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Effect of Orientation on Human Posture in Neutral Buoyancy and Parabolic Flight

Julianne Zimmerman
Payload Systems Inc.

David L. Akin
University of Maryland Space Systems Laboratory

ABSTRACT

Neutral buoyancy (NB) and parabolic flight (PF) are the only presently available human-scale three-dimensional spaceflight simulation environments, and as such, both NB and PF are used extensively to simulate spaceflight conditions for both research and mission operations purposes. However, there is little or no quantitative (or even qualitative) material in the literature to characterize the fidelity of either environment to its analog. The present study was undertaken as part of a larger research effort to begin to build such characterizations. Eight healthy adults (4 men and 4 women) were asked to adopt relaxed postures while “standing” in space shuttle middeck standard-type foot restraints, in NB and during the 0g periods of PF. Subjects were tested in NB in 9 orientations, 3 trials each: Upright; tilted 45° Front, 45° Back, 45° Right, 45° Left; tilted 90° Front, 90° Back, 90° Right, and 90° Left. PF limitations on test time and physical volume prohibited 90° testing; consequently the PF test protocol included only the Upright and 45° orientations. All NB testing was performed at the bottom of a 25’ deep NB facility, using SCUBA certified, experienced test personnel. All PF testing was performed during four flights on the NASA KC-135. Subjects were fully informed of the test protocol prior to and during testing. Reaction loads were recorded for each foot independently and normalized to subjects’ masses; hip, knee, and ankle angles were measured from photographs. Trunk and shank angles (defined respectively by hip-shoulder ray and ankle-knee ray angles to the foot restraint plane) were also recorded. ANOVA (analysis of variance) calculations were performed for individual and group comparisons. All subjects completed all trials for NB; however, some trials were lost during PF, due to subject motion sickness. Nonetheless, statistically significant differences ($p<.05$) between orientations for each environment (e.g., PF 45F v. 45B) were present, in agreement with previous orientation results. Differences were also found between environments (NB v. PF), indicating that results from one are not necessarily applicable to the other.

INTRODUCTION

The best — and only — terrestrial “zero-gravity” simulation environments for human applications are neutral buoyancy (NB) and parabolic flight (PF). At first glance both seem to provide reasonable representations of the on-orbit microgravity environment they seek to model. Qualitatively at least, subjects seem to ‘float’ in both environments in much the same way they do in space, and after all there aren’t any foreseeable alternatives for simulating spaceflight conditions on Earth.

Anecdotal evidence from astronauts trained in neutral buoyancy for on-orbit tasks indicates that the training prepares the astronauts well for performing their prescribed tasks, but not for feeling acclimated to the on-orbit environment. In fact, many astronauts have reported a temporary sense of spatial disorientation during the first several minutes of performing a highly practiced task on orbit (particularly during extravehicular activity, or EVA), in direct conflict with an equally strong sense of familiarity with the task protocols and the objects in their visual fields. Furthermore, parabolic flight experience is not a predictor for space motion sickness (SMS), as there is no correlation between motion sickness episodes experienced by astronauts on the KC-135 and on orbit. These and other fragments of information indicate after fairly superficial examination that there is no strong correlation between the sensory landscapes of either NB or PF and spaceflight, or their respective interpretations by human sensory systems.

Under NB conditions, the subject’s body is balanced in the water such that his or her buoyancy is compensated exactly by his or her weight. The subject ideally has no preferred orientation, and neither sinks nor rises. During PF, an aircraft is flown in a Keplerian trajectory, producing periods of “zero gravity” (0g) alternating with periods of up to twice-Earth gravity accelerations. Several studies using different experimental approaches, and performed over a period of multiple decades [e.g., 1-6], demonstrated that human subjects evidence asymmetric responses to neutral buoyancy conditions, particularly with respect to orientation; similarly, Lackner and colleagues [e.g., 7, 8], among others, have also shown that human subjects experience a wide variety of perceptual effects during exposure to PF, and that these effects arise in response to both internal and external cues. However, the implications of these effects for the successful simulation of spaceflight conditions in NB and PF are not explicitly understood. Those implications must be clarified in order to improve the fidelity of human subject research and training exercises performed in these two environments.

We have previously reported [9] on some vision effects on NB and PF posture. The purpose of the present study is to examine the measurable effects of subject orientation on relaxed human posture in NB and PF environments, and determine if possible whether asymmetries similar to those previously reported for NB are also present in PF.

METHODS

In this study, quiescent, or neutral, restrained posture was studied during both sighted and blindfolded conditions in NB and PF. Tandem space shuttle middeck-type intravehicular activity (IVA) foot restraints were used, one under each foot. Each of these restraints consists of a flat nylon web strap attached to an aluminum plate. The plate is in turn attached to a sensor described below. The restraint is used by sliding the foot under the strap and then either dorsiflexing, plantarflexing, or rotating the ankle to exert an anchoring load on the restraint. Users may choose any or all of the available ankle or subtalar motions to hold themselves in position, and may alternate from one method to another during extended use or to adjust lower or upper body configurations.

Eight subjects (4 men, 4 women), all experienced NB test divers, volunteered to take part in the study. All subjects were fully informed of the test protocol and goals prior to giving their consent to participate. The average age of the subjects was 30.4 [range 26- 39]; average height 1.7m [range 1.6m – 1.9m]; and average weight 72.5kg [range 56.7kg – 94.3kg]. None of the subjects had any history of vestibular or other sensory dysfunction. After completing the NB testing, and all NASA-required training, medical clearances, and paperwork, all subjects reported for testing on the KC–135, and all were authorized for flight.

Prior to each test in either NB or PF, each subject was reminded of the protocol and goals for that test. All subjects were given the opportunity to familiarize themselves with the IVA-type foot restraints used in this study, prior to participating in the test. Subjects were instructed for each trial to adopt the most comfortable and relaxed posture for their own bodies and not to attempt to consciously adhere to any particular postural configuration, including either erect or compact posture. They were informed that the test conductor and subject handler would be responsible for providing them cues to enter or exit the foot restraints and also assisting them in moving safely and smoothly onto and off of the experiment apparatus. The subjects were asked to remain in the foot restraints for the duration of each trial unless they felt symptoms of disorientation or motion sickness interfering with their ability to continue. If they became fatigued, disoriented, or ill, they were instructed to notify the test conductor or subject handler for assistance in pausing or terminating their trials. In each environment, 3 successive trials were conducted for each condition. Each trial lasted 30 seconds (NB) or for the maximum available reduced gravity period after subjects were positioned comfortably (PF). Subjects were asked to exit the foot restraints at the end of each trial in the KC-135, to prevent risk of falling during the transitional and increased gravity periods.

Joint angle data were collected from still photographs taken during testing in both environments. The photographer was instructed to position himself as accurately as possible 3 meters from the subject and facing the subject's sagittal plane[1] (side view). One photograph was taken from this perspective for each trial. Postural angles were measured from the side view frames by locating the malleolus, (upper) head of the tibia and greater trochanter on the subject, comparing those locations with the subject's swimsuit and dive socks, and then marking and connecting the ankle, knee, hip, and shoulder joint centers on each still print. The error in this angle measurement method is estimated to be ±7°, based on results from a preliminary study [(unpublished)10]. The same method was used for collecting joint angle data on the KC-135, with the following exceptions: due to the limited dimensions of the aircraft cabin and the extremely short duration of each parabola, the photographer used a 28mm lens and positioned him/herself approximately 1-2 meters from the subject; due to the limited time available on the KC-135, the photographer was instructed to take two frames per parabola in an attempt to guarantee the availability of joint angle data.

IVA-type foot restraints as described above were attached to Assurance Technologies Gamma model sensors, which were in turn anchored to the test stand. Subjects were permitted to wear cotton socks during KC–135 testing and dive socks or booties during NB testing. This is consistent with astronaut use of the IVA foot restraints, as astronauts typically wear socks during on-orbit middeck activities.

[1] Under the lighting conditions present in the NBRF, 3m is an optimal focal distance of the Nikonos II underwater 35mm still camera used in this study. At that distance, the subject fills approximately 75-80% of the length of the frame.

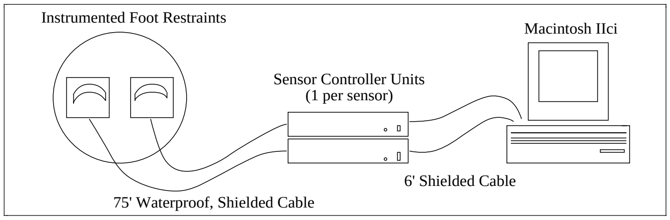

Figure 1. Data Collection System

A total of 12 channels of data were recorded through two controller units connected to the printer and modem ports on an Apple Macintosh IIci™, using a specially developed C language program. The data files were subsequently reduced using original MatLab® language programs.

RESULTS

Neutral buoyancy tests were conducted in the Space Systems Laboratory Neutral Buoyancy Research Facility (SSL NBRF) during one two-week period. All subjects completed all trials satisfactorily.

Parabolic flight tests were conducted on the NASA JSC KC-135 during one four-day mission. All subjects participated in at least one flight each. The author took part in three of the four flights. During one flight, the sensor data collection system failed; this means that for two subjects, there are only joint angle data and no reaction loads data. These are admittedly non-trivial holes in the data set. However, this outcome represents a realistically successful human subject parabolic flight campaign.

One subject was not included in the results presented for the group. The decision to exclude this subject's results was made on the basis of his extremely large reaction forces and torques, which were at least twice as large as the rest of the group in almost every case. Other subjects demonstrated unusually large or small reactions in a small number of cases, but no other subject consistently fell outside the group patterns. Thus this particular subject is thought to present a different self-stabilization strategy than the rest of the subjects, who appear to share more common patterns. This hypothesis will be discussed in a separate communication. The final subject pool for the present study thus consists of a total of 7 subjects, 3 male and 4 female.

ANGLE RESULTS — Angle measurement conventions were defined to be consistent with the Skylab model, as represented in Figure 2. In addition to the hip, knee, and ankle measures, two other angle measures were also tabulated: trunk and shank angles were defined by the intersection between the foot restraint plane and the trunk and shank (ankle-knee) rays, respectively.

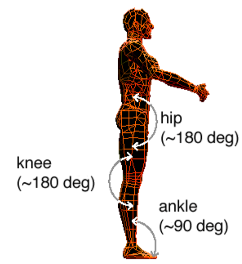

Figure 2. Postural Joint Angle Measurement Conventions

Hip, knee, and ankle angles are defined as shown here, to concur with the Skylab angle reporting convention. Trunk and shank angles are defined by the intersection between the foot restraint plane and the trunk and shank rays, respectively, such that both would be approximately 90° for an upright, erect figure such as the one shown here.

Individual subject postural angles were found by calculating the mean of each three-trial measurement series. These were averaged to produce mean values for the subject pool as a group. Postural angle means for the group are presented in Tables 1 and 2; graphical representation is provided in Figure 3.

Table 1. NB Postural Angles

Test Case	Postural Angles (degrees)				
	Hip	Knee	Ankle	Trunk	Shank
Upright (0°	144.9	145.1	101.2	88.2	88.0
45F	143.2	143.0	104.7	97.1	93.1
45B	140.1	150.8	103.1	80.4	90.5
45R	135.6	134.9	102.6	87.7	86.6
45L	147.2	132.3	103.5	85.9	87.9
90F	140.8	134.9	115.6	108.9	102.2
90B	135.8	143.0	99.8	86.4	89.7
90R	128.4	124.0	101.1	92.2	88.5
90L	131.4	127.9	99.2	90.5	87.2

Table 2. PF Postural Angles

Test Case	Postural Angles (degrees)				
	Hip	Knee	Ankle	Trunk	Shank
Upright (0°)	148.7	152.9	96.4	82.6	86.9
45F	133.5	138.4	106.8	84.4	89.5
45B	135.3	145.7	94.7	70.3	83.3
45R	135.7	144.7	93.5	76.8	86.5
45L	131.2	137.0	90.6	76.6	82.5

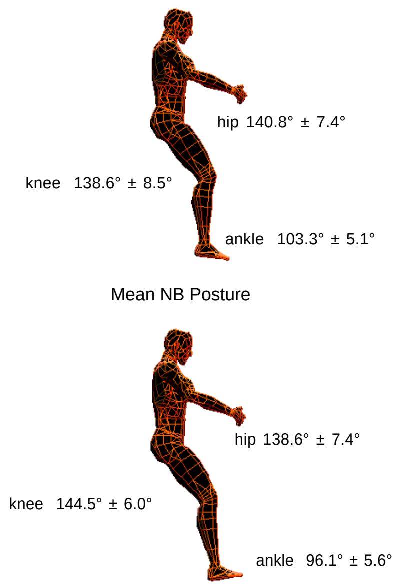

Figure 3. Mean Posture Angles for NB and KC

These figures are posed in each of the mean postures, to simplify visualizing the similarities and differences in the features of these mean postural configurations. Note that the figures are aligned by their trunks, to highlight the hip, knee, and ankle angles.

To determine whether the angle values provided in the above tables actually represent different postural patterns, or whether they are merely examples of postural arrangements which surround a single mean posture, ANOVA (analysis of variance) measures were calculated for several comparisons. Normally, results of $p \leq .05$ would be considered compelling for human subjects. However, in this case, because so many comparisons are performed, and the number of samples per test case is not constant, experiment-wise error is assessed to be greater than in the ideal case. For this reason, results of $.04 \leq p \leq .05$ are interpreted as statistically significant but perhaps not meaningfully so (marginally significant), and values of $p < .04$ are accepted to be not only statistically significant but also meaningful. Marginally significant outcomes are considered weak results and are denoted by an asterisk.

The first set of comparisons was performed to determine whether the test orientations in NB were distinguishable. The results of this set of comparisons are provided in Table 3. Curiously, the trunk angle is the only measure which exhibited significant differences between test orientations in NB. Neither the ankle angle nor the shank angle produced significantly different outcomes for either of the cases in which the trunk angle did.

Table 3. Results of ANOVA Comparisons between NB Test Orientations

	Hip	Knee	Ankle	Trunk	Shank
0 v. all 45s	—	—	—	—	—
0 v. all 90s	—	—	—	—	—
45F v. 45B	—	—	—	—	—
45R v. 45L	—	—	—	—	—
All 45s v. All 90s	—	—	—	.049*	—
45F v. 90F	—	—	—	—	—
45B v. 90B	—	—	—	—	—
45R v. 90R	—	—	—	—	—
45L v. 90L	—	—	—	—	—
90F v. 90B	—	—	—	.002	—
90r v. 90L	—	—	—	—	—

The next set of comparisons was performed to determine whether the test orientations in PF were distinguishable. These results are provided in Table 4. Although the knee angle clearly differs between the upright and 45 orientations, only the ankle angle differs between 45Front and 45Back.

Table 4. Results of ANOVA Comparisons between PF Test Orientations

	Hip	Knee	Ankle	Trunk	Shank
0 v. all 45s	—	.0068	—	—	—
45F v. 45B	—	—	.036	—	—
45R v. 45L	—	—	—	—	—

Test orientations were then compared between NB and PF, to determine whether the environments themselves were distinguishable. These results are given in Table 5. Here note that the ankle angle is the only measure which turned up a statistically significant difference, for 45Left and all 45 orientations.

Table 5. Results of ANOVA Comparisons between NB and PF

	Hip	Knee	Ankle	Trunk	Shank
0	—	—	—	—	—
45F	—	—	—	—	—
45B	—	—	—	—	—
45R	—	—	—	—	—
45L	—	—	.003	—	—
All 45s	—	—	.037	—	—

None of the other measures produced any significant outcomes, indicating that the two environments did not cause this subject pool to adopt consistently different postures, except at the ankle. Note that the trunk and shank angles were not statistically different between NB and PF; thus the ankle angles did not contribute to discernibly different postural tilts in these environments.

It is quite possible that some patterns may not be discernible because of subject variability, which was considerable. Interesting patterns were noted associated with both between-subject (group) and within-subject (individual) variability. The results of between-subject and within-subject analysis are in preparation and will be communicated elsewhere.

REACTION LOAD RESULTS — Root-mean-square values were calculated for each trial reaction load record. Those RMS values were normalized to each subject's mass, to eliminate scaling effects. Group means were then calculated; these are presented in Tables 6 and 7.

Table 6. Normalized NB Reaction Loads

	Fx	Fy	Fz	Mx	My	Mz
Left						
0	0.0392	0.1063	0.1741	0.0083	0.0224	0.0065
45 Front	0.0526	0.1320	0.1611	0.0112	0.0385	0.0086
45 Back	0.0688	0.0792	0.2346	0.0108	0.0444	0.0086
45 Right	0.0368	0.1077	0.2111	0.0092	0.0160	0.0084
45 Left	0.0416	0.1359	0.2623	0.0161	0.0328	0.0095
Right						
0	0.0508	0.0867	0.1904	0.0095	0.0296	0.0062
45 Front	0.0542	0.1129	0.1492	0.0095	0.0367	0.0082
45 Back	0.0580	0.0921	0.4106	0.0136	0.0460	0.0073
45 Right	0.0425	0.1623	0.2830	0.0163	0.0280	0.0074
45 Left	0.0465	0.0971	0.1716	0.0086	0.0200	0.0090

Table 7. Normalized PF Reaction Loads

	Fx	Fy	Fz	Mx	My	Mz
Left						
0	0.0102	0.0309	0.0876	0.0019	0.0090	0.0010
45 Front	0.0361	0.0283	0.0446	0.0027	0.0119	0.0013
45 Back	0.0601	0.0309	0.0677	0.0027	0.0248	0.0033
45 Right	0.0272	0.0328	0.1015	0.0027	0.0074	0.0025
45 Left	0.0373	0.0951	0.1692	0.0083	0.0115	0.0044
90 Front	0.0481	0.0414	0.0442	0.0021	0.0202	0.0026
90 Back	0.0747	0.0507	0.0307	0.0036	0.0283	0.0051
90 Right	0.0463	0.0394	0.1368	0.0046	0.0125	0.0043
90 Left	0.0511	0.1355	0.1679	0.0111	0.0093	0.0068
Right						
0	0.0135	0.0312	0.0965	0.0032	0.0116	0.0017
45 Front	0.0607	0.0342	0.1410	0.0037	0.0169	0.0015
45 Back	0.0548	0.0363	0.0849	0.0034	0.0257	0.0034
45 Right	0.0260	0.0973	0.1455	0.0097	0.0070	0.0043
45 Left	0.0350	0.0273	0.0997	0.0034	0.0083	0.0042
90 Front	0.0677	0.0464	0.0314	0.0040	0.0204	0.0024
90 Back	0.0829	0.0468	0.0518	0.0042	0.0316	0.0052
90 Right	0.0497	0.1164	0.1367	0.0088	0.0153	0.0073
90 Left	0.0484	0.0529	0.1629	0.0046	0.0088	0.0051

Once again, ANOVA analyses were conducted to identify the differences between test conditions. The outcomes of comparisons between test orientations in NB are provided in Table 8.

Here there are widespread but sporadic differences between test orientations in NB. However, note that there are across the board differences between 0 and 45 and also between 0 and 90 orientations for the Left foot, while for the Right foot, contrarily, the differences are much less marked. Interestingly, no significant outcomes arose for either foot in comparisons between 45Front and 90Front, or between 45Left and 90Left.

Table 8. Results of ANOVA Comparisons between NB Test Conditions

		Fx	Fy	Fz	Mx	My	Mz
Left	0 v. 45s	<.001	<.001	.003	.001	.004	<.001
	0 v. 90s	<.001	<.001	.035	<.001	.005	<.001
	45F v. 45B	.040*	——	——	——	——	.001
	45R v. 45L	——	.002	——	.039	——	——
	90F v. 90B	*	——	——	——	——	.006
	90R v. 90L	——	<.001	——	.018	——	——
	45F v. 90F	——	——	——	——	——	——
	45B v. 90B	——	——	.043	——	——	.016
	45R v. 90R	.025	——	——	——	——	——
	45L v. 90L	——	——	——	——	——	——
Right	0 v. 45s	<.001	——	——	——	——	——
	0 v. 90s	<.001	——	——	——	——	.013
	45F v. 45B	——	——	——	——	——	*
	45R v. 45L	——	.004	——	.031	——	——
	90F v. 90B	——	——	——	——	——	.030
	90R v. 90L	——	.027	——	——	——	——
	45F v. 90F	——	——	——	——	——	——
	45B v. 90B	.040*	——	——	——	——	——
	45R v. 90R	.020	——	——	——	——	——
	45L v. 90L	——	——	——	——	——	——

Analysis outcomes approached but did not achieve statistical significance for two cases: Left foot, 90F v. 90B; and Right foot, 45F v. 45B. The asterisk in these cases indicates that $.05 < p < .06$, which is not statistically significant for this analysis, but which suggests that these cases might prove significant if a larger subject pool were examined.

The PF comparison results are even sparser than the NB results. Here there are no statistical differences between 0 and the 45s. However, there are again sporadic significant differences in reaction loads between 45Front and 45Back and between 45Left and 45Right. It is again noticeable that the Left foot patterns differ from the Right foot patterns.

Table 9. Results of ANOVA Comparisons between PF Test Conditions

		Fx	Fy	Fz	Mx	My	Mz
Left	0 v. 45s	——	——	——	——	——	——
	45F v. 45B	.044*	——	——	——	——	——
	45R v. 45L	——	——	——	——	.020	——
Right	0 v. 45s	——	——	——	——	——	——
	45F v. 45B	——	——	.050*	——	——	——
	45R v. 45L	——	——	——	*	——	——

These results echo the asymmetries found in the NB reaction load data, but again, the cause of these asymmetries is unknown The lone asterisk indicates .05 < p < .06.

When NB and PF were compared, nearly two-thirds of the outcomes for the Left foot were significant, and over one-third of the outcomes for the Right foot were significant. As with angle results, subject variability was marked for both between-subject (group) and within-subject (individual) comparisons, which may well contribute to peculiarities in the NB V PF outcomes.

Table 10. Results of ANOVA Comparisons between NB and PF

		Fx	Fy	Fz	Mx	My	Mz
Left	Upright	.001	.046*	.001	.012	.014	——
	45F	——	.038	.001	.009	.001	.046*
	45B	——	——	.008	.043*	——	.044*
	45R	——	.016	——	.014	.027	.008
	45L	——	——	——	.008	.002	*
	All 45s	——	——	.011	.004	.002	.001
Right	Upright	.002	——	.006	——	.001	——
	45F	——	——	——	——	——	——
	45B	——	——	.002	.026	——	——
	45R	——	——	——	——	.049*	——
	45L	——	.036	——	<.001	.010	.025
	All 45s	——	——	.043*	.008	.027	——

The lone asterisk indicates .05 < p < .06.

Although these comparison results are not statistically significant across the board, NB and PF are clearly distinguishable: PF loads tend to be higher and differently distributed than NB loads for all orientation cases. However, it is plain that the Left foot reaction loads again generally differed more between NB and PF than did the Right foot reaction loads. ‘Footedness’ effects will be discussed in a later communication.

DISCUSSION

In light of the results described above, the following conclusions may be drawn:

(1) Subject orientation has an unclear effect on externally observable postural features (joint and body angles) in both NB and PF. Only scattered orientation effects were seen for postural angles (knee, ankle, and trunk), but no larger trends were apparent; wider patterns were demonstrated for reaction loads. There is definitely some effect associated with the 45Left orientation; effects are also apparent but inconsistent for 45° versus 90° inclinations and particularly Front versus Back attitudes. However, the causes or origins of these effects are unknown. These may well be signatures of sensory asymmetries, as proposed by earlier research.

For example, in 1960 Schock [2] found that subjects asked to locate the gravitational vertical or horizontal vector in NB generally, <u>but not necessarily always</u>, performed worse than in 'dry' laboratory conditions. He also reported a marked asymmetry in the errors, namely that when subjects were tilted leftward (as opposed to rightward), they produced their largest errors. In a similar study, Lechner-Steinleitner and Schöne [11] also found asymmetry in their subjects' ability to locate the vertical and further found that while subjects performed worse underwater than in dry conditions for high-inclination cases ($\geq$ 120°), they actually performed better in 'wet' conditions than in dry conditions for low-inclination cases ($\leq$ 60°). These results concurred at least in part with Schöne's earlier study [3]. Brown [5] reported marked dissimilarities between front and back orientations; Knight [1] found that his subjects were occasionally unable to identify orientation changes as large as 190°, in concurrence with Quix [6] (as cited by Brown and Knight). Nelson [4] found that orientation perception accuracy varied both with subject and with orientation, but subjects showed a marked pitch forward bias in conjunction with a smaller rightward tilt bias, “in at least moderate agreement with … previous studies.”

Asymmetries were thus expected in the present study neutral buoyancy results, but the cause of these asymmetries is still not understood. Furthermore, it was not known whether similar asymmetries might be found for parabolic flight. We found that PF does produce similar asymmetries to those in NB, although the specifics of the patterns associated with each environment are as yet unclear.

The rationale behind the design of this experiment was that it should illuminate the effects of subject orientation on reduced gravity posture, at least in the available simulation environments. Given the small subject pool and the number of variables examined, it is remarkable that more than a few significant findings would emerge. The fact that so many significant outcomes appeared in spite of these limitations gives the current results greater emphasis.

(2) Posture maintenance appears to demand a greater exertion level in parabolic flight than it does in neutral buoyancy, as evidenced by the fact that the PF reaction loads were higher than the NB reaction loads. In every orientation common to both environments, comparisons between NB and PF produce statistically

significant outcomes. This should not be surprising, due to the greater stimulus set presented by PF. Although we prefer to think exclusively about the reduced gravity periods of PF when planning experiments, subjects experience cyclic loading, along with cyclic lighting, noise, visual field, and vibration stimuli, which should be considered as central features of the entire PF environment, rather than as disturbances around the desired 'weightless' periods. PF subjects respond to increased gravity stimuli just as they respond to reduced gravity stimuli [e.g., 12], and it makes sense to expect that PF subjects respond and acclimate to the entire cyclic experience, rather than only the part we choose to study for a given research project. Qualitatively, subjects in the present study reported feeling much less relaxed than in NB, and many experienced mild to severe motion sickness at some point during the flights. This is not unusual, and is ready evidence that PF challenges the human body (and mind) in different ways than NB.

(3) Foot restraints allow subjects in some sense to maintain "neutral posture," but not entirely so. The foot restraints seem to impart a compelling reference frame and organization to subject posture — they cause the subjects to orient themselves approximately orthogonally to the foot restraint plane, and the IVA-type restraints in particular demand the subjects produce a dorsiflexion of the ankle to remain in the restraints. This makes intuitive sense. The foot restraints do not impose a categorical orientation, however, as demonstrated by the differences between ankle angles in neutral buoyancy as opposed to parabolic flight.

In the present study, subjects were predicted to (a) straighten their postures somewhat from the muscular demands of using the restraints, and (b) assume the orientation reference frame offered by the foot restraint surface, and "stand" more or less orthogonally to that plane. However, the cues offered by the foot restraint surface and strap are likely subject-dependent, since subjects were allowed to exert as much force and/or torque as they felt necessary to maintain their stances. There is a wealth of evidence that such cues might have compelling influence on subject self-perception (and by extension, posture) under terrestrial conditions, but that evidence is not necessarily *directly* applicable to reduced gravity conditions [e.g., 8]:

> "On the earth, or in level flight, a blindfolded subject being rotated at constant velocity about his recumbent long body axis experiences illusory orbital motion of his body in the opposite direction. By contrast, during comparable rotation in the free-fall phase of parabolic flight, no body motion is perceived and all sense of external orientation may be lost; when touch and pressure stimulation is applied to the body surface, a sense of orientation is reestablished immediately "

and yet,

> "...in the absence of other imposed linear accelerations the otolithic and touch-pressure receptor systems no longer yield effective orientational information when the gravitoinertial force is less than $\simeq$ 0.2g"

Thus the foot restraints themselves may pose interesting orientation effects. At least in the present study these are unquantified. But they seem likely significant for both parabolic flight and neutral buoyancy. Since most NB and PF studies involve restrained subjects, this question should not be overlooked.

(4) Finally, then, the postural joint angle and reaction force data provide evidence that the results presented in this paper do not describe the workings of a purely mechanical system – that is, the postural patterns exhibited by the restrained subjects in either neutral buoyancy or parabolic flight (and probably in the space shuttle middeck as well) are not explicable solely by the mechanical properties of their body segments. Although a relaxed and unrestrained body in either NB or PF may theoretically seek a posture determined almost entirely by agonist-antagonist muscle pair equilibria (and in neutral buoyancy, segment buoyancy / mass balance relationships associated with limb inertias, densities, fat content, etc.), such a case isn't really useful for operational research purposes (and may not be readily achievable in PF). Furthermore, the joint angles reported here clearly are not determined exclusively by these factors, as demonstrated by the existence of orientation effects, and the joint angle and reaction load data agree in indicating that subjects employ different joint configurations across orientations in NB as compared to PF.

Latash and Anson [13] propose that 'normal' movement strategies are not constant, as many of us may consciously or unconsciously assume them to be, but determined by individual capabilities, and especially plastic in response to damage to any part of the neuromusculoskeletal structure. It seems a very small step, then, to argue that surely "normal" movements are also plastic with respect to settings with altered gravity cues, and that the specific features of normal movement in those environments might differ dramatically. Neither NB nor PF offers particularly high-fidelity representation of spaceflight conditions, and based on the current findings, NB and PF cannot be assumed to be interchangeable environments. How then should we manipulate test conditions in NB and PF, in order to make optimal use of the simulations?" Although that question remains open, orientation is clearly a relevant factor in both settings.

CONCLUSION

Postural configurations adopted by test subjects in NB and PF are found to differ in curious ways: statistical analyses showed that between-orientation and between-environment discrepancies are present, but lacking patently coherent patterns. These results support earlier results for NB but suggest somewhat different patterns for PF, thereby supporting the notion that the human body, individually and in general, perceives and responds uniquely to orientation in these two environments.

Further studies currently in preparation will report on subject and 'footedness' effects.

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REFERENCES

The following are cited explicitly in this paper. For a more extensive bibliography, please contact the main author.

1. Knight Maj LA. 1958. An Approach to the Physiologic Simulation of the Null-Gravity State. *J. Aviation Medicine* 29:283-286.
2. Schock GJD. 1960. Perception of the Horizontal and Vertical in Simulated Subgravity Conditions. *US Armed Forces Med. J*. 11(7):786-793.
3. Schöne H. 1964. On the Role of Gravity in Human Spatial Orientation. *Aerospace Medicine* 35 (8): 764-772.
4. Nelson JG. 1968. Effect of Water Immersion and Body Position upon Perception of the Gravitational Vertical. *Aerospace Medicine* 39:806-811.
5. Brown, JL. 1961. Orientation to the Vertical During Water Immersion. *Aerospace Medicine* 32:209-217.
6. Quix, FH. 1928. Un Nouvel Appareil pour L'Examen du Nystagmus de Position. *J. Neurologie et de Psychiatrie* (Brussels) 3:160.
7. Lackner JR. 1992 . Spatial Orientation in Weightless Environments. *Perception* 21:803-812.
8. Lackner JR and Graybiel A. 1979. Parabolic Flight: Loss of Sense of Orientation. *Science* 206: 1105-1108.
9. Zimmerman, J and Akin, D. 1997. The Influence of Vision on Human Postural Maintenance in Neutral Buoyancy and Parabolic Flight Microgravity Simulation Environments. *Proceedings of the 27th ICES.* Society of Automotive Engineers, Warrendale PA.
10. Zimmerman, J. 1996. Results of Preliminary Study on Postural Comparison between Simulation and On-Orbit Environments. SSL Report 96-005. University of Maryland Space Systems Laboratory.
11. Lechner-Steinletner S and Schöne H. 1980. The Subjective Vertical Under 'Dry' and 'Wet' Conditions at Clockwise and Counterclockwise Changed Positions and the Effect of a Parallel-Lined Background Field. *Psychological Research* 41: 305-317.
12. Marcus JT, Kuipers A, and Smoorenburg GF. 1993. Otolith Responses in Man During Parabolic Flight. *Experimental Brain Research* 96: 328-334.
13. Latash, ML and Anson, JG. 1996. What are "Normal Movements" in Atypical Populations? *Behavioral and Brain Sciences* 19:1, 55-68.

CONTACT

Please direct correspondence to Ms. Zimmerman at Payload Systems Inc., 247 Third Street, Cambridge MA 02141 USA; or zimmerman@payload.com. Dr. Akin may be reached at the University of Maryland Space Systems Laboratory, Building 382/NBRF, College Park MD 20742 USA; or dakin@ssl.umd.edu. The SSL website is located at http://www.ssl.umd.edu.