "Horizon*Texture*Day" (pr > F = 0.0248).

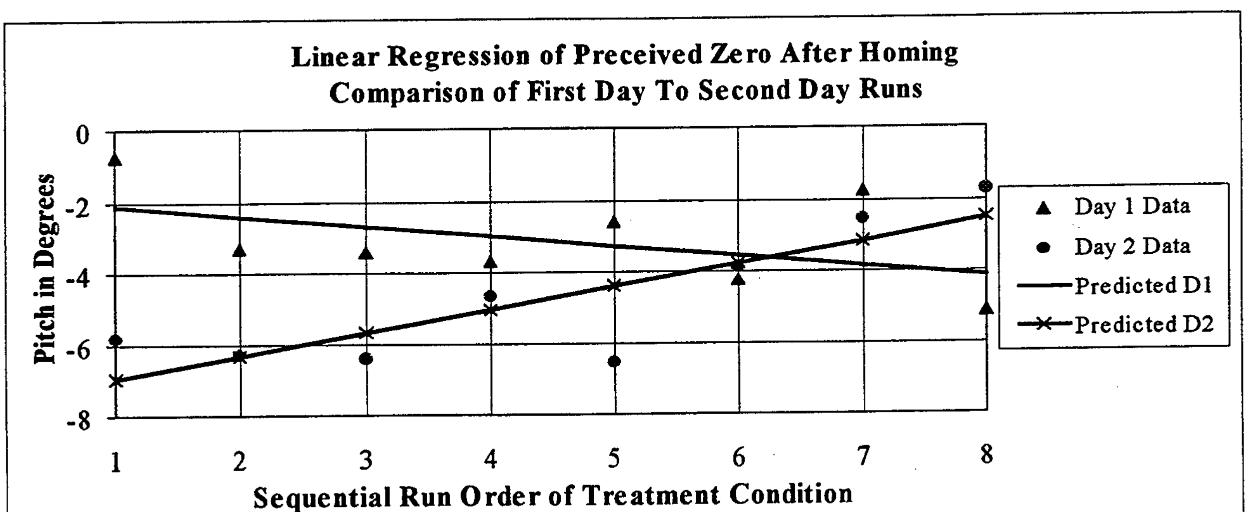

Figure 7. Linear Regression plots of perceived zero after ASDD homing.

The findings of differences in "day of run" resulted in futher evaluation with regression analysis of the SGI zero measurements (after homing) over time, i.e., the order of treatment or the sequence in which the SGI scenes were presented to the subjects. The resulting regression lines for both days are shown in Figure 7. An analysis of covariance showed that the second day zero-measurements had a positive slope (also a decreasing error from true zero) with time that was significant ($F = 19.8$, $p = 0.0005$) when compared to the first day (slight negative slope).

If the two days are averaged, the resulting slope would not be viewed as a significant phenomenon. If the two days are not averaged, one could postulate that the positive sloping trend towards a decreasing error may indicate learning by subject's the neural-muscular systems involved in positioning the down-pointer to zero pitch. One could further infer that the learning may be the result of the procedures used at the end of each somatogravic run, when the subject is told to follow the operator's instructions of moving the down-pointer forward, backward, then slowly forward until told to stop. However, the fact that the slope is in a different direction each day may suggest that this may not be the case and is probably artifactual.

The final analysis is the evaluation of the vection ratings for the various scenes. Tables 7 and 8 contain individual vection ratings by Subject and Condition.

TABLE 7
FIRST DAY VECTION RATINGS

				CONDITION					
Sub #	***H1***	***T1***	***P1***	***HT1***	***HP1***	***TP1***	***HTP1***	***MEAN***	***SD***
1	0	2	1	2	1	3	3	**1.71**	**1.11**
2	0	2	1	2	1	3	2	**1.57**	**0.98**
3	1	3	1	3	1	3	3	**2.14**	**1.07**
4	0	2	1	3	2	2	3	**1.86**	**1.07**
5	1	3	2	3	1	3	3	**2.29**	**0.95**
6	1	2	2	2	0	3	3	**1.86**	**1.07**
7	0	1	1	1	0	1	2	**0.86**	**0.69**
8	2	3	1	2	1	2	3	**2.00**	**0.82**
9	0	3	2	2	2	3	3	**2.14**	**1.07**
10	0	3	2	3	2	3	3	**2.29**	**1.11**
11	0	2	0	2	3	2	1	**1.43**	**1.13**
12	1	2	2	2	1	3	3	**2.00**	**0.82**
13	0	2	0	2	1	1	0	**0.86**	**0.90**
14	0	2	1	2	0	3	3	**1.57**	**1.27**
15	0	3	1	2	1	3	3	**1.86**	**1.21**
16	1	2	1	3	1	2	3	**1.86**	**0.90**
MEAN	**0.44**	**2.31**	**1.19**	**2.25**	**1.13**	**2.50**	**2.56**	**1.77**	**1.04**
SD	**0.63**	**0.60**	**0.66**	**0.58**	**0.81**	**0.73**	**0.89**	**1.04**	

In Table 7, first day vection, mean and standard deviation values for each subject are given in the last two columns; whereas, the between subject mean and standard deviation values (by treatment condition) are given in the last two rows. Subject variability is not an issue, as the range of the mean values by subject is from 0.86 to 2.29, and the range of the mean values by condition is from 0.44 for "Horizon" only to 2.56 for the combination of "Horizon Line, Texture Elements, and Perspective Lines". The grand mean value of the 112 Day 1 observations is 1.77 with an overall standard deviation of ∓1.04. Any scene containing "Texture Elements" received a mean rating of 2.25 or higher; whereas, scenes which did not contain "Texture Elements" received a mean rating of 1.19 or less. Ten of the subjects did not experience any feeling of forward motion with the "Horizon Line" scene, resulting in the lowest mean vection rating of 0.44 and a standard deviation of ∓0.63. The second day vection, mean and standard deviation values in Table 8 are similar to the mean and standard deviation values given in Table 7. In Table 8, the range of the within-subject mean values is from 0.86 to 2.14, and the range of the between-subject means values (by condition) is from 0.13 for "Horizon" to 2.63 for "Texture Elements". The grand mean value of the 112 Day 2 observations is 1.70 with an overall standard deviation of 1.11. As was the results from the first day vection mean ratings, any scene containing "Texture Elements" received a mean rating of 2.31 or higher; whereas, scenes which did not contain "Texture Elements" received a mean rating of 1.00 or less. Fourteen of the subjects did not experience any feeling of forward motion with the "Horizon Line" scene, resulting in the lowest mean vection rating of 0.13, with a standard deviation of 0.34.

TABLE 8
SECOND DAY VECTION RATINGS

	CONDITION								
Sub #	**H2**	**T2**	**P2**	**HT2**	**HP2**	**TP2**	**HTP2**	**MEAN**	**SD**
1	0	2	1	2	1	3	3	**1.71**	**1.11**
2	0	3	1	3	1	2	3	**1.86**	**1.21**
3	1	3	1	3	1	3	3	**2.14**	**1.07**
4	0	3	0	2	0	2	1	**1.14**	**1.21**
5	0	3	0	3	1	3	3	**1.86**	**1.46**
6	1	2	2	2	2	3	3	**2.14**	**0.69**
7	0	3	1	2	0	2	3	**1.57**	**1.27**
8	0	3	1	2	1	2	2	**1.57**	**0.98**
9	0	3	2	2	1	2	3	**1.86**	**1.07**
10	0	3	1	3	1	3	3	**2.00**	**1.29**
11	0	2	0	2	0	1	1	**0.86**	**0.90**
12	0	3	1	2	1	3	3	**1.86**	**1.21**
13	0	2	2	1	1	1	1	**1.14**	**0.69**
14	0	3	1	3	1	3	3	**2.00**	**1.29**
15	0	2	1	3	1	3	3	**1.86**	**1.21**
16	0	2	1	2	1	3	2	**1.57**	**0.98**
MEAN	**0.13**	**2.63**	**1.00**	**2.31**	**0.88**	**2.44**	**2.50**	**1.70**	**1.11**
SD	**0.34**	**0.50**	**0.63**	**0.60**	**0.50**	**0.73**	**0.82**	**1.11**	

Figure 8 are bargraph representations of the mean vection ratings (contained in Tables 7 and 8) of the SGI scenes from the first and second days.

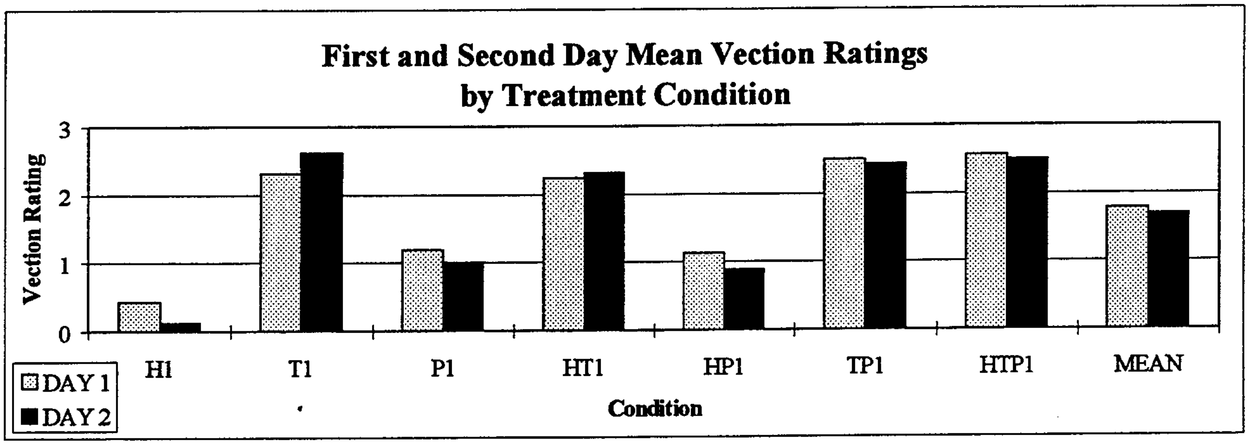

Figure 8. Bargraphs of the averaged vection ratings (N=16) versus treatment condition from the first and second days of runs.

Figure 9 shows frequency histograms of the number of times (expressed in percentage) that subjects rated a particular scene as vection-1, vection-2, or vection-3 during the two days of trials. The histograms indicate that when texture was included in a scene, subjects experienced the greater feelings of forward motion.

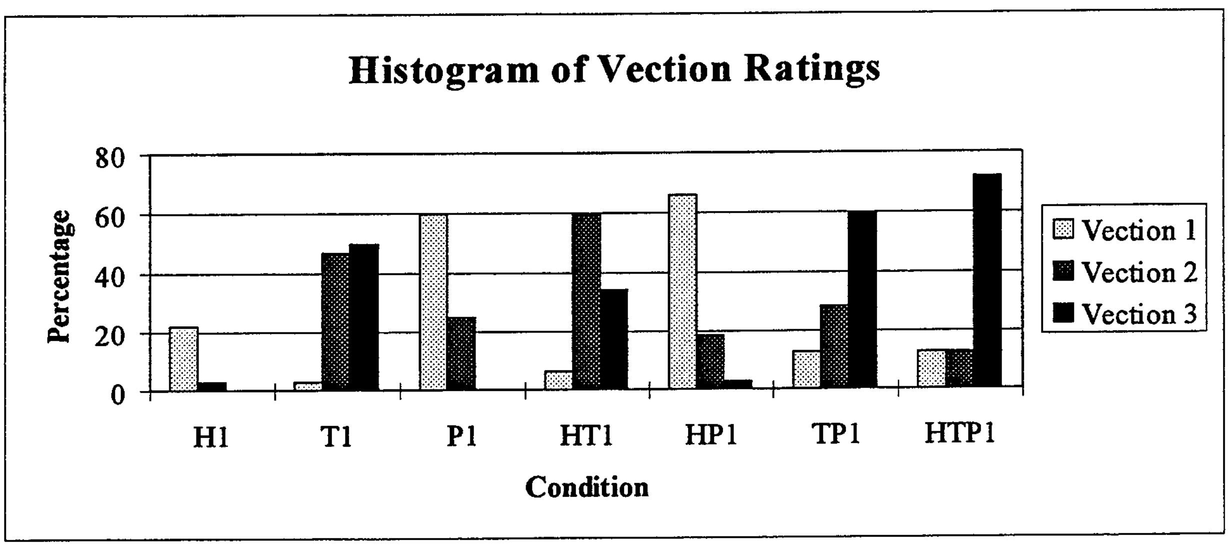

Figure 9. Summary histogram of vection ratings of the SGI scenes.

A secondary part of this study included comparing a subthreshhold rotation about the pitch axis to 30 degrees of pitch, termed "Slow Pitch". This profile was similar to the static +30 degrees pitch profile with the exception that the angular velocity was constant at one degree per second (normally, subthreshhold to human perception). This part of the study included two run conditions; "Eyes Closed" and the "HTP scene" which contained a horizon line, texture elements, and perspective lines.

In Table 9, the overall mean value of the two days with eyes-closed condition is close to the actual +30-degrees of pitch (Mean = 29.72, σ = $\mp$16.73), even with the large range in subjects' perceptions of tilt from 9.42 degrees to 64.12 degrees. The overall mean value for the two days with presentation of the HTP scene (Scene Mean = 27.05, σ = $\mp$15.06) is not much different than the eyes-closed mean. Large variations are also present in the range of subjects' perceptions of tilt with the HTP scene condition, from 8.48 degrees to 58.27 degrees.

TABLE 9
SLOW PITCH-UP TO +30 DEGREES: FIRST AND SECOND DAY RUNS

	EYES CLOSED			SCENE		
Sub #	***EC D1***	***EC D2***	***EC MEAN***	***HTP1***	***HTP2***	***HTP MEAN***
8	16.64	18.21	**17.42**	12.66	12.04	**12.35**
9	28.98	16.43	**22.70**	21.97	18.52	**20.25**
10	19.04	16.95	**18.00**	19.04	15.80	**17.42**
11	50.74	50.21	**50.47**	58.27	51.36	**54.82**
12	44.77	27.62	**36.20**	37.45	22.81	**30.13**
13	64.12	59.10	**61.61**	44.56	46.34	**45.45**
14	20.51	9.42	**14.96**	8.48	8.58	**8.53**
15	28.56	31.07	**29.82**	33.27	29.40	**31.33**
16	15.07	17.58	**16.32**	21.87	24.48	**23.17**
MEAN	**32.05**	**27.40**	**29.72**	**28.62**	**25.48**	**27.05**
SD	**17.28**	**16.10**	**16.73**	**16.86**	**14.74**	**15.06**

Figure 10 presents bargraphs of the means from nine subjects, first and second sessions of runs (N = 18). From the summary graph of "Slow Pitch" rotation to 30 degrees, no differences are noted between the means from the "Eyes-closed" (EC) runs and the means when the visual scene "HTP" (Horizon Line, Texture Elements, Perspective Lines) was presented.

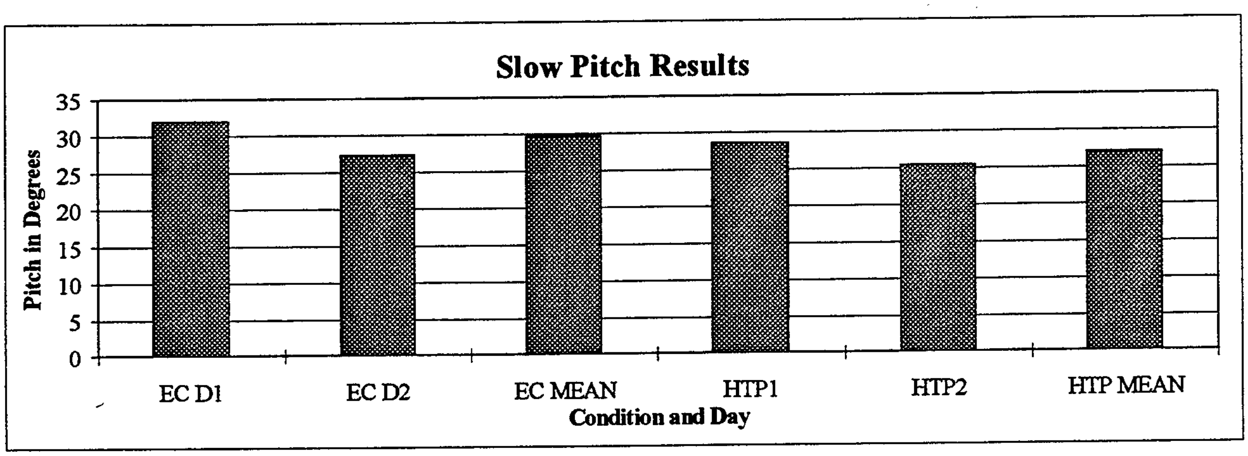

Figure 10. Summary Plot of "Slow-Pitch" rotation to 30 degrees with "Eyes-closed" (EC) and visual scene "HTP" (Horizon Line, Texture Elements, Perspective Lines).

Figure 10 presents bargraphs for the means of nine subjects, first and second days of runs. Only nine subjects were paticipated in the slow-pitch treatment, since the other 7 subjects had already completed their two days of sessions. The graphs show that the mean value of the HTP scene condition is slightly less than the mean value with eye-closed condition.

DISCUSSION AND CONCLUSIONS

This study was undertaken to determine the relative importance of various visual scene cues in achieving "visual dominance" over nonvisual orientational inputs. It was hypothesized that some visual cues would be more effective than others in reducing the magnitude of the perceived somatogravic pitch-up illusion when compared to the eyes-closed SGI condition. The conclusion reached in this study is that no statistically significant differences were observed between the perceived pitch during eyes-closed somatogravic condition and the perceived pitch during any of the visual conditions. This conclusion means that none of the factors in the scenes (Texture elements, Perspective lines, or Horizon line) resulted in a significant reduction of the somatogravic pitch-up illusion. It is suggested that the scenes used in this study were too basic, abstract, and black and white (similar to night conditions), or the scenes were not bright enough and perhaps not as realistic as a bright daytime scene. The Previc *et al.* study [8] showed that even with a full-cue, daylight scene, the somatogravic illusion could not be broken.

In discussions of why the scenes may not have had an effect on the somatogravic illusion, the physiology behind the SGI is the linear acceleration or deceleration of a human which is sensed by the otolith organs. The otolith organs in the utricles are position sensors which respond to both linear acceleration and tilting; whereas, the semicircular canals respond to the rate of change of rotation or angular acceleration. [10] The semicircular canals act as rate sensors, so that when the rate is constant, adaptation of the semicircular canal receptors begins within a second and generally returns to its resting position within 15 to 20 seconds. [7] Guyton points out that many individuals with complete destruction of the vestibular system have normal equilibrium if their eyes are opened and their movements are slow, but will loose equilibrium if their motions are rapid or their eyes are closed. Likewise, figure skaters can suppress post-rotary sensations with visual fixation. Are the rotational illusions easier to break with visual dominance as compared to the somatogravic illusion? Should we be looking at the optokinetic effects during rotation?

It was noted that the overall mean value of the down-pointer measurements during somatogravic (SGI) runs was less than the overall mean value of the down-pointer measurements during slow-pitch runs by 7.0 degrees. A possible explanation may be that vestibular input from the semicircular ducts may interact or interfere with the otolith input resulting in a reduced perception of the gravitoinertial vector. On-the-other-hand, one could argue that it is within the noise of the measurements, since the variances are large.

Additionally, the reliability and validity of the down-pointer method of measuring subjects' subjective perception of down must be addressed. The position of the down-pointer at shoulder height, 12 inches to the right and slightly aft of the right shoulder, may have created a difficult and uncomfortable method to adequately indicate the perceived direction of gravity. It is recommended that alternative methods for subjects in the ASDD to indicate their preception of down.

An argument against the validity of the vection rating results was raised, since one must consider the possibility of training effects from the process. Recall that the process includes having the subjects view a "Maximal Vection Scene" as the basis for comparison. The subjects were told that the "Maximal Vection Scene" was considered to be a rating of three (3). The Maximal Vection Scene consisted of only texture elements at a velocity equivalent to SGI scene velocity. Although this scene was, by definition, given a rating of "3", it actually failed to produce a feeling of self-motion in some subjects. The argument suggests that the subjects were trained to view, compare, and rate subsequent SGI scenes with the moving texture pattern of the "Maximal Vection Scene"; therefore, any moving scene with texture elements would appear similar to the "Maximal Vection Scene".

RECOMMENDATIONS

From the conclusions of this study, the following recommendations are made:

1. That the somatogravic study in the ASDD be expanded to evaluate the effects of bright, daytime scenes simulating various acceleration rates at very low levels of flight even though Previc's study may suggests that negative results are highly probable. However, the ASDD visual display may produce a better visual scene stimulus to achieve visual dominance that was not achieved with a low-cost, helmet-mounted scene used in the Previc, Varner, and Gillingham (1992) study.

2. That a study be undertaken to evaluate the effect of rotation on the perception of where down is during slow-pitch rotation to +30 degrees. Results from such a study may be compared with the results of this study.

3. That a study be undertaken to evaluate optokinetic effects during rotation (the somatogyral illusion).

4. That a study should be conducted to determine the field of view necessary to break the somatogravic illusion and subsequently, the somatogyral illusion.

5. That the vection rating method be evaluated in a separate study. Perhaps a vection scene not included as one of the treatment scenes may preclude potential "biasing effects."

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