Tilt Bed Testing of the Subjective Horizontal

by

Elizabeth A. Dewell

Submitted to the Department of Mechanical
Engineering in Partial Fulfillment of the Requirements for the
Degree of

Bachelor of Science

at the

Massachusetts Institute of Technology

June 2002

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ABSTRACT

Mittelstaedt (1987) suggested that inversion illusions which caused space sickness in astronauts was associated with a net headward bias in the body's gravireceptor organs, which could be measured on Earth using a tilting bed. Mittelstaedt showed that when individual subjects were asked to repeatedly position themselves to the gravireceptive subjective horizontal, individuals showed a small (<5 deg.) but consistent head up or head down bias that remained stable when retested weeks, months or even years later. A correlation with inversion illusion was noted in a small number of astronauts. The purpose of the present project was 1) to construct a new bed of slightly different design and 2) to verify Mittelstaedt's findings using a different subject population. Nine subjects each lay on their left side with their head immbobilized using a bite bar. They positioned the bed (and themselves) at the subjective horizontal ten successive times starting from standardized initial tilt angles which ranged from +/- 10 degrees. Tests were then repeated on right side. Four subjects returned a day later for retesting. Results showed that subjects repeatedly positioned themselves at their own subjective gravitational horizontal, which differed from true horizontal by several degrees a head down direction. Results of tests on the left and right side had similar means for most of the nine subjects; however 4 were statistically different. Left and right sides were combined, noting the above error. Mean biases in the subjective horizontal varied from -3.26 to -0.82 degrees head down between subjects, with overall mean -1.65 and s.d. 0.80. There was a statistically significant difference between responses of some subjects. Data from four subjects tested on both days was compared. A statistically significant correlation was not found, perhaps due to the small subject retest population. The differences between Mittelstaedt's data and present results are discussed.

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1.0 INTRODUCTION

1.1 Background

Space perception and space sickness are far from understood, although several hypotheses have been suggested and extensive research has been done. In Mittelstaedt's paper, the Determinants of Space Perception in Weightlessness, he offered "gravireceptor bias" as an explanation for the cause of 0-G inversion illusions among astronauts, defined as perception of the spacecraft and oneself as upside down which persists, even when eyes are closed. (Mittelstaedt, 1987) Mittelstaedt (1987, 1996) argued that the body has multiple gravireceptive sensory organs, including the utricular and saccular otoliths in the inner ear, a distributed system of cardiovascular baroreceptors, and also mechanoreceptors located in the region of the kidneys. The vestibular contribution probably comes largely from the saccular otoliths. Both the saccular and somatosensory mechanoreceptors are presumably sensitive to forces along the body's longitudinal axis, oriented in the direction of gravity when standing erect. The Z-axis was defined as this longitudinal axis, taken positive through the body from feet to head with the origin of the Z-axis at the midpoint between the ears. He studied 44 normal subjects and 5 astronauts, and found evidence that each person has a net gravireceptor bias either towards the head or towards the feet. A person with a headward gravireceptor bias would be expected to feel inverted in weightlessness. If this same person lay supine on a bed in 1-G, and was allowed to adjust the bed until they felt subjectively horizontal, the person should consistently set the bed slightly head up, in order to overcome the headward gravireceptor bias. Conversely, a person with a net footward gravireceptor bias would feel upright in 0-G, and in 1-G set the bed slightly head upward, relative to the feet. A tilt bed thus can be used on Earth to measure a person's net saccular and somatosensory Z-axis bias. If head is on average lower than the feet, it is deemed a positive bias.

1.2 Purpose

The scientific goal of this project was to replicate Mittlestaedt's experiments using a tilting bed constructed at MIT. The bed was different structurally by having its axis of rotation through the waist, as opposed to rotation at the head. The MIT bed was actuated by the subject using an electric linear actuator, rather than by the experimenter using a mechanical winch. The head restraint and padding on the bed was likely also different. As in Mittelstaedt's experiments, the subject set the bed to the subjective horizontal ten times lying on each side, and the mean response was taken. It was unclear whether these minor changes in equipment and protocol would produce a different result. Subject's net gravireceptor bias data were analyzed with respect to one another and results compared to Mittelstaedt's data.These tests were valuable in determining whether a small group of individuals demonstrated test-retest reliability during each session, from left to right side, and days later. I hoped to gain further understanding of these effects and obtain repeatable results that were statistically conclusive.

2. METHODS

2.0 Subjects

Nine subjects (** men, *** women, ages ***-***) were recruited from the MIT community. They were in good health and had no positive history of vestibular disease.

2.1 The Tilt Bed

A 36" wide by 87" long bed made of wood with a Unistrut support structure was constructed by Lindsay Howie, Nate Newby, and myself.

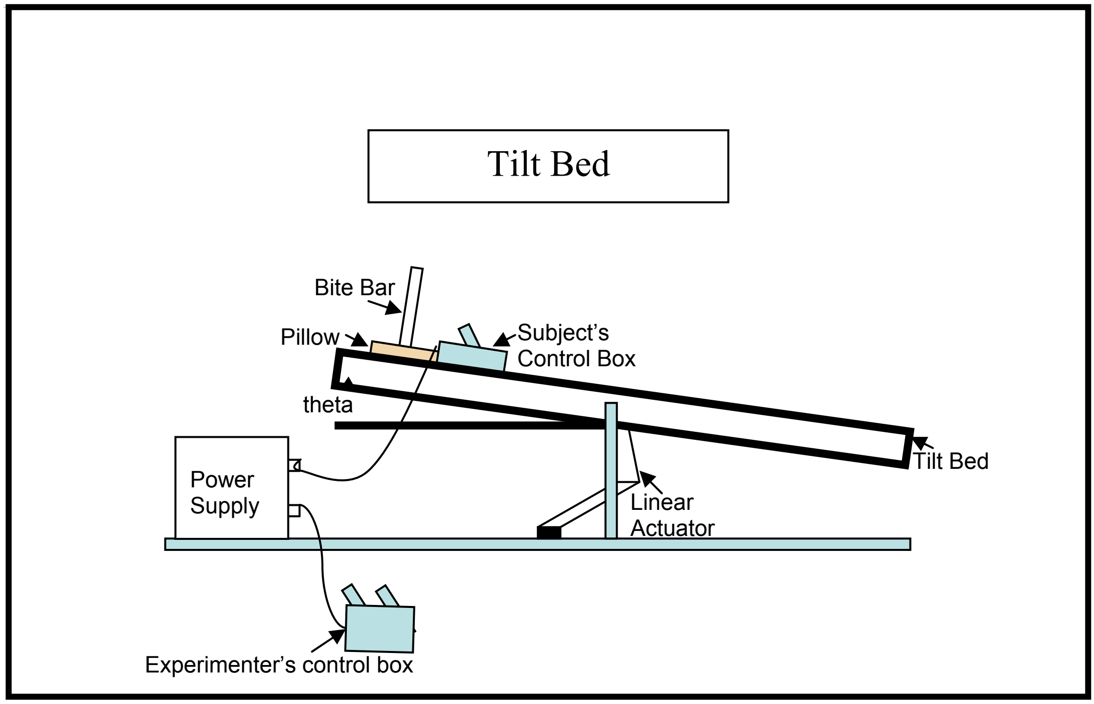

Figure ###: A schematic of the tilt bed apparatus.

The bed had one axis of rotation, through the center. See Figure 2 for a picture of the bed.

Figure ###: Tilt Bed

The bed could be rotated relative to horizontal by means of a commercial linear actuator (Thomson Saginaw, Model PPA 7828525), with 18” stroke. See Figure 2.

Figure 2: Linear Actuator-2 views

A DC power supply of 24 volts was used to power the actuator. The actuator had limit switches set at +/- 30 degrees, to prevent the bed from hitting the floor. Further mechanical support limited rotation to +/- 15 degrees to maintain a safe environment for subject. The bed’s rotation was fixed at 2 deg/sec. Most subjects found the bed’s angular rotation itself difficult to perceive, probably because the rate was just below the normal average threshold detection by the semicircular canals. Controls were built to have 2 operators: experimenter and subject. The experimenter’s control box had a switch which toggled between the two operators. See Figure 4.

Figure 4: Experimenter and Subject Control Switches

Bed tilt was measured by a digital inclinometer (***model number and manufacturer) which was positioned beside the subject's head. An LCD display on the inclinometer indicated bed tilt in degrees, to an accuracy of **** (do you know ?). Head up tilt of the bed resulted in a positive indication.

A bite bar was made to keep the position of the subject's head constant relative to the bed throughout the experiment. It was a simple device made of a threaded aluminum rod covered by 3/8" diameter polyethylene tubing. The bar protruded perpendicularly from the surface of the bed and was secured by two 2"x2" aluminum plates. A channel was designed for the rod to slide back and forth so that the position of the subject was constant. The center of rotation of the bed was also the center of rotation of the subject. See Figure 5.

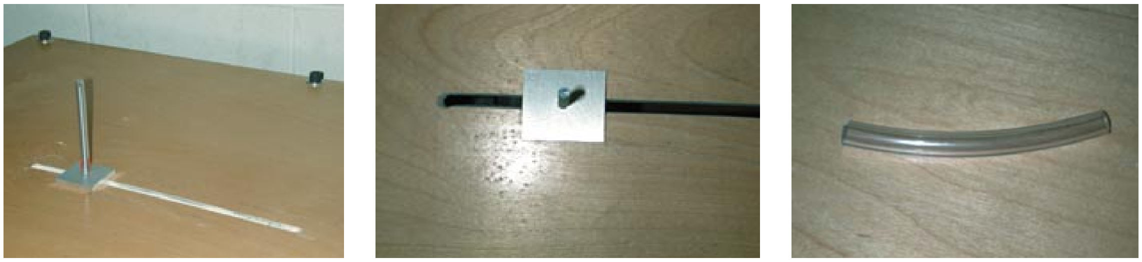

Figure 5: Bite Bar and Disposable Polyethylene Tubing

The nut, on the underside of the table, could be unscrewed easily to adjust the location of the bite bar. A foam pad the full area of the table, 1.5" thick, was placed on top of the wood. It provided a comfortable cushion for the subject to lie on. As a protective layer, a black fitted sheet was placed over the pad and wood. Two pillows made of foam padding were available for head and neck support. See Figure 6. Other restraints such as a waist belt were not used. Any tendency for the subject to slide up or down was minimized by friction from the compressible foam pad on the bed and the force of the bite bar. The bite bar proved relatively comfortable to use over the range of bed tilts used in this experiment.

Figure 6: Pillow Support for Head and Neck

2.2 Procedure

The subject mounted the bed from the center using a kitchen-type stepping stool, if necessary. The subject was asked to lie down on her side, centered on the tilt bed with her waist at the table's axis of rotation. The bite bar was adjusted to the vicinity of the subject's mouth and the nut was secured. A clean piece of polyethylene tubing was cut and slid over the shaft of the bite bar. 1 or 2 foam pillows were placed beneath the head so that the neck was approximately straight in relation to the body. The sheet was fixed in place. The subject was then asked to bite comfortably on the bar. The bite bar was further adjusted if necessary to alleviate any discomfort. The power supply, located on the floor next to the experimenter's chair, was flipped to the ON position. The digital inclinometer was positioned on the bed near the subject's head and a zero degree reading was verified; otherwise, adjustment was made to reposition the bed to zero degrees. The subject then rested on the bed for 10 minutes to partially equilibrate extracellular fluids in the body which normally shift from the feet towards the thorax and head in supine subjects. Mittelstaedt apparently also did this, but for an unspecified amount of time. After the 10 minute period, testing began. The subject then adjusted her body position to lie on her left shoulder. An eye mask was placed over her eyes, which blocked all visual cues to the horizontal. Lights in the room were turned off; a small red lamp was left on to read the output from the protractor. The experimenter handed a control box to the subject to adjust tilt bed angle. The experimenter used her own control box to position the bed at specific starting tilt angles, no greater than +/- 10 degrees as shown in Table 1. The experimenter’s controls were switched to “Subject,” and then the subject was instructed to move the bed so that their head and body felt subjectively gravitationally horizontal. After verbal affirmation that the subjective horizontal had been reached, the location was recorded. Table 1 shows the order the trials were run.

Run Number	Body Side	θ_0 (starting angle)
1	Left	2.5
2	Left	-7.5
3	Left	10
4	Left	0
5	Left	-5
6	Left	5
7	Left	0
8	Left	-10
9	Left	7.5
10	Left	-2.5
11	Right	2.5
12	Right	-7.5
13	Right	10
14	Right	0
15	Right	-5
16	Right	5
17	Right	0
18	Right	-10
19	Right	7.5
20	Right	-2.5

Table 1: Datasheet for Tilt Bed with Starting Positions

The starting angle varied between +/- 10 degrees. This range was believed large enough to account for any subject who might have a strong bias. It also alternated between positive and negative and was symmetric about the zero, i.e. 2.5 was the 1st run, and -2.5 was the 10th run. Once 10 trials had been completed on the left side, the subject switched to the right side. The order was the same for each of the 9 subjects tested. Repetition of this test was performed *** days later for four subjects.

3.0 RESULTS

Tilt bed tests were run on nine individuals on Day 1. Four individuals returned on Day 2. Analysis of this data was performed to obtain answers to the following series of questions:

3.1 Does approaching the subjective horizontal from above and approaching it from below yield the same result?

When plotting θ_0 vs. θ_{final}, a trendline was apparent in the data for some of the subjects. Two apparent trendlines, s. 6 and s. 3, were graphed in Figures ### and ###, below. Either left or ride sides were graphed, because it had not been proven that the left and right side could be combined statistically.

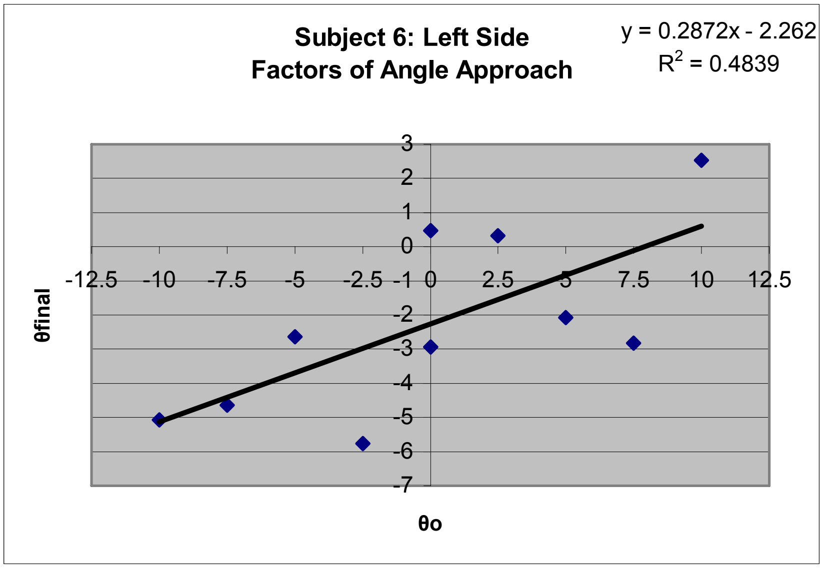

Figure ###: Subject 6, Day 1, left side. Plot of θ_o vs. θ_{final}

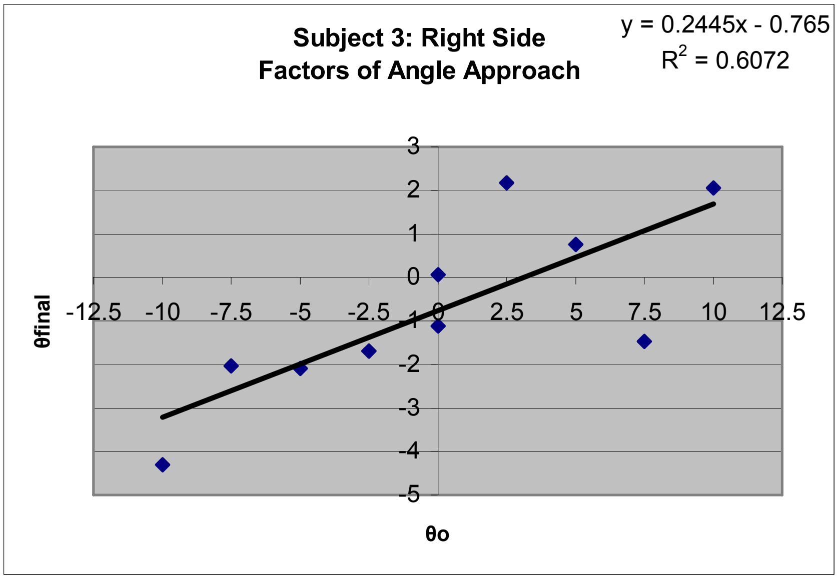

Figure ###: Subject 3, Day 1, right side. Plot of θ_o vs. θ_{final}

Note that the magnitude of the starting tilt bed angles, θ_o, seemed to influence the final tilt bed angle θ_{final} for large θ_o (+/- 10). This could have been due to habituation at the new angle, so that the horizontal seemed to shift towards the direction of approach. This showed how important it was to balance the trials by alternating head up and head down and large and small tilt angles. This helped to partially cancel the effect large starting angles could have on θ_{final}. By evenly spacing θo between -10 and +10 and following the same trial order for left and right sides, it was still possible to estimate the true gravireceptor bias of an individual as the value where a first order regression trendline crossed the y-axis because effects on the left and right side average out. The numerical bias was the b term of the y=mx+b equation displayed on the graph, and is also the mean response, since an identical set of positive and negative initial starting angles were used. However, in many subjects the effects of starting angle were not always as clear, as shown in Figure ###.

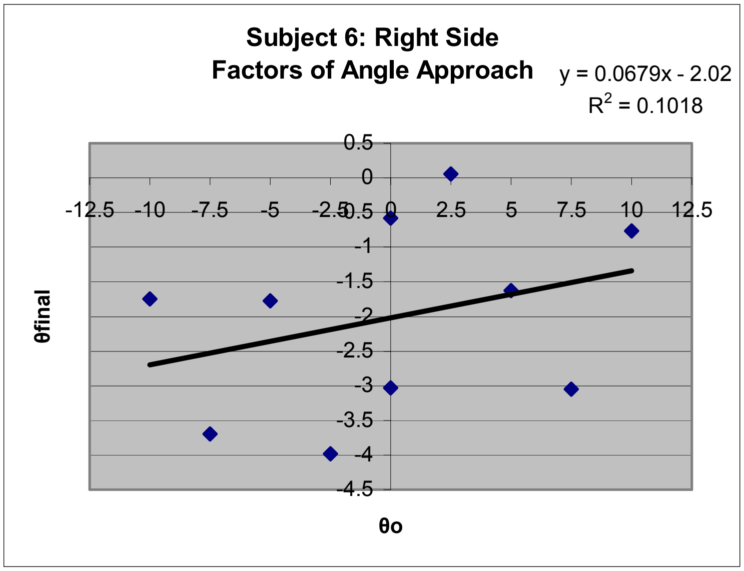

Figure ###: Subject 6, Day 1, Right side. Plot of θ_o vs. θ_{final}

In many cases, large negative or positive starting angles did not seem to have an consistent effect on θfinal. The gravireceptor bias was calculated in the same way.

3.2 Was the difference between left and right sides significant?

The ten left side and 10 right side θ_{final} values were input values to obtain the results below, see Table ###. Microsoft Office 2000 (v 9.0.2720) Excel data analysis pack was used to perform a t-test: Paired Two Sample for Means. Mean left and right sides, t, and p(two-tail) values were outputs. The standard deviations of left and right sides were calculated using Microsoft Excel's stdev() function. The difference of means was found by subtracting μR from μL.

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Table ####: Measurements of Critical Parameters of 9 Subjects

The values of p indicated whether differences in the means were most likely due to chance. Comparisons between left and right side were judged statistically significant if $p < 0.05$, with 95% confidence. Five subjects, numbers 3, 5, 6, 7, and 9, had p values greater than 0.05 indicating that the left and right side gravireceptor biases were not statistically different. See Figure ####, of s. 5. Note the range of θ_{final} values which are both approximately between -2.5 and 0.2. However, subjects 1,2,4 and 8 had p values less than 0.05, indicating a significant difference between gravireceptor bias measured on opposite sides. What factors might have made their responses different ? S. 2 did not take as much time as other subjects (approx. ½ time) to find her subjective horizontal. S. 2 and s. 4 both reported feeling less confident with their judgment skills on the right side for some reason. See Figure #### below for a comparison of left and right sides of s. 4. Note the cluster of points around the respective mean values of -.2.86 and -0.42. The left side was consistently lower than the right side.

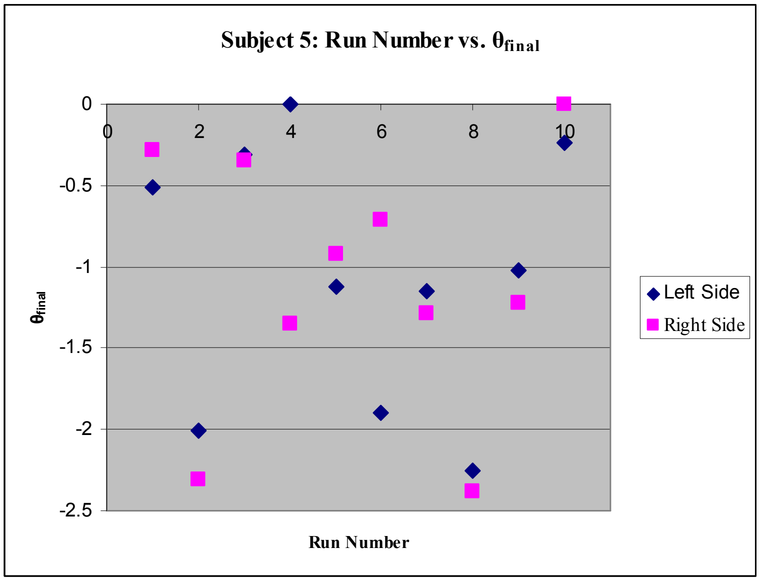

Figure ###: Subject 5, left and right side θ_{final} values, in degrees. Left and right sides produce similar mean values.

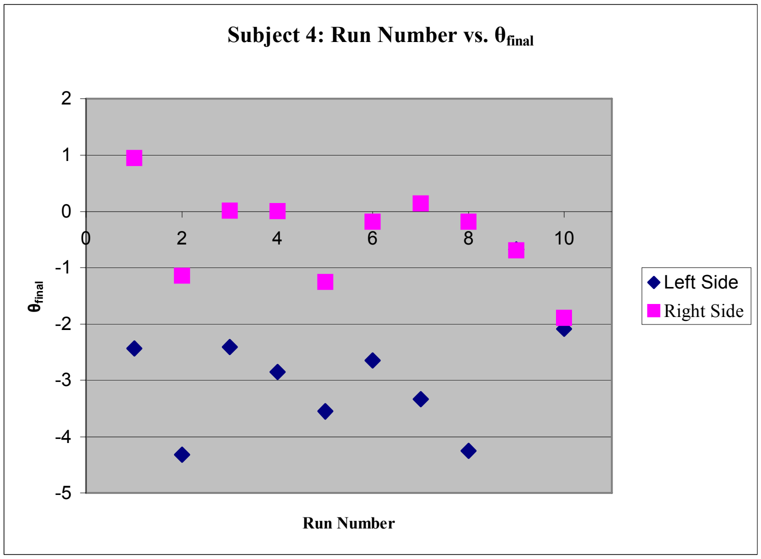

Figure ###: Subject 4, left and right side θ_{final} values, in degrees. Left and right sides do not produce similar mean values.

Since 5 of 9 subjects had a consistent mean between sides, for the purposes of further discussion, the data of the two sides was combined to a single metric of gravireceptor bias set for each individual. The new mean degree value was noted to be the best fit point for each subject's data set, noting that for certain subjects who respond differently on different sides, most points would not lie at this location, but instead at two separate peaks on either side.

3.2 Was there a significant difference between day 1 and day 2?

Four subjects (s. 2, s. 5, s. 6, and s. 9) returned for tilt bed testing on day 2. Day 2 ranged from one day later to five days later. (Note that only one of these subjects had a significant effect of side). See Figure ### for mean and standard deviation of θ_{final} on day 1 and day 2.

Subject No.	Mean θ_{final} µ (deg)		St. Dev.
2	Day 1:	-1.00	2.46
	Day 2:	-1.93	1.89
5	Day 1:	-1.06	0.78
	Day 2:	-2.11	1.60
6	Day 1:	-2.41	2.07
	Day 2:	-0.41	2.08
9	Day 1:	-3.26	2.10
	Day 2:	-0.83	2.37

Table ####: Mean and Standard Deviation of Day 1 and Day 2.

Figure ### shows the results of day 1 and day 2 graphically.

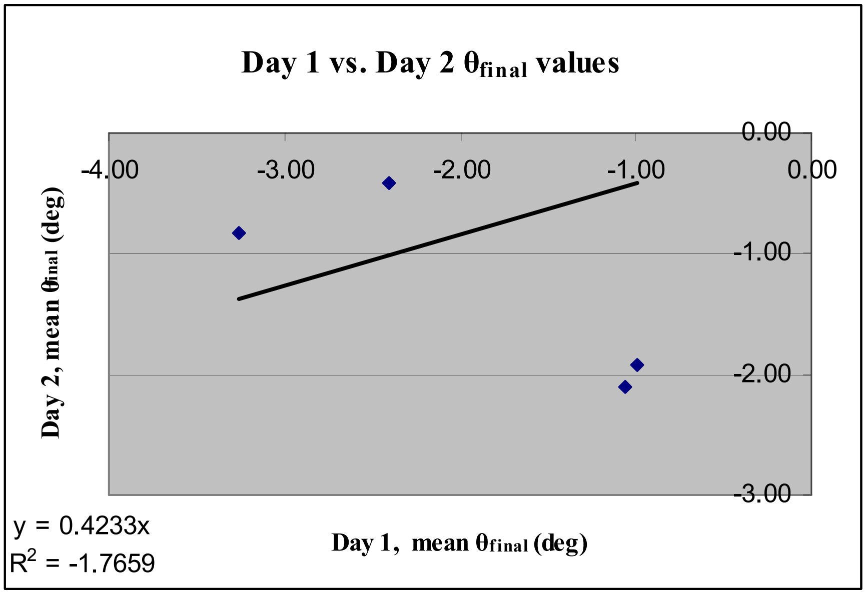

Figure ####: Day 1 vs. Day 2 θ_{final} values

These results were not significant to conclude correlation between day 1 and day 2. A trendline was fitted to the points, including the origin because the data should include this point. The R^2 value was 0.95 (N-2, where N=4) to prove correlation. If this was true, then the closer the slope was to -1, the better the correlation from one day to the next. However, the R^2 value was -1.7659. Definite conclusions could not be drawn either way because of the small number of subjects who were willing to return on day 2. More subjects should be obtained in order to increase numbers of subjects tested check the validity of the results.

3.3 Was there a significant difference between subjects in gravireceptor bias?

Table ### compares the θ_{final} of subjects 1-9, including standard deviation.

Subject No.	**Mean θ_{final} μ (deg)**	**St. Dev.**
1	-1.00	2.46
2	-1.93	1.89
3	-2.15	1.98
4	-1.64	1.56
5	-1.07	0.78
6	-2.14	2.06
7	-0.82	1.89
8	-0.91	2.07
9	-3.26	2.10

Table ###: Mean values and standard deviations of θ_{final} of subjects 1-9.

Graphically,

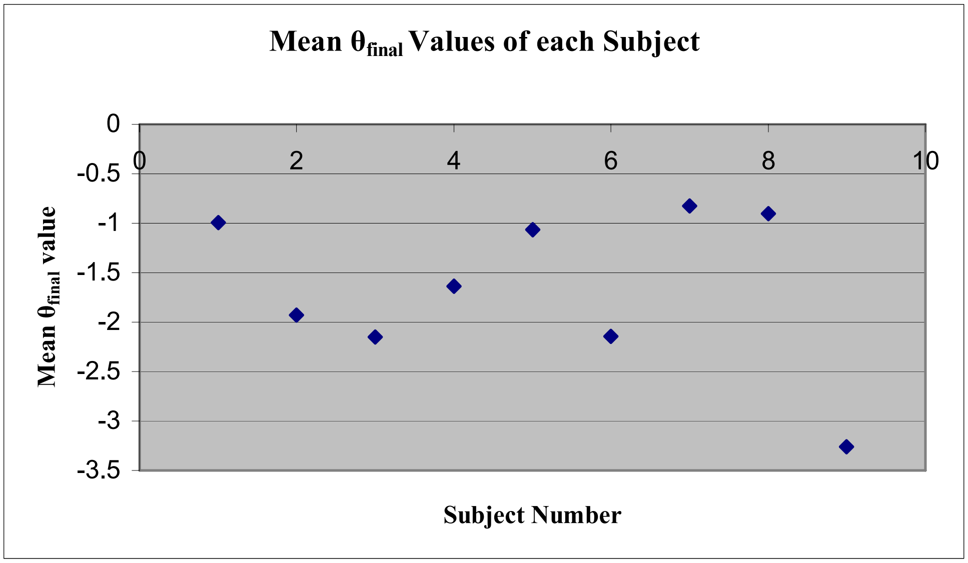

Figure ###: Mean Values, Subjects 1-9

The standard deviation of the gravireceptor bias was typically 2 degrees, and since the mean bias was computed from 20 measurements, the standard error in the mean is on the order of 0.5 degrees. Hence a difference in mean gravireceptor bias of more than a degree is probably significant. Even more precise comparisons between subjects can be made by making paired comparisons. For example, comparing s. 7 and s. 9 (See Table ####.) a paired t-test between subjects of θ_{final} for each trial on day 1, was used to calculate t and p (two-tail).

Subject No.	Mean μ (deg)	St. Dev.	Diff. of μ μ7 - μ9	deg. freedom	t	p two-tail
7	-0.82	1.80	2.44	9	6.86	3.66E-05
9	-3.26	1.56				

Table ####: Comparison of Subject 7 and Subject 9 on Day 1

The chance of the null hypothesis being due to chance is 3.66E-05. To graphically see the differences between s. 7 and s.9, see Figure ### below.

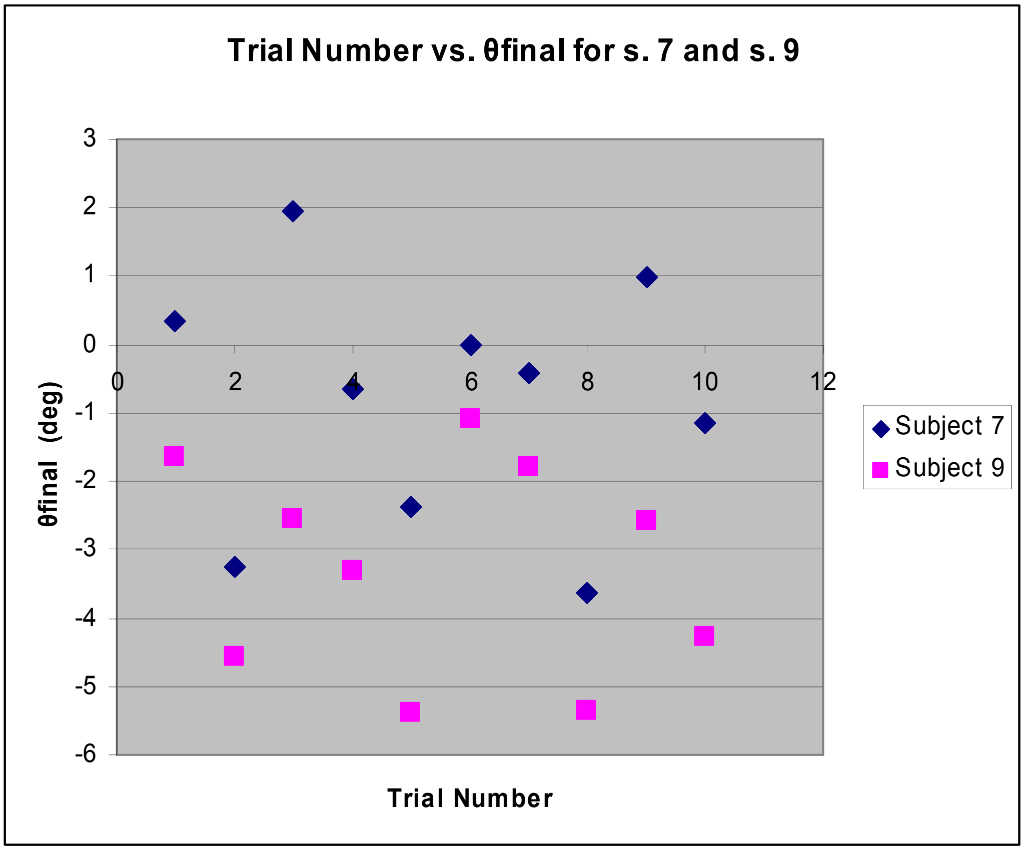

Figure ###: A comparison of s. 7 and s. 9 by trial number.

Clearly, s. 7's response to the subjective horizontal yielded consistently smaller θ_{final} values than s. 9 for each trial. Thus, s. 7 had a smaller average tilt bias than s. 9.

The differences between some people were apparent, although not every case had the same definite distinction between θ_{final} values. Most notably however, was the mean value of all subjects: -1.65 deg., s.d. +/-0.80 deg. Not a single subject among the group of nine tested had a positive (head up) mean gravireceptor. Given Mittelstaedt's finding of approximately equal numbers of subjects who have head up vs head down bias, this finding is somewhat surprising. Although differences in subject population may contribute, other factors could account for this outcome. For example, errors of five degrees in positioning of the body relative to the table or the position of the neck relative to the bed could have biased the current results. It is possible that equipment differences (i.e. material on the bed pad, use of a bite bar, or possibly even the location of the rotation axis) could have had a effect on the θ_{final} response.

4.0 DISCUSSION

Mittelstaedt's experimental setup differed from the present one. See Figure 27 below.

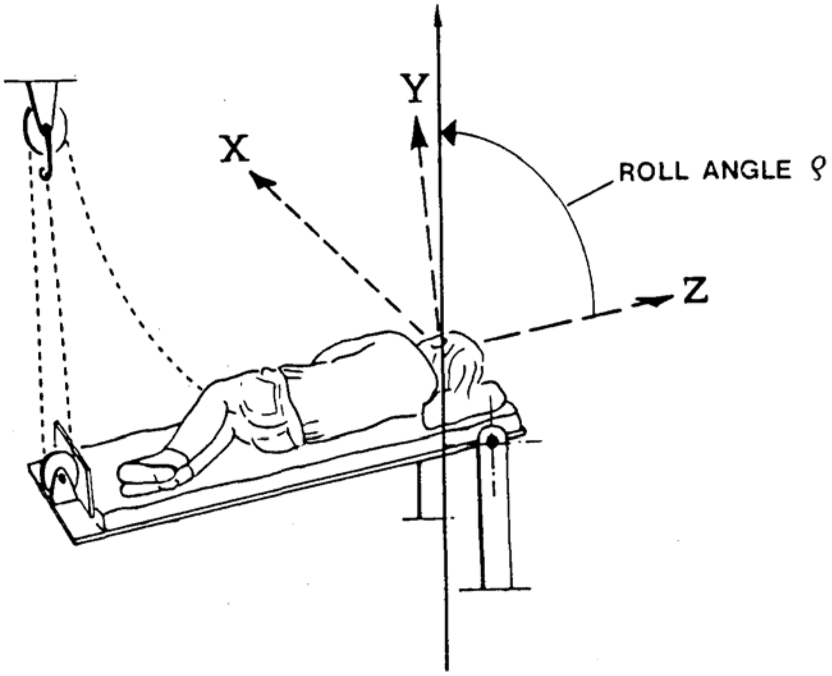

Figure ###: Mittelstaedt's Tilt Bed Apparatus

The rotational axis was at the head. A mechanical pulley system controlled raising and lowering of the table. However it is doubtful that these factors had any substantial effect on the results, because the tilt of the body was the same regardless of the position of the rotation axis and the method of rotation. With this setup and alternating head up and head down measurements, Mittelstaedt recorded 44 control subjects, 3 labyrinthine defective subjects, and 5 postflight astronauts over a number of years. See Figure 28.

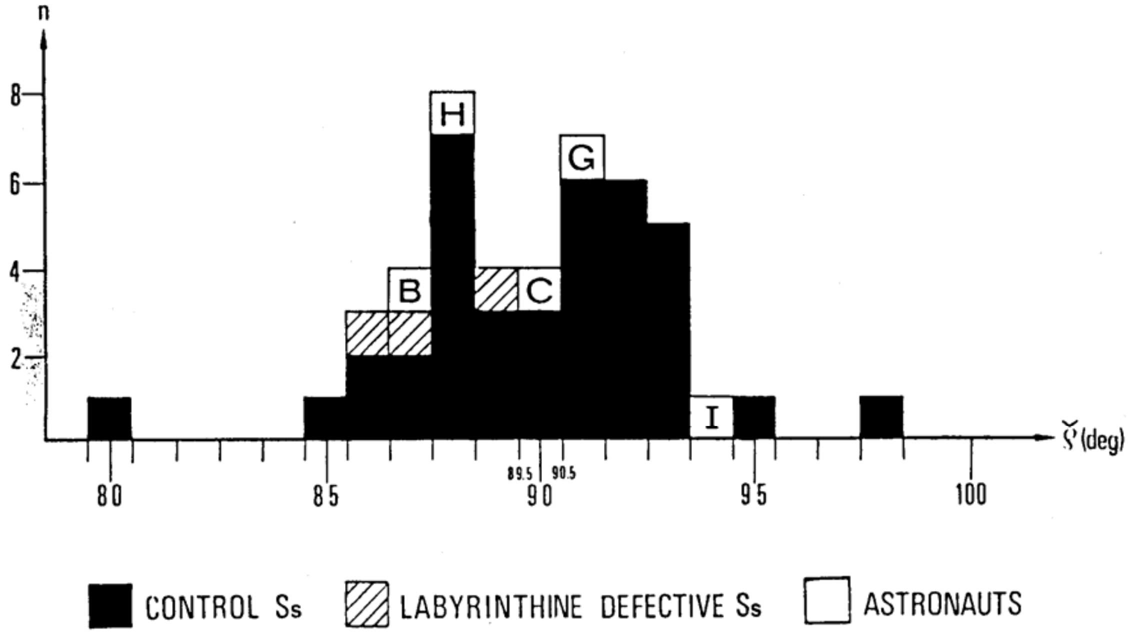

Figure ###: 44 Control Subjects, 3 Labyrinthine Defective Subjects, and 5 Astronauts

The reference point in Figure 28 was 90 degrees, i.e. 90 degrees from vertical. The results collected in this experiment centered at 0 degrees, or Earth's horizontal. Thus, these two reference points were physically identical. The mean of all subjects centered at 90 degrees, but individual means ranged from 85-95, ignoring the 2 outliers at 80 and 97. Part of his data was also taken on 5 astronauts. See Figure ### below.

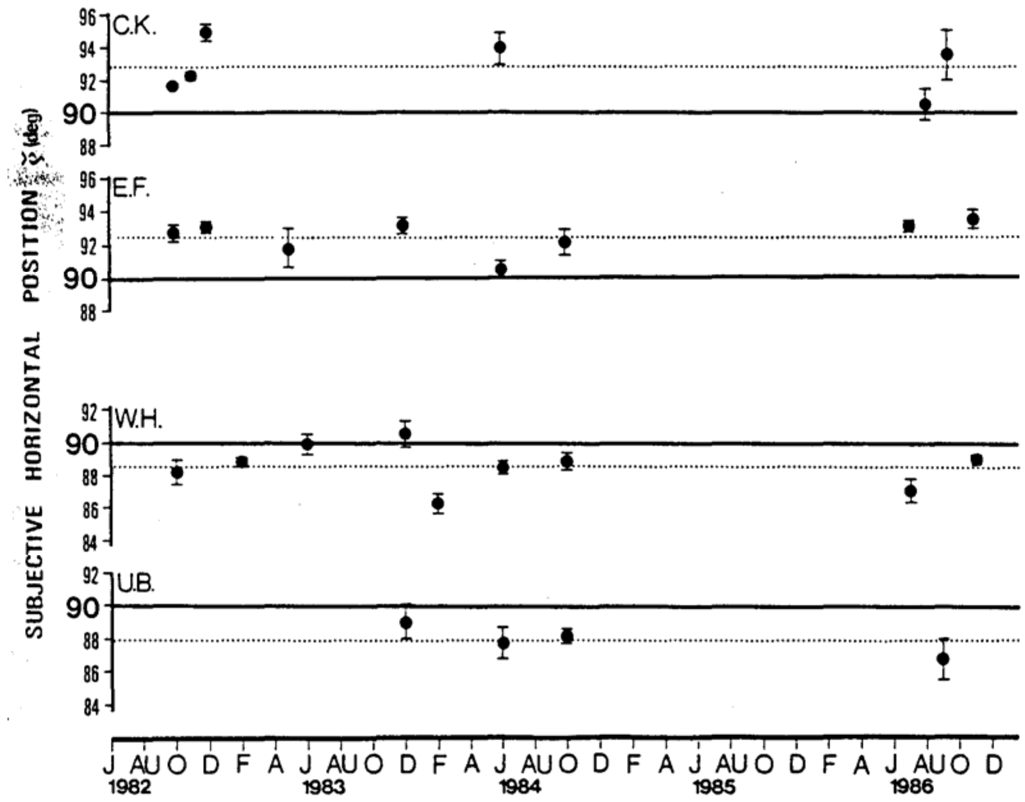

Figure 28: Mittelstaedt's Data of the Subjective Horizontal Plotted over 1982-1986

The results were that the means and s.d.'s were practically identical in astronauts and controls. Means values were: 86.9 +/-1.6, 86.9 +/- 0.4, 91.3 +/- 0.5, 88.3 +/- 1.0, and 93.5 +/- 0.7; standard deviation ranged from 0.2 to 1.6. Control (n=9) mean was 88.8 +/- 0.2.(Mittelstaedt, 1987). Results remained consistent over a number of years (1982-1986). Another important point was that Mittelstaedt combined data from the left and right side because his results correlated between the two sides. The most important point was that subjects had consistent biases that differed significantly from one another. Note that C.K., mean= 93.5 was clearly much different than U.B., mean 88.3.

The results from the present experiments differed from Mittelstaedt's. Discrepancies could have come from a number of factors, such as pressure from the bite bar, time from θ_o to θ_{final}, frictional cues from the table, or the subject population themselves. Some subject's tilt angle judgements were biased by initial starting angle, though the procedure used was designed to balance out this effect. Furthermore, left and right side responses were not always statistically the same in all subjects according to t-test values with degrees of freedom equal to nine. Also, we did no formal screening of subjects for vestibular function. It was possible –though unlikely - that individuals did in fact have unreported vestibular problems which could have distorted results. Furthermore, preliminary graphs of day 1 vs. day 2 results, of only 4 subjects, were analyzed. However, no strong correlation could be found, partially because of the small population size. It would have been best to perform tests on more than two days and on a much larger subject population. There were clear differences in the mean value between some subjects, but the most significant trend was the mean value of subjects. All subjects mean values lay below the zero degree mark. (-3.25 to -0.40) More research should be done to understand the reasons behind these results.

5.0 CONCLUSION AND RECOMMENDATIONS

Results of the present study did not completely replicate and confirm the study of Mittelstaedt. Both studies showed that subjects had gravireceptor biases which differed significantly between subjects. The standard deviation of the data (2 deg) was qualitatively similar or slightly larger than that obtained in Mittelstaedt's study. However Mittelstaedt's data in 4 subjects studied over a number of years showed a consistency not clearly seen in the present study. Also, Mittelstaedt's subjects showed both head up and head down biases, whereas in the present study all nine subjects had a mean gravireceptor bias which was head down. The mean bias of the nine subjects was -1.65 deg., s.d. 0.80. This population mean is shifted approximately 2 degrees from Mittelstaedt's, and had a smaller range of θ_{final} mean responses. It is possible that the subject population was biased, which would partially explain the unbalanced negative mean. However, other factors may have contributed: The bite bar used in the present experiments may have provided different proprioceptive cues and influenced the data. Further tests should be done on a larger sample population, and with and without a bite bar to determine if this was the case. The bite bar could be replaced with a permanent dental device to give more surface area within the mouth for added comfort and possible change in receptive cues, and the bedpad and sheeting material changed to have different characteristics. Other testing might include changing the degree angles of $\theta_{o.}$ It seemed like starting values of -10 and + 10 influenced the data set in some cases. Running less extreme values might alleviate this problem. Another option is to change the resting time of the subject, by leaving her longer on the table (t>10 minutes).

6.0 BIBLIOGRAPHY

Howie, Lindsay. 2001. COUHES Protocol, Application Number 2814.

Mast, Fred, and Thomas Jarchow. 1996. Perceived Body Position and the Visual Vertical. Brain Research Bulletin 40, 5-6.

Mittelstaedt, H. Somatic Graviception. 1996. Journal of. Physiol. 42:53-74.

Mittelstaedt, H. Determinants of Space Perception in Weightlessness. 1987. Perception & Action 146.

Schrenk, Prof. Janet. 2002. Error Analysis-Lecture 3. 5.310.