Final Technical Report:
KC-135 Flight Opportunities for Undergraduate Program

Floatin' Rams

Biomechanical Evaluation of the Straight Leg Deadlift Technique in Microgravity using the Constant Force Resistive Exercise Unit (CFREU)

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July 2001

KC-135 Quick Reference Data Sheet

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Experiment Title: Biomechanical Evaluation of the Straight Leg Deadlift Technique in Microgravity using the Constant Force Resistive Exercise Unit (CFREU)

Flight Dates: July 12 – July 20

Overall Assembly Weight (lbs.): ~100lbs.

Assembly Dimensions (LxWxH): 60X24x74

Equipment Orientation Requests: No Preference

Proposed Floor Mounting Strategy: Blots/Studs

Gas Cylinder Requests: None Requested

Overboard Vent Requests: No

Power Requirement: 1 outlet: 110 Amp. 60Hz.

Flyer Names for Each Proposed Flight Day:

DAY 1	**DAY 2**
Erin McFadden	Michael Blackledge
Donny Newsom	Dave Bower

Abstract:

In space, muscles atrophy due to the lack of a gravity vector against which to do work (Convertino, 1996). Countermeasures against muscular atrophy have become a focus with the International Space Station (ISS) and regular long-durations in microgravity. Our proposed KC-135 experiment investigates the efficiency of the straight leg deadlift (SLD), a required resistive exercise performed in microgravity. Our hypothesis is that due to the lack of gravity and stabilization devices, the current straight leg deadlift done in microgravity is prone to incorrect form and thus may be recruiting non-targeted muscle groups, therefore creating a possibility of injury to astronauts.

To investigate muscle response in microgravity during a muscle strengthening routine, we will use the Constant Force Resistive Exercise Unit (CFREU). The CFREU is a gravity-independent exercise unit designed at Colorado State University in 1999 and 2000, to provide constant resistive forces on muscles. Current microgravity exercise devices do not provide **constant** resistive forces necessary on muscles to replace gravity. We propose to utilize the CFREU machine during the SLD exercise technique due to its ability to provide a constant force. Thus, allowing for quantitative analysis of muscle activity in the hamstrings and erector spinae muscles, using a surface electromyography (sEMG) machine.

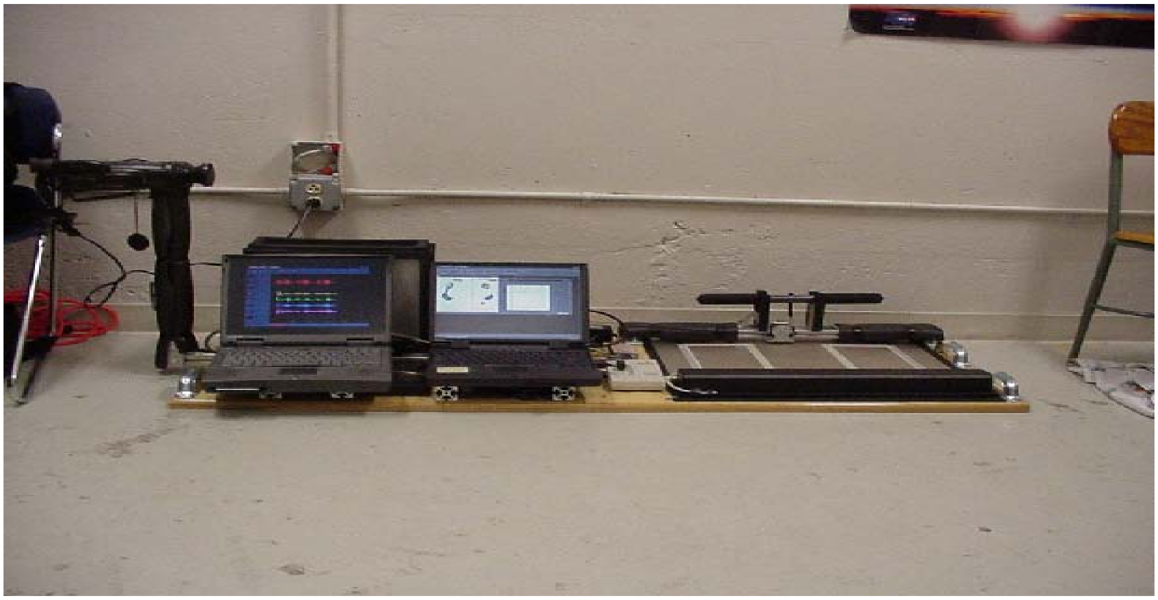
Research indicates that during stance in humans, equilibrium is preserved when the projection of the center of mass onto the ground is located within the foot support area. (Mouchnino, 1996) Thus, we will use pressure sensors to analyze subjects weight distribution fluctuations at their feet. Using a slightly modified CFREU, sEMG's, pressure sensors, and video motion analysis to investigate any difference between exercise technique and posture in gravity and microgravity, we will investigate the validity and efficiency of the current exercise protocol and equipment which will be necessary for extended stays in microgravity such as on the ISS.

Results/Discussions/Conclusions:

This section of the report is divided into three concentrations. For each of our three data acquisition systems (sEMG/BioRadio®, foot pressure analysis/Tekscan, and video analysis/Peak Performance), scientific findings, results, discussions, and conclusions were done individually. First, there will be a short introduction to each of the three systems. Next there will be some procedures and results. Finally there will be a discussion and conclusions section for each data acquisition system included here will be the perceived effectiveness of each system. Erin McFadden was primarily responsible for the sEMG analysis. Josh Porter and Michael Blackledge were responsible for the Tekscan analysis. Donny Newsom and David Bower were responsible for the video analysis.

Surface Electromyography Analysis using Bio-Radio:

Final Results and Conclusions Report 2001
SEMG Analysis using the BioRadio 110 system



The Colorado State University Floatin' Rams Exercise Unit
Summer 2001

Introduction

This experiment's focus was to analyze any differences in exercise technique in microgravity to gravity in order to examine the current NASA exercise protocol. focusing on the straight leg deadlift. In order to examine any differences in exercise technique in the two different environments, three different data analysis systems were used, surface electromyography, a pressure sensor and video analysis. It was the initial hypothesis that microgravity and gravity data would differ among individuals within these three systems. The results of this research indicates that there is different exercise technique and posture in microgravity compared with gravity during the straight leg deadlift, which could lead toward injury among astronauts if used during long duration missions in zero gravity such as on the International Space Station.

Methods

The BioRadio 110 system was used to analyze the muscle activity in microgravity and gravity within four muscle groups during the straight leg deadlift (SLD) exercise. The erector spinae, hamstrings (semitendinosis), tibialis anterior and the gastrocnemius muscles (mm) were examined because these muscles (mm) are used during the SLD as the stabilizer, main flexor muscle unit, and postural control respectively.

More specifically, the erector spinae mm (lower back) was chosen because it is used as a stabilization mm during the straight leg deadlift, which means it aides in balance and the control of movement throughout flexion of the trunk. Specifically, the erector spinae is composed of three different mm extending the length of the spine and we are examining the lower and largest muscle, longissimus. This muscle is the chief extensor of the vertebral column it is also the target mm for back injury and could possibly be overused in a situation of poor posture.

The gastrocnemius, or calf muscle is responsible for raising the heel during walking and flexing the leg at the knee joint. This muscle was examined during the SLD because it reflects differences in knee flexion between microgravity and gravity exercise techniques.

The tibialis anterior was examined purely for interest in its role in posture changes between microgravity and gravity testing. Because this mm attaches to the base of the 1st metatarsal and medial condyle of the tibia, it will detect any postural change at the foot.

The hamstrings and specifically the semitendinosus mm, was chosen because it is the main activator mm in the straight leg deadlift exercise. The hypothesis was that there would be less activity in the hamstrings during microgravity than in gravity due to recruitment of other muscles.

There were two different flight days, July 17th and 18th , each of these days two individuals engaged in the experiment aboard the KC-135: Day 1 (Michael Blackledge, Erin McFadden) and Day 2: (Donny Newsom, David Bower). The flight pattern consisted of 30 data-possible parabolas and two SLD exercises were attempted per parabola (25sec). A preset uV scale was used to view the individual mm during flight and during data analysis, these were, erector spinae(350), hamstring(450), Gastroc(350), Tibalis(200). Additionally, a sampling rate of 200Hz, transmitter RF Frequency of around 900mH and low and high filter passes on all channels were used.

<u>Analysis</u>

There were four ways to analyze the BioRadio sEMG data; peak to peak, RMS, integration and FFT. All of these options were explored and it was determined that peak to peak analyzation only gives a rough estimate of overall values. Therefore, RMS was used to find the quantitative differences between individual's data in microgravity and gravity. The RMS data can show increased or decreased amounts of activity within an individual muscle group when gravity data is compared to microgravity data. Additionally, the analysis program provided by Bioradio was used to perform a Fast Fourier Transform (FFT) analysis. Although FFT is a more unconventional means of measuring sEMG values, it was used to see when and in what mm slow-twitch mm begin to dominate total mm energy. This is seen by an overall average of lower frequency and indicating possible fatigue and poor posture. See Fig 1.0 for specific function methods for RMS data in Excel.

Fig. 1.0

(1) To translate bd files to Excel files you have to export individual files (to .dat) after they are open in BioRadio.
(2) To graph raw data in Excel open file (.txt), Delimited/Tab style and graph X/Y scattered points.
(3) To get specific RMS values take the +ABS(column#) of each individual column graph these and $RMS=(1/N * \Sigma(i^2))^{1/2}$

Results

Significant differences in muscular activity were found in all of the chosen muscle groups between microgravity and gravity trials. First, the data was analyzed using the RMS analysis in Excel and found that all the erector spinae, gastrocnemius, and tibialis anterior muscles show an increase their RMS average in microgravity and hamstrings show a decrease. This is due to the erector spinae, gastrocnemius and tibialis anterior muscles activating as the stabilizer and postural muscles in the microgravity environment, which provides no stability. In other words, the most active muscle in gravity, the hamstrings, became second in activity due to recruitment of these other muscles in order to correct posture. See Fig. 2.0. Second, there was an overall increased muscular activity indicated when comparing a microgravity test to a gravity test in BioRadio's view mode. This is due to the lack of stability in microgravity again causing the body to increase its communication to the examined muscles to attempt to stabilize the body into a perceived correct posture. See Fig. 3.0. Thirdly, there was a greater difference in the asymmetry between right and left muscle group activity in microgravity. This analysis was done by comparing the RMS graphs of each individual muscle group between gravity and microgravity data using the DSP program. This indicates again a less stable or symmetric posture in microgravity when the right or left side of the body shows more muscular activity than the other. See Fig. 4.0. Finally, some indication of muscular fatigue was found in the erector spinae muscle group using the DSP program and FFT or spectral analysis. This was discovered through examining and comparing microgravity BioRadio files individually for right and left erector spinae groups and noting any divergence toward lower frequencies over time in microgravity trials. The indication of fatigue is an increase in lower frequency signals over time. See Fig. 5.0.

RMS Data from Flight Day 2

* indicates higher average RMS values

Donny Microgravity

	Erector Spinae	Hamstrings	Gatroc	Tib. Ant	Erec.Sp(l)	Hamstrings(l)	Gastroc(l)	Tib. Ant(l)
RMS	166.135052	48.35633368	59.86462	40.42006	112.8604	72.51445357	41.04037	100.8843
RMS	151.3314879	47.90494395	60.79979	40.67608	155.1501	73.28479479	46.13485	111.897
RMS	188.106333	52.37244917	58.9753	43.84833	235.8362	67.62799996	41.64639	126.7391
RMS	188.5505916	58.98510616	57.72501	43.19424	161.3105	75.58937953	45.46745	101.195
RMS	187.6838492	45.06039194	64.31404	42.65488	145.8921	67.27887152	40.128	82.66012
RMS	235.1786861	54.72146651	56.66418	39.38696	127.4351	96.0220426	46.46854	113.4971
RMS	213.1242485	48.89934645	63.7983	40.92212	152.4383	86.15633831	52.98754	151.2845
	***190.0157498**	**50.90000541**	***60.30589**	***41.5861**	***155.8461**	***76.92484004**	***44.83902**	***112.5939**

Donny PreGravity

	Erector Spinae	Hamstrings	Gatroc	Tib. Ant	Erec.Sp(l)	Hamstrings(l)	Gastroc(l)	Tib. Ant(l)
RMS	137.6219858	51.93542486	27.05319	20.24545	111.6094	42.54592555	35.13203	14.9676
RMS	74.19869362	54.27789373	20.12631	19.27872	65.58372	53.97405691	20.42589	24.27724
RMS	199.9705785	91.62586136	26.06905	32.1092	157.1765	69.13582615	29.91184	36.80568
RMS	110.3167901	60.59737408	22.08794	18.63621	69.23135	56.26875163	25.52547	24.35262
RMS	82.84884078	51.2003445	22.84882	20.96472	62.65532	49.44302928	27.31557	25.90434
RMS	102.0539641	56.94174425	19.48184	22.96409	69.56081	53.40609092	19.49836	26.73131
RMS	125.1984129	52.71572337	18.99778	22.69161	74.96729	50.78018319	18.91098	27.00123
RMS	114.4810796	54.38110031	24.71641	23.39677	71.75032	50.14103946	25.31897	31.04661
	118.3362932	**59.20943331**	**22.67267**	**22.53585**	**85.31683**	**53.21186289**	**25.25489**	**26.38583**

Donny Post Houston Gravity

	Erector Spinae	Hamstrings	Gatroc	Tib. Ant	Erec.Sp(l)	Hamstrings(l)	Gastroc(l)	Tib. Ant(l)
RMS	135.6025364	46.94812965	24.35186	16.45293	101.4999	38.8143766	25.51632	16.47411
RMS	137.6219858	51.93542486	27.05319	20.24545	111.6094	42.54592555	35.13203	14.9676
RMS	184.7495737	51.26762965	20.90053	20.15476	154.7246	37.74312397	24.66227	16.75643
RMS	100.8045449	46.64658658	29.65104	19.43401	101.838	34.31121693	31.24104	20.98058
RMS	109.9114417	50.40561379	27.21526	16.85108	111.5238	37.54766444	24.98535	17.65215
RMS	163.0748678	43.68852823	22.56071	16.96082	158.2031	29.39863905	28.83497	16.25185
RMS	126.6211328	35.47511276	24.21199	16.71696	129.0544	22.70586249	24.89946	16.31904
	136.9122976	**46.62386079**	**25.13494**	**18.11657**	**124.0647**	**34.72382986**	**27.89592**	**17.0574**

Fig. 2.0

BioRadio View Mode

Gravity

Microgravity

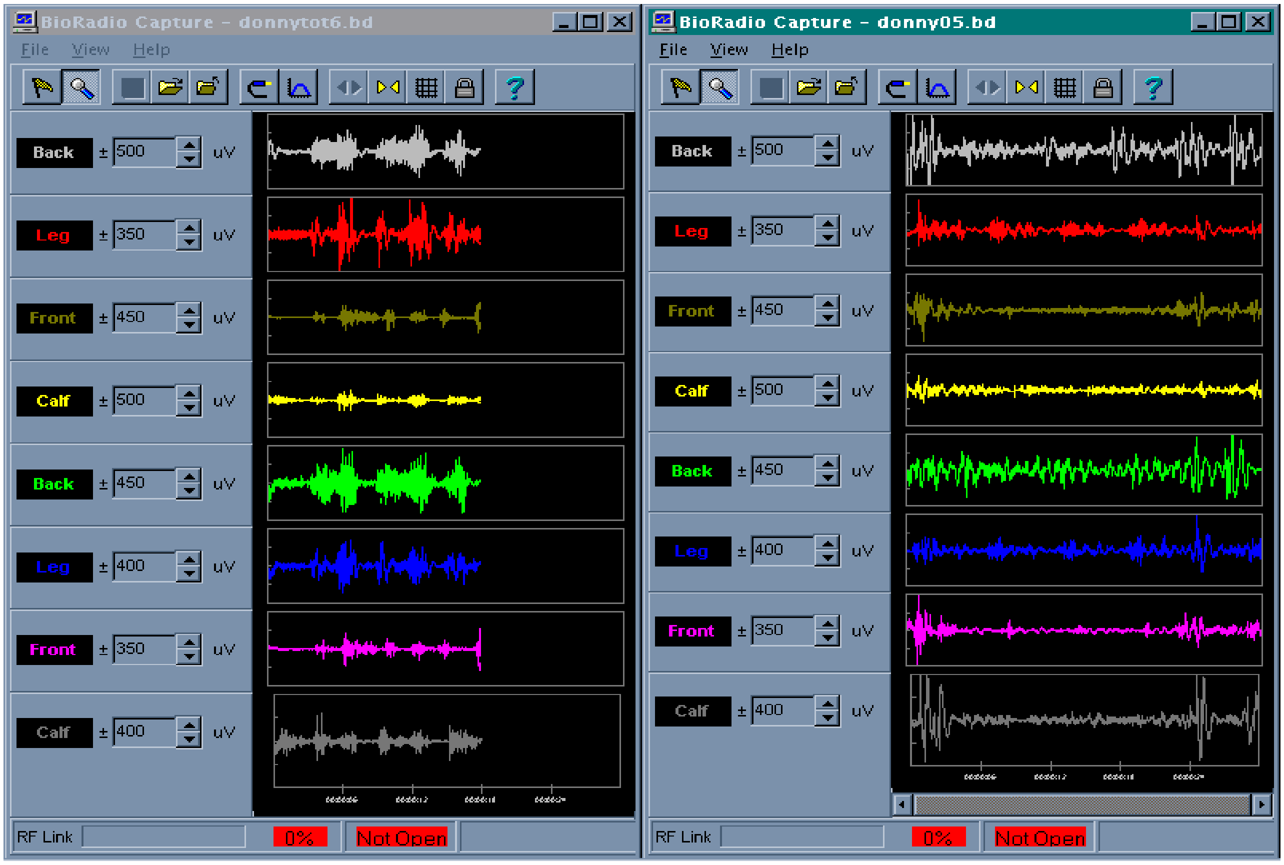


Fig. 3.0

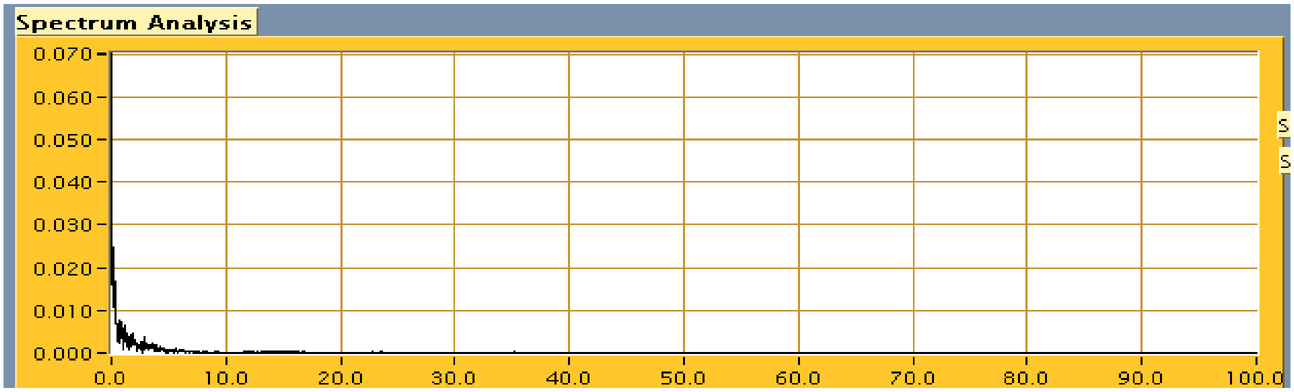
Donny Microgravity

	Erector Spinae	Hamstrings	Gatroc	Tib. Ant
Right Side	190.0157498	50.90000541	60.305892	41.5861
Left Side	155.8461103	76.92484004	44.839019	112.5939
Difference	**45**	**26**	**26**	**71**

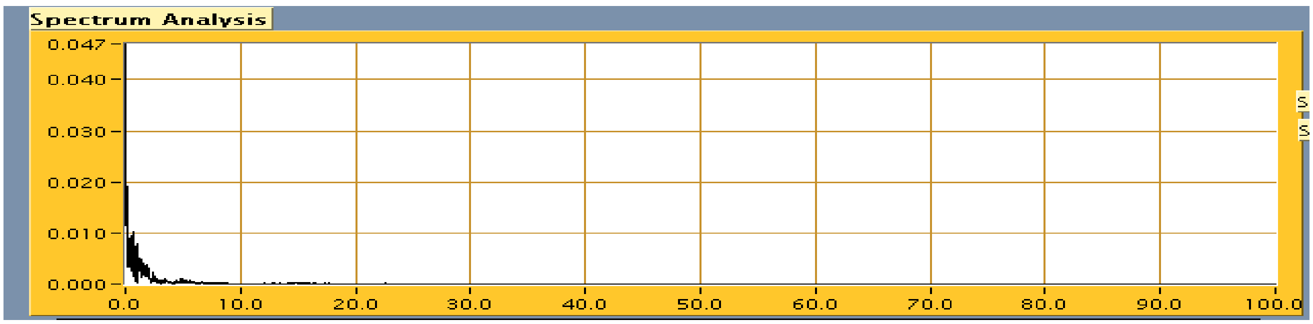
Donny Gravity

	Erector Spinae	Hamstrings	Gatroc	Tib. Ant
Right Side	308.3520429	110.1094387	82.97856	64.12194
Left Side	241.1629392	82.97856035	70.093907	138.9797
Difference	**67.18910375**	**27.13087837**	**12.884653**	**74.85778**

Fig.4.0

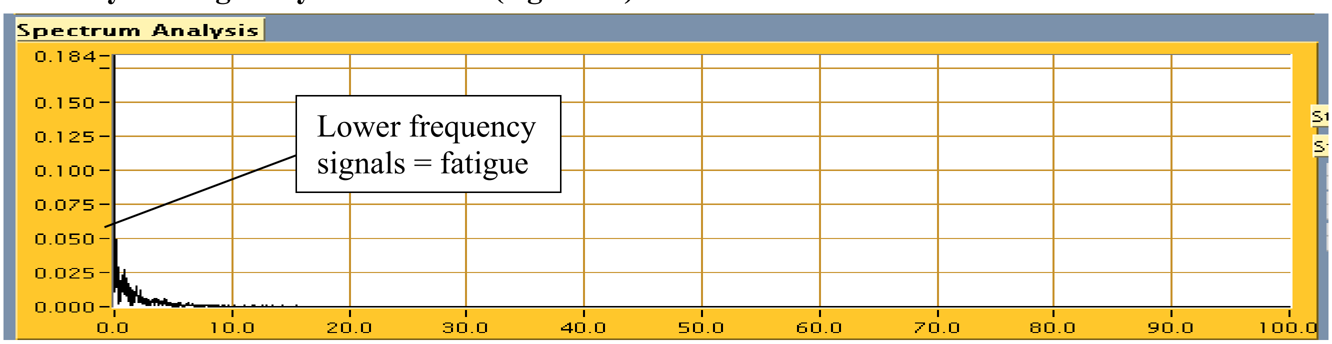


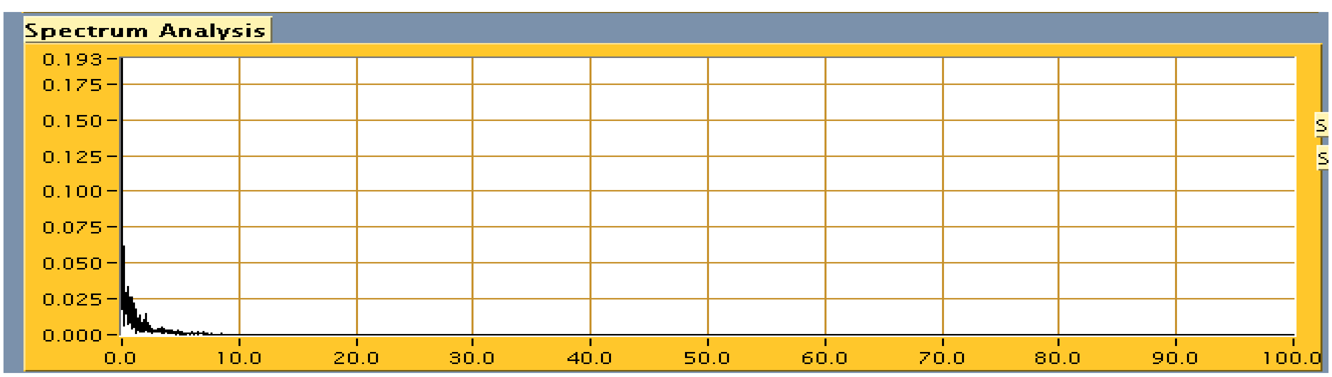
Donny Microgravity Parabola 1 (Rightside)



Donny Microgravity Parabola 1 (leftside)

Donny Microgravity Parabola 10 (rightside)





Donny Microgravity Parabola 10 (leftside)

Erector Spinae Spectrum Analysis Microgravity (Fig. 5.0)

Conclusions and Recommendations for further investigation:

Overall, it is safe to say that there is a significant difference between muscle activity in microgravity and gravity while doing this exercise. When the surface electromyography data is examined separately from the other data analysis systems, a few conclusions can be made about the effects of the microgravity environment on the overall muscular electrical activity. First, due to the change in environment and lack of gravity the body attempts to right itself through increasing the movement of ions across a muscle unit (sarcomere) and increasing the electrical signal detected in all of our examined muscles during exercise. This can be expected in any change in environment or excitable situation, however, it is interesting to note that even during exercise there is very little variation between concentric and eccentric muscular activity in microgravity as seen in gravity. Fig. 3.0 This indicates that the muscles, which contract regularly in gravity, were activated erratically during the same exercise in microgravity. This is a reflection of the body trying to stabilize itself into a correct posture without a gravity vector to work against and to create a need for concentric and eccentric contractions.

Second, from looking at the differences in muscular symmetry in the two environments one can conclude that it was more difficult to stay balanced in microgravity because of the large differences in right and left side activity of the same muscle groups. Thirdly, we found that even within on set of microgravity data the erector spinae muscle shows more fatigue than it does in gravity. This may be a result of the increased excitement but it also could indicate an increased possibility for lower back injury due to changes in the exercise technique in microgravity.

On the first flight day only obtained three parabolas of BioRadio data were collected on Erin due to difficulty adjusting to the microgravity environment (motion sickness). On the second flight day we were able to get 7 good sets of BioRadio data on Donny and none on Dave due to difficulty in transmission (the ground electrode slipped off). Thus, there was little microgravity data to analyze. If future analysis is attempted aboard the KC-135 in July, the temperature should be considered because sweat caused from high humidity and heat caused the electrode stickiness to be compromised. Additionally, small adjustments can effect the BioRadio signal, including concentrating on a specific muscle group and breathing control during the exercise. In future analysis, it is recommend that these be practiced from the beginning. Needless to say, the data gathered confirmed our hypothesis about change in exercise technique in microgravity and gravity and because of this it should be high priority of NASA to reexamine their current exercise protocol to help prevent astronauts from possible injury and to aide in the fight against muscle atrophy.

Foot Pressure and Center of Force Analysis using Tekscan:

Final Results and Conclusions Report 2001
Foot Pressure and Center of Force Analysis using Tekscan

Introduction:

The CSU "Floatin' Rams" team used two basic tools to study the posture of a patient in two very different environments (gravity and microgravity). These tools were Tekscan, the focus of this section, and the other was Peak Performance video analysis. As mentioned earlier, it has been shown that bones and muscles atrophy in space due to the lack of proper use. Currently, NASA uses an exercise protocol, which includes the straight leg deadlift, the focus of the experiment conducted by the CSU team. The team chose the straight leg deadlift because it is a staple in the exercise regime for astronauts and also because it exercises muscles in the lumbar region which have been shown to be the most significantly used muscles for walking.

Procedures:

The exercise begins by the patient bending down at the waist with slightly bent knees and grabbing a bar with weight. (Fig 1a). With the feet spaced shoulder width apart, the lifter then brings the weight to his waist keeping his knees bent through the range of motion. (Fig1b) As a point of interest, most of the lifters weight is supposed remain on the heels. (This ensures better posture) The exercise is a dangerous one due to how easy it is to perform with poor posture, which certainly leads to back injury. This again was another motivation for the team to examine this exercise and particularly the posture of the patient in microgravity.

Fig 1a

Fig 1b

One can gain insight into posture by examining the pressure distribution of a patient's foot while he is performing the exercise. For example, if there is more pressure on the ball of the foot, this means that the patient is leaning forward and balancing himself on the balls of his feet. Also by tracking the Center of Force (COF) through the range of motion (dynamic and static portions), one can determine how much and when a patient is leaning or altering his posture during the lift. Using the Tekscan system, the team has gathered these pieces of information. Tekscan provided the team with a full system including the pressure sensing mat, the docking ports, and software. This naturally made the job of data collection much easier. Figure 2 shows how the CSU team incorporated the Tekscan hardware into the machine. The flat pad on the right is the Tekscan pad. The laptop computer on the right is displaying a previously recorded pressure distribution of a patient's foot.

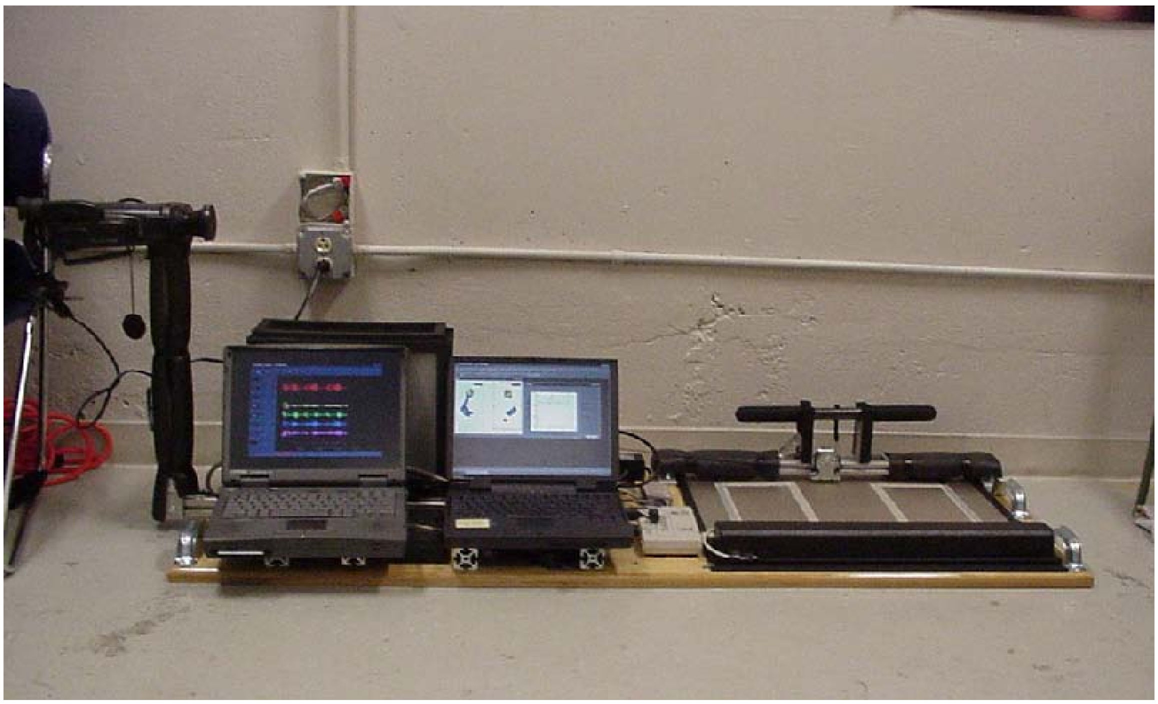


Fig. 2

<u>Analysis and Results</u>:

The team examined three people, Erin McFadden, Donny Newsom, and David Bower. The following portion of this section is a breakdown of their performance of the straight leg deadlift in gravity and microgravity. Hundreds of movies were recorded and watched very carefully. Information concerning posture and foot pressure distribution was noted for all the recordings taken in both environments. In the interest of time only a couple pictures and graphs, which are representative of all the recordings, are included in this report. However, conclusions drawn later in the report are made from all the recordings. Many Tekscan tools were studied when considering the posture analysis. The team chose to use the COF tracking information and peak pressure areas as the main tools for quantitative analysis. By saving a movie as an ASCII file and opening it in Excel, one can see the information about the test run and a list of COF locations throughout the entire movie. This proved to be very useful. One can tell how much and when a patient leans forward or back by simply observing when the COF changes locations. The location of the COF is also designated to a time or data point as a reference. Some very important trends in how a patient does this exercise with correct posture in gravity were discovered using this tool. It was realized that in the first dynamic movements of the lift starting from the bent position, the patient's COF jumps forward toward the toes of the foot. Then, most of the weight should be placed on the heels of the foot to stabilize the patient for the remainder of the motion. Fig 3 is a graph of the COF location when Erin did a typical lift in gravity. Note that she performed the lift twice. One can see the peak of the COF in two locations, this is where she was in the bent position beginning to raise herself.

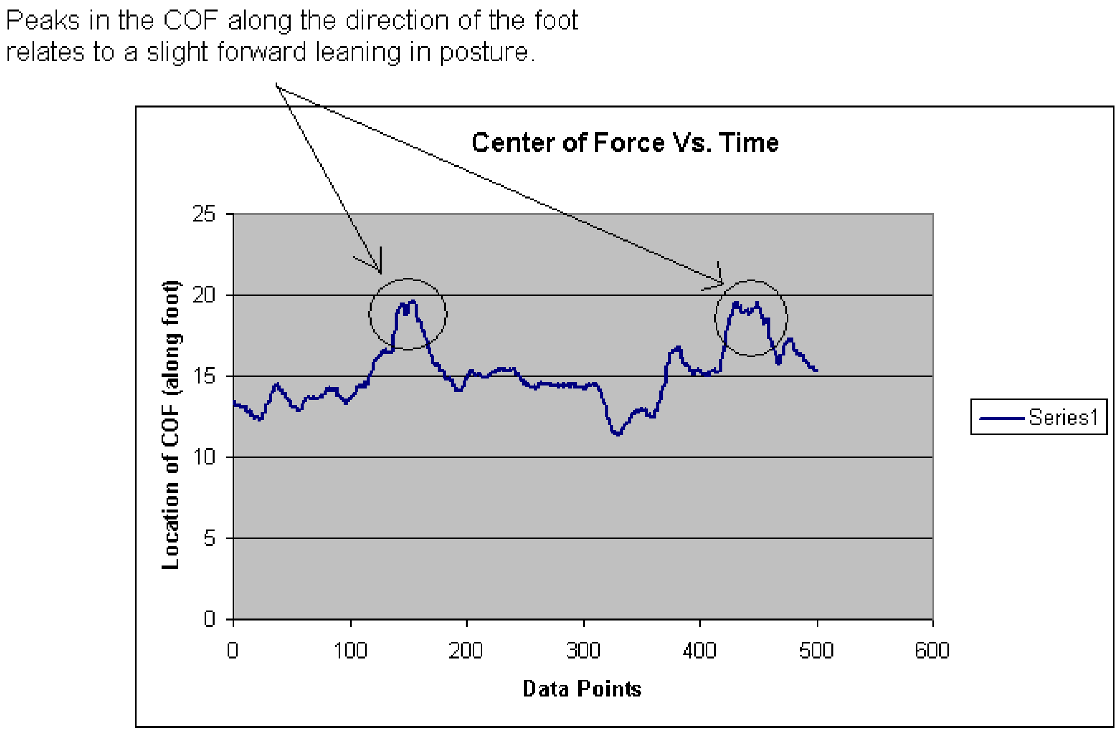


Fig. 3

Some analysis was done before the team went to Houston to fly. In the next portion of this section, preflight posture analysis is discussed for the three patients and then directly compared with the data taken on board the KC-135 (zero gravity environment).
After many movies were watched and analyzed, some conclusions were drawn about how Erin performs the exercise in gravity. As expected, Erin rocks forward very slightly as she begins the lift from the bent position. This is seen in Fig. 3. Also, it was discovered that on a typical lift, Erin balances herself with one of her big toes on one foot and the heel of the other during the dynamic portions of the lift. This can bee seen in Fig. 4. Note the black boxes on each of the foot imprints. The boxes represent the highest pressures on the foot. Note also the checkered boxes. These are the COF locations, one for each foot and then one in the middle for an overall COF.

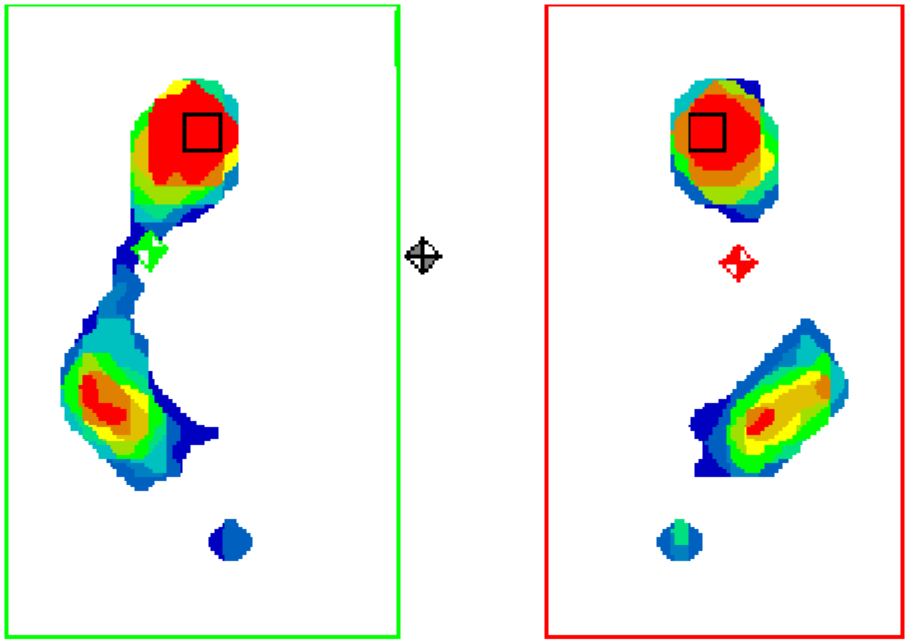


Fig. 4

As seen in other sections of this report, Erin's posture was completely different in microgravity. She was leaning forward significantly. This can be seen in Tekscan by noting that all the pressure is placed on the ball of the foot. Notice in Fig. 5 that the two spots of sensor activation are only the balls of her feet. This says that she is leaning forward and it is confirmed strongly by the video motion analysis. The team chose to display this information with a 3-D color display, as it is easier to see what is happening. The foot is placed on the mat such that the back of the display is the heel and the front is the toe. Note sensor activation only on the front.

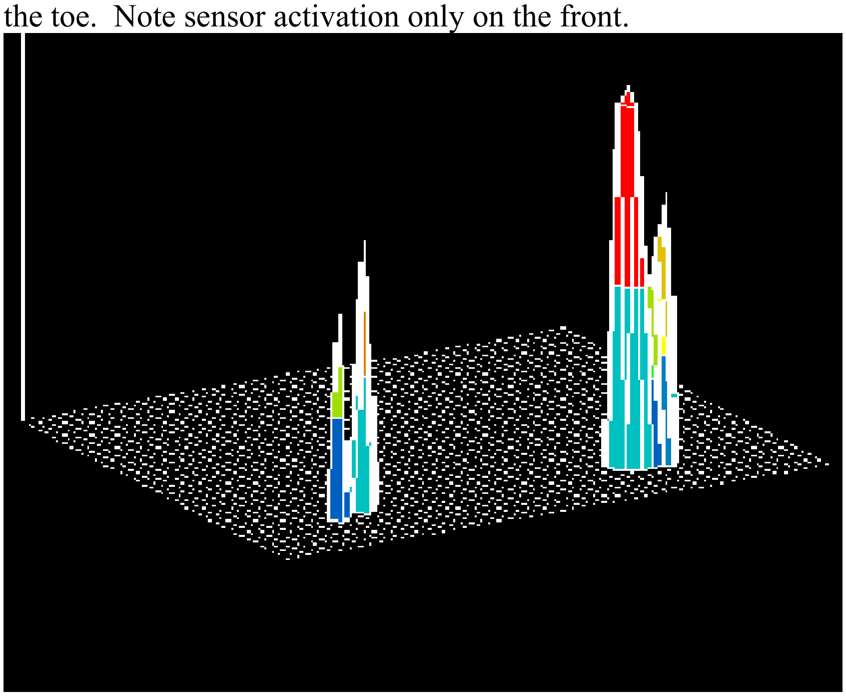


Fig. 5

Needless to say, the peak pressures on the foot were always on the balls of the feet for the entire range of motion for Erin.

Donny performs the lift with slightly different posture in gravity compared with Erin. Donny puts almost all of his weight on the heels of his foot over the full range of motion. However, Donny does still rock slightly forward when lifting up from the totally bent position. When tracking his COF for typical trials, this was confirmed and appears similar to Fig. 3 so it won't be shown again. In Fig. 6, one can see that Donny does put most of his weight on his heels. The snapshot was taken when he was in a dynamic portion of the exercise. Note how far back Donny keeps his COF, almost right on his heels. Again, the black boxes represent the peak pressure locations and the checkered boxes locate his COF.

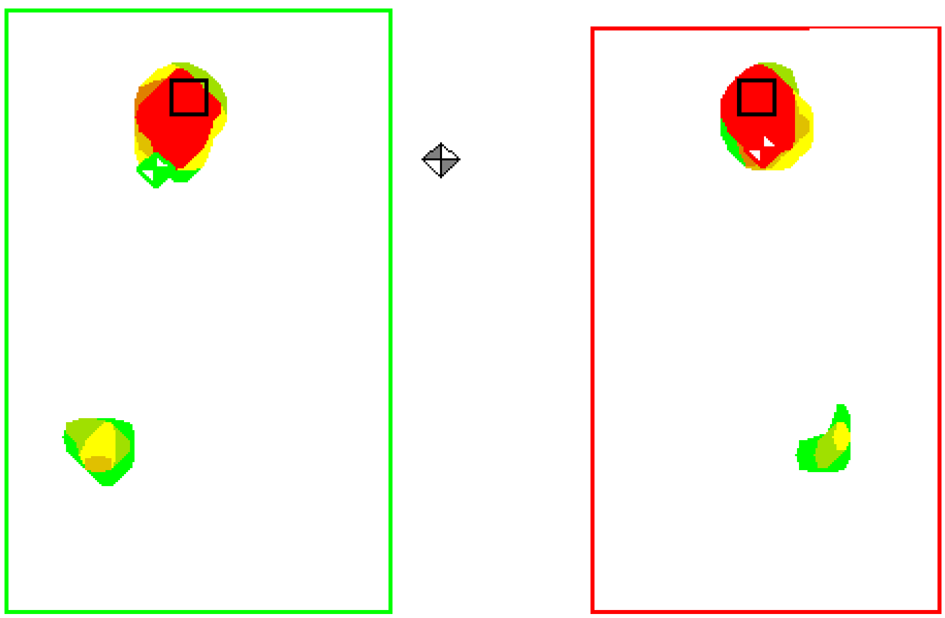


Fig. 6

Donny flew on the second day and was able to remedy some of the problems incurred on the first day. On the first day, the patient leaned forward significantly. To fix this, Donny and Dave flew on the second day with a tether, which helped them stay more upright. Donny and Dave (flyers on the second day) were able to do the exercise in a vertical position. Even so, Donny still put all of his force on the balls of his feet. This can be seen in Fig. 7. It was expected for Erin to have all the force on the balls of her feet since she was leaning so far forward. When the results returned saying that Donny, whose posture remained mostly upright, put all the force on the balls of his feet, this suggests that there may be a more internal posture problem for Donny in microgravity. As mentioned earlier correct posture of the straight leg deadlift calls for the patient to place most of his weight on the heels of the foot, which Donny does in a gravity environment. If the weight is placed on the ball of the foot this could suggest a couple of things. First, the patient is leaning forward, or second, that the patient is doing the lift with an arched back. Since video analysis shows us that Donny isn't leaning too far forward, this points to an arched back as the problem. Doing a straight leg deadlift with an arched back has been shown to lead to chronic back injury. However, do to unexpected conditions of the microgravy, which are discussed later in this section, the conclusion that Donny was doing the exercise in a posture that leads to back injury is not absolute. Fig. 7 is a 3-D color display and looks similar to Erin's microgravity data.

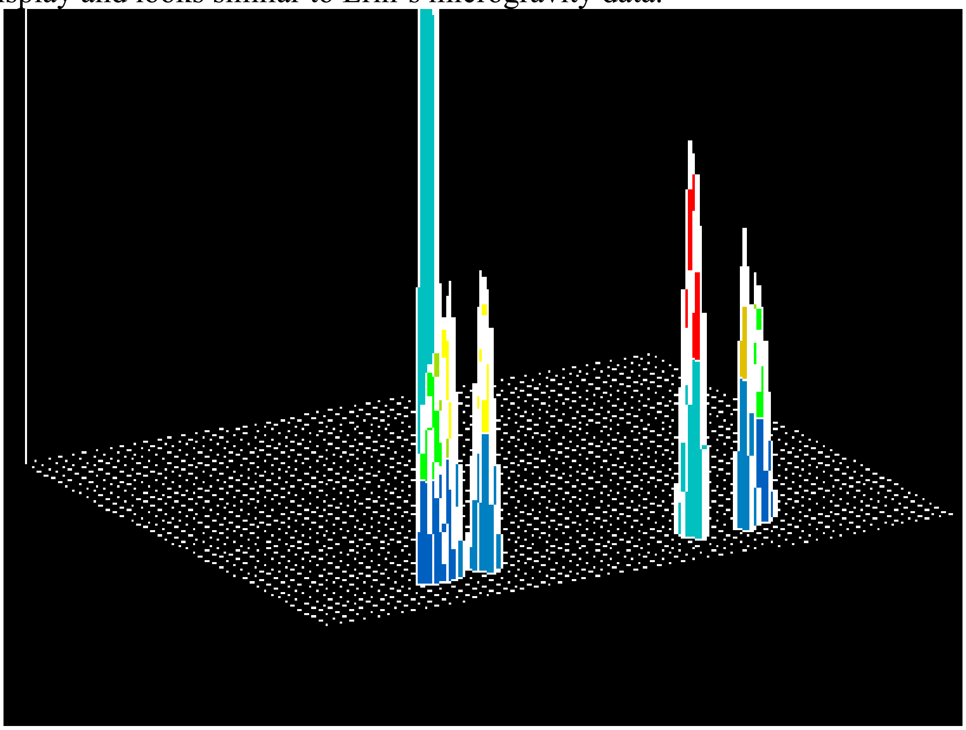


Fig. 7

David was the third patient whose posture was examined. His posture was studied in a normal gravity environment before flying in Houston. Several similarities were found between him and the other patients. For instance, David leans slightly forward at the beginning of the lifting process. This is normal. However, David did tend to place too much pressure on the balls of his feet. This again has been shown to lead to a possible back injury. As seen in Fig. 8, David's peak pressure is on the balls of his feet when they should be on the heels. Viewing the Peak Performance motion analysis section of this report will confirm that David does arch his back a little more than the other patients. Another piece of information about David's posture gathered from Tekscan is that he uses the side of his foot to stabilize himself. These characteristics may be viewed in Fig. 8 (David's gravity posture data)

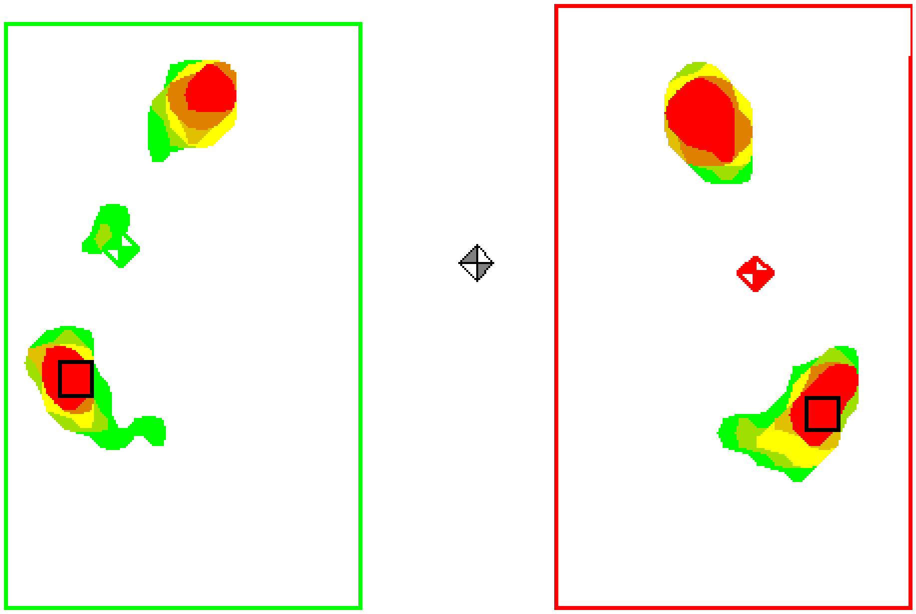


Fig. 8

David's microgravity data simply confirms what has been seen with the other patients. In microgravity, the posture is altered such that only the balls of the feet are touching and activating the Tekscan pad. Fig. 9 displays the same type of foot pressure distribution. The phenomenon is exaggerated in David's microgravity exercises. Only a very small portion of his foot (the front part) is touching the pad.

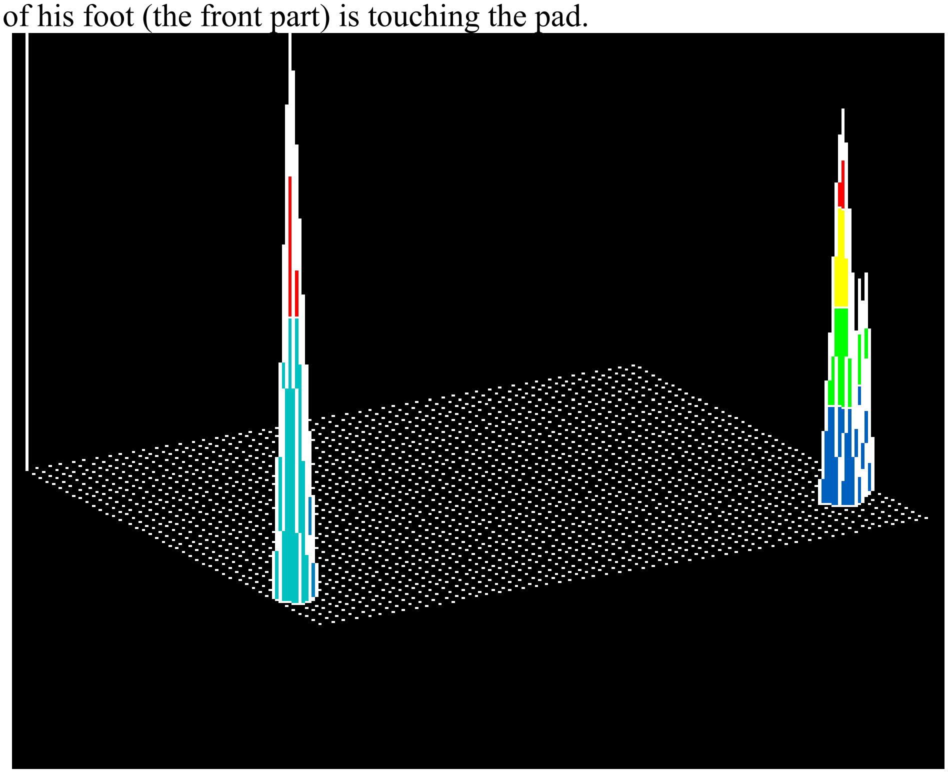


Fig. 9

Conclusions and recommendations for future implementation:

From the data collected, it seems to be a safe conclusion to say that the posture of a patient changes when in microgravity. The data for all the subjects shows that when performing the exercise in microgravity, most if not all of the forces are placed on the balls of the feet. This is a negative result. Exercise studies have shown that if the forces of weight or resistance aren't on the heels of the foot, injury will most likely occur. Also, if the posture is not correct, which has been shown to be true, bone loss will occur as well as muscle loss. In order to maintain healthy bone and muscle masses in microgravity, the forces of exercise must travel along a prescribed line through the body from shoulders to toes as it does when an exercise is done with proper form in gravity. Naturally, if the forces don't travel through a well-defined line connecting joints in the body, then both bone and muscle mass will be lost.

However, there was an inherent problem with the research. The pulley that the subjects were pulling on was approximately 1 inch in front of their feet. In gravity this is a totally negligible moment created and is unrecognizable to the patients. In microgravity however, this very small torque is significant. To remedy this small torque, a simple string tether was implemented to stabilize the subjects. Fig. 10a,b show the torque created and the unstable (day one) and stable (day two) configurations respectively.

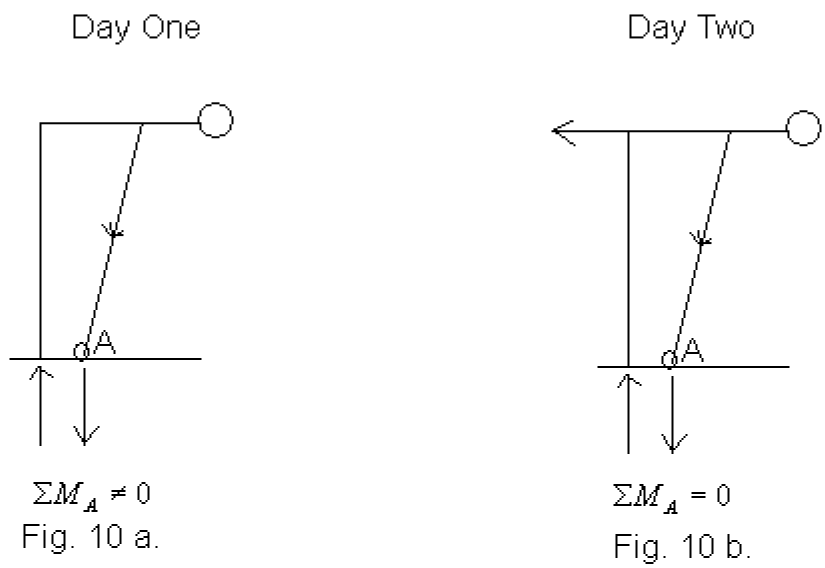


Fig. 10

For future implementation a few considerations should be made to ensure better posture. First, an exercise machine must be designed and built which allows the patient to have the resistance or weight vector sourcing from the location of the projection of a patient's COF when the patient is standing with a natural posture in gravity. Another concept is to use a resistance source on each side of the patient so there is nothing to get in the way of the patient's foot placement, this way the patient has some room to move the feet until a comfortable posture is found. Another consideration to remember in the design on a future unit is that more weight should be used in microgravity compared with the amount of weight in gravity; this is because a patient doesn't need to lift his weight in microgravity. The weight increase while seemingly small is certainly significant.

Video Motion Analysis using Peak Performance

Final Results and Conclusions Report 2001
Video Motion Analysis using Peak Performance

Background to Video Analysis:

Because of a lack of a gravity vector during stays in microgravity, muscles and bones in living creatures atrophy in space. Exercise slows the process of muscle and bone deterioration. Using video analysis, we recorded and analyzed the difference of the straight leg deadlift exercise in gravity and microgravity. The video analysis allows watching for changes in posture between zero-g and one-g exercise. If an astronaut or cosmonaut is under an intense exercise regimen during their time in space and their exercise posture is poor, they could be promoting muscle growth and activation in the wrong muscle groups. For example, incorrect posture could cause lower back problems. The video analysis of the straight leg deadlift shows the qualitative difference in the movement while performing this exercise. It can show whether the participant is leaning to far forward or bending their knees in a way that deteriorates the effectiveness of the exercise and could potentially harm the subject rather then helping them to recruit from the correct muscle groups. This is of utmost concern with new long term manned space projects such as the International Space Station because astronauts need to exercise properly to maintain their physical stature.

Method:

A home camcorder with a wide-angle lens was set on a tripod approximately 63 inches from the closest foot of the participant doing the exercise. This distance, with a wide angle lens, allows for viewing the full range of motion of the subject. The subject was marked in six spots along their body for later video analysis. Using standard electrodes, athletic tape, and other visible stationary marking objects, we marked six major points on the body that showed the exercise motion best. These points were the ankle, knee, hip, shoulder, and wrist. The head was not utilized because the space provided us in the airplane was not great enough to set the camera at a distance where the full range of motion of the head was available. These six points signify the major points of pivot while doing this exercise. With the use of these markers, we could take our film footage and put it into a computer program called Motus by Peak Performance Industries. This program tracked the markers and gave us the exact position of these markers in a 2-D plane. Essentially, it made the exercise participants into stick figures. These stick figures make it very easy to see differences during the same part of the exercise in different gravity forces because they take out all other background information, allowing for a concentrated study of the actual posture. For two of the three participants (Dave and Donny), very specific measures were taken to allow for as little variation as possible between gravity and microgravity data. First, the majority of markers were placed directly on the skin so that they cannot move in exercise. The ones that could not were put directly onto clothing that showed no movement during exercise. The data was collected on the ground and in the plane wearing the same electrodes, assuring that the markers were in the exact same spot on each participant. The camera is set at exactly the same distance and with the same tripod for accuracy in recording distances and data. Because of outside conditions, the accuracy of the third participant (Erin) was followed as closely as possible, but not all of these protocols could be implemented during her trials. However, this does not hinder the accuracy of the data because the computer program makes allowances for such discrepancies. Between the actual film footage and the modified stick figures provided by Peak Performance, the posture could be visually analyzed and conclusions could be made.

Discussions:

Day One

Erin McFadden and Michael Blackledge were the first two exercise participants on July 17, 2001. The first day, the participants were unrestrained while doing the exercise. They had no tethers or any other forces acting upon them besides the flight director, who spotted Erin while she performed the exercise. This led to an unforeseen problem with the machines design, because in microgravity, the participant leaned too far forward. This forward motion created a rub on the cable, causing it to break. The pulley that provided the force for the exercise would have to be directly under the center of mass of the participant or a moment would be created. The machine was designed with the source of force a couple of inches in front of the subjects toes, which meant that when they pulled upon the bar in microgravity, they were pulled forward (toward the ground) by the moment created. (Figure EM2) This led to the cable rub that broke the cable the first day. As well, Erin had to be spotted by a flight director, and without this direct intervention, she would have pulled herself all of the way to the ground. However, the spotter pushed Erin up about one third of the way to the ground for her safety. This had to be corrected during the second day. Michael was unable to perform the exercise because of these outside sources of complication.

Day Two

Donny Newsom and David Bower were the latter exercise participants, flying on July 18, 2001. A tether was introduced to the experiment the second day. This tether provided a force to counter the forward force that broke the cable on the first day. The tether was created by 4 mm climbing cord attached to a harness that each participant wore. The harness attachment was at the lower back of the participants and served the dual purpose of holding the participant in place so that the cable would not rub and so that the flight instructor spotting was no longer necessary. This tether had a significant impact on the data gathered because it held the exercise participants in a much more stable posture, countering the forward moment. Therefore, the results from the first and second days are substantially different.

Results:

Day One - Erin

On day one, the straight leg deadlift was performed using no restraining devises. There was some webbing placed around Erin's ankles to prevent her from floating away while trying to get into position to perform the exercise. The webbing did not perform any restraining forces and did not aid in any sort of help with balance.

The results yielded by Erin shows that posture could change significantly without a gravity vector present. All the figures show that in a microgravity environment Erin is in a position that is far forward from the correct position obtained in a One-G environment. The forward leaning is due to a number of reasons that would be corrected for on flight two.

The initial start position in gravity (Figure EM 1) and microgravity (Figure EM 2) are very different. This difference is due to the pulley being located beyond the front of the toes, which creates a resulting moment causing Erin to lean forward. This trend of leaning forward is present throughout the entire range of motion.

Observing the full upright position for One-G (Figure EM 5) and microgravity (Figure EM 6) it is shown that in microgravity the full upright position for the straight leg deadlift (body fully erect, shoulders square, and legs and back straight) was not achieved. During the straight leg deadlift, the knees should not be locked; they should be slightly bent. However, in the microgravity case, the knees are bent too much putting strain on the knees during the exercise. The full upright posture also shows the tendency of leaning forward, which could possibly put strain on the calves and the ankles.

Figures EM 11 and EM 12 show the full range of motion for Erin in a One-G environment and a Zero-G respectively. By observing the two figures, one can examine and compare the two ranges of motion. In the microgravity range of motion the knees are bent slightly greater than in the One-G environment and the body appears to be in a more crouched position. The forward leaning of the body throughout the entire range of motion is shown very clearly by these two figures.

Day Two - Donny

The tether attached to the participants for the second day of the experiment created substantially different results than the first day, but there is still an obvious change in exercise posture in gravity and microgravity. The tether on Donny is just long enough to allow his legs to be fully extended and to do the exercise in gravity without the tether acting on him in any way, so in microgravity, it was intended to simply hold him back so that the cable did not rub and a spotter would not be unnecessary. Webbing was placed behind his ankles to prevent the feet from moving backwards.

The gravity data that is presented is accepted as good exercise posture for this experiment. The results presented are that of the difference that microgravity caused to the participant's exercise posture.

His initial posture in microgravity still shows a forward lean that is not present in gravity. (DN2) His knees are slightly buckled and his arms are reaching backwards at a far greater angle than in his gravity starting position, which his legs and arms are nearly vertical and he shows only a slight lean backwards.

By the middle of his raise in microgravity, the tether has caught his forward moment. (DN4) However, his knees still show the bent posture and he is substantially more humped over. His back is nearly parallel to the base of the plane while his arms are leaning back to make up for this forward motion.

At the top of the lift in gravity, Donny is nearly perfectly vertical. Both his body and his arms are straight, and he is stationary. (DN5) In microgravity however, we see that his knees and shoulders are advanced to his hips. (DN6) The tether is acting on him to hold him in place. Because of the forward motion of his shoulders, his arms are at a much more perpendicular angle to the floor. Instead of his entire body being straight, he is showing an overall forward lean.

While lowering during exercise, we see the same postures as during rising. In microgravity, he has a slight forward lean with bent knees, almost as if he is sitting down. (DN8) The end microgravity positions are also identical to the starting. (DN10) With the bar at the base of the machine, Donny's knees are bent and his hips are over his ankles, rather than leaning back to compensate for the weight of his torso.

Overall, the final motion difference shows that in microgravity, the knees were bent forward for the entire exercise. (DN12) The arms had to operate at a far greater angle to account for this forward motion. As well, the back is never quite perpendicular to the floor in microgravity, leaning farther forward than in gravity.

Day Two – Dave

The stabilizing tether was adjusted to a length thought to be necessary so that Dave had the same full range of motion as Donny. His gravity posture is different than Donny's gravity posture. However, proper posture is in some cases analyzed for the individual based on body type, flexibility, exercise regimens, and other factors. Therefore, Dave's posture will also be considered correct for him and results will be drawn from the difference in gravity versus microgravity.

Initially, Dave's knees are drastically bent in microgravity compared to gravity, which places his hips farther back in the exercise position. (DB2) This brings him lower to the board and makes his back more parallel to the ground. The arms are bent a little more to make up for this change in posture as well.

The mid-raise position shows that the lower leg is nearly the same in microgravity. (DB4) The hip is farther back than in standard gravity posture, which makes the back closer to parallel in microgravity. The arms are nearly identical as well. Essentially, the mid-raise appears to shows a backwards lean.

The upright position is similar to the raising position in the fact that the lower leg is still slightly leaning forward, but the upper leg and hip have a slight backwards appearance. (DB6) This means that the back must again be lower to compensate for the placement of the hips. In gravity, the subject's body is nearly straight, but leans forward rather than stands perpendicular to the ground. (DB5)

As seen in the other subjects, the straight-leg deadlift exercise is nearly symmetric, and the initial and raise positions mimic the end and lower positions. The same is true of Dave.

Overall, the gravity motion is very fluid. It shows the movement from the start position to a nearly perfectly straight upright position, and the corresponding lower. (DB11) The movement in microgravity shows knees bent substantially forward in relation to the rest of the body. (DB12) The hips and mid-section are held back and the back has to compensate by leaning farther over. The arms do not show as much change as the lower body and back do.

Conclusions:

Posture and exercise technique change in a microgravity environment. Many aspects must be considered in trying to perform an exercise in microgravity. Restraining devises play an important role with assisting someone to achieve the correct posture and range of motion. Adaptation to a new environment can be challenging and trying to perform an exercise correctly in that new environment can be even more challenging.

To obtain better results in the future one should design a machine in which the lifting force is directed in a way to create equal and opposite reaction forces. This can be achieved if the force being lifted can be directed and supported near the arches of the feet. This will allow for any moments created to be balance by pressured in different locations of the feet. Our force, lying only a couple of inches in front of the toes, did not do this successfully and a restraining device was needed to correct this.

The use of a restraining device might not be necessary if the force directly under the center of mass. However, with our machine design, the tether became necessary. The results of the tether are apparent. Erin, without a tether, pulled herself towards the ground. Donny and Dave, both attached to a restraining device, were held much closer to vertical with the tether. It appears that the tether did more than just stabilize the subjects; the tether also greatly influenced their posture. The tether held back the mid-section of the body. It is important to understand that tethers, although in our case necessary, might also hinder exercise posture if applied incorrectly. The difference between Dave and Donny in microgravity is best explained that the tether on Dave was not adjusted to the same distance needed to match Donny, and it therefore held him back more during exercise.

The overall forward motion of the exercise implies bad exercise posture. The adjustment of the back does not recruit from the gluteus muscles; rather it leads to lower back recruitment. This can lead to problems in the lumbar region. As well, the lean in the knees will put heavier pressure on them while doing the exercise in microgravity. Because the weights used in space will need to compensate for the missing weight of the body, any poor posture can hinder any of these areas.

The video analysis was very effective in capturing data regarding exercise posture. Both the film and the stick figures from analysis are very revealing regarding position and motion. Overall, the posture of the straight-leg deadlift is substantially different in gravity and microgravity, and such information needs to be taken into account when designing exercise machines and protocol for space flight.

Start Position for the Straight Leg Deadlift:

Figure EM 1: Erin McFadden One-G Start Position

Figure EM 2: Erin McFadden Zero-G Start Position

Mid-raise Position for the Straight Leg Deadlift:

Figure EM 3: Erin McFadden 1-G Mid-Raise Position

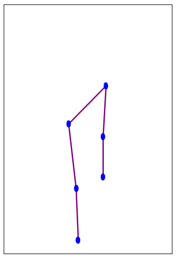
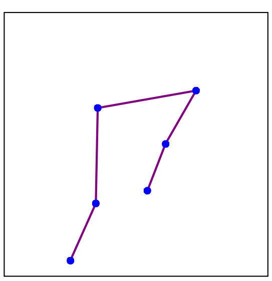


Figure EM 4: Erin McFadden Zero-G Mid-Raise Position



Upright Position for the Straight Leg Deadlift:

Figure EM 5: Erin McFadden One-G Upright Position

Figure EM 6: Erin McFadden Zero-G Upright Position

Mid-lower Position for the Straight leg Deadlift:

Figure EM 7: Erin McFadden One-G Mid-Lower Position

Figure EM 8: Erin McFadden Zero-G Mid Lower Position

End Position for the Straight Leg Deadlift:

Figure EM 9: Erin McFadden One-G End Position

Figure EM 10: Erin McFadden Zero-G End Position

Motion for the Straight Leg Deadlift:

Figure EM 11: Erin McFadden One-G Motion

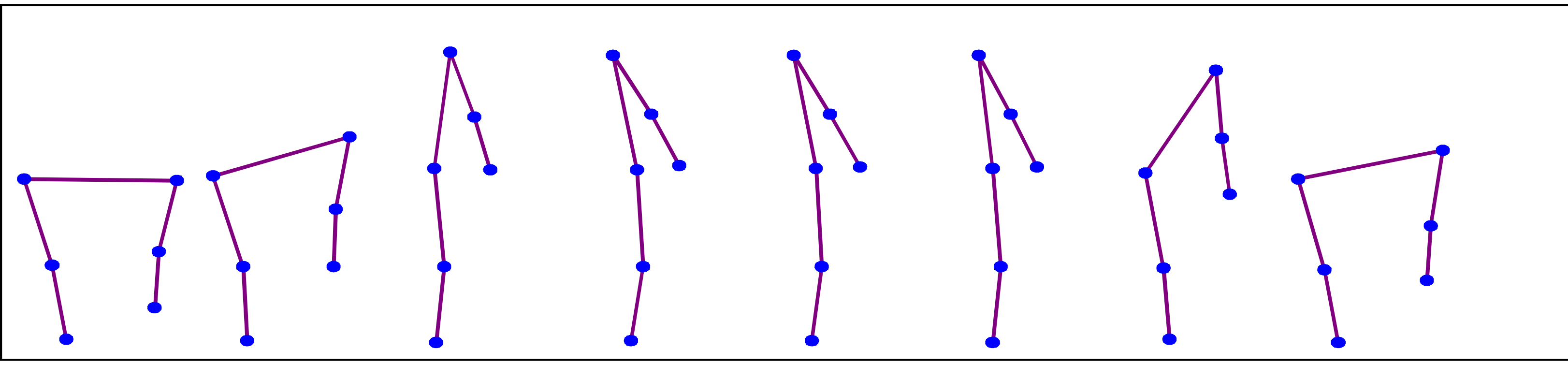
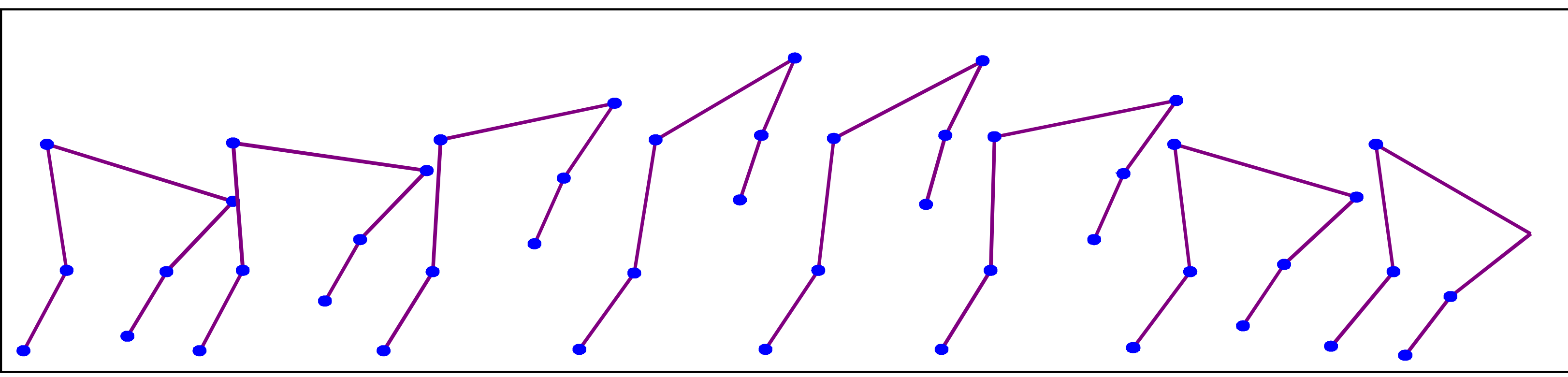


Figure EM 12: Erin McFadden Zero-G Motion



Start Position for the Straight Leg Deadlift:

Figure DN 1: Donny Newsom One-G Start Position

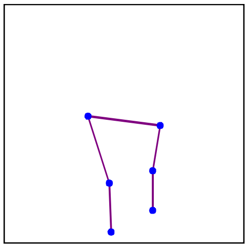
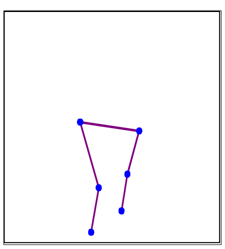



Figure DN 2: Donny Newsom Zero-G Start Position




Mid-Raise Position for the Straight Leg Deadlift:

Figure DN 3: Donny Newsom One-G Mid-Raise Position

Figure DN 4: Donny Newsom Zero-G Mid-Raise Position

Upright Position for the Straight Leg Deadlift:

Figure DN 5: Donny Newsom One-G Upright Position

Figure DN 6: Donny Newsom Zero-G Upright Position

Mid-Lower Position for the Straight Leg Deadlift:

<u>Figure DN 7: Donny Newsom One-G Mid-Lower Position</u>

Figure DN 8: Donny Newsom Zero-G Mid Lower Position

End Position for the Straight Leg Deadlift:

Figure DN 9: Donny Newsom One-G End Position

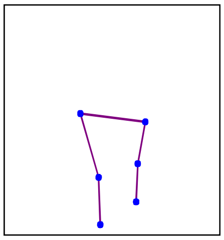
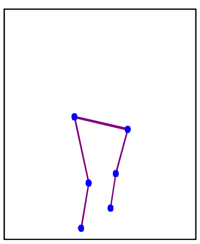


Figure DN 10: Donny Newsom Zero-G End Position



Motion for the Straight Leg Deadlift:

Figure DN 11: Donny Newsom One-G Motion

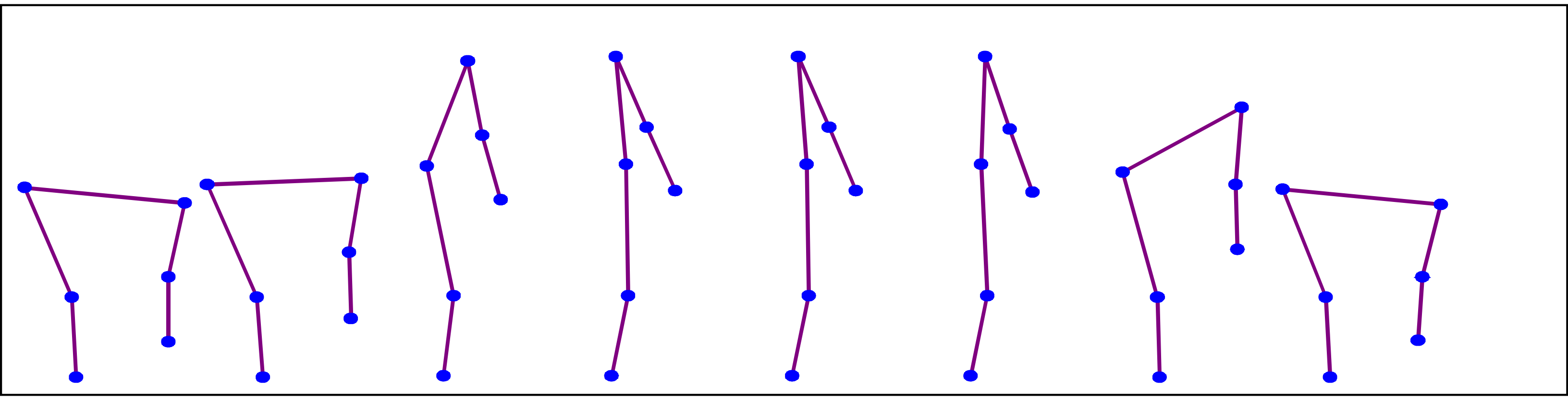
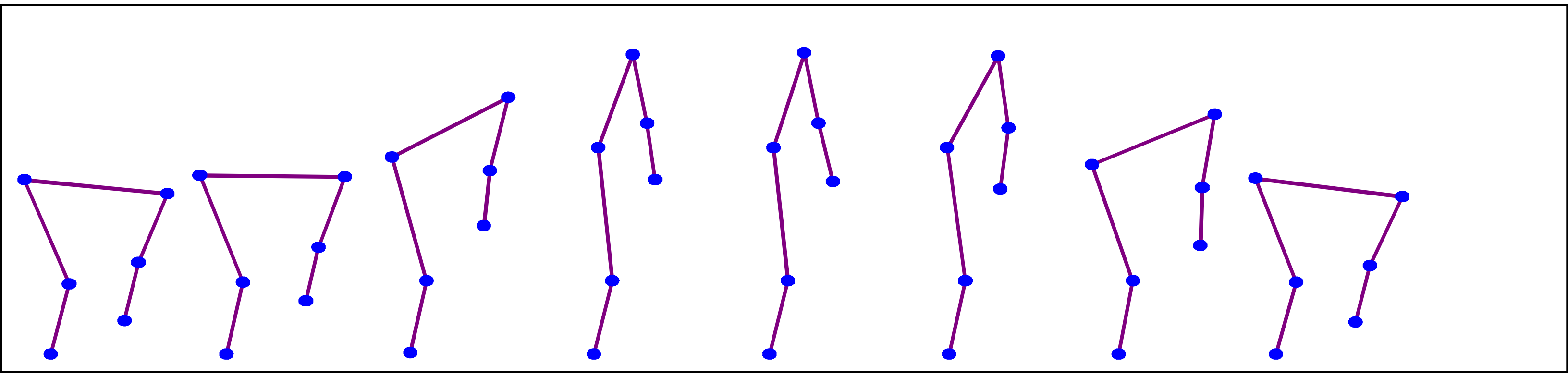


Figure DN 12: Donny Newsom Zero-G Motion



Start Position for the Straight Leg Deadlift:

Figure DB 1: David Bower One-G Start Position

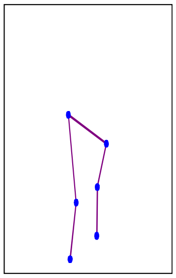
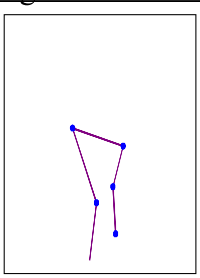


Figure DB 2: David Bower Zero-G Start Position



Mid-Raise Position for the Straight Leg Deadlift:

Figure DB 3: David Bower One-G Mid-Raise Position

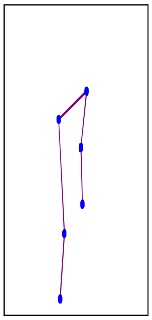
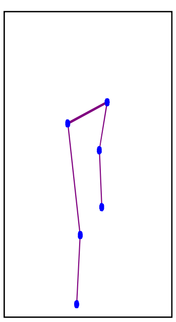


Figure DB 4: David Bower Zero-G Mid-Raise Position



Upright Position for the Straight Leg Deadlift:

Figure DB 5: David Bower One-G Upright Position

Figure DB 6: David Bower Zero-G Upright Position

Mid-Lower Position for the Straight leg Deadlift:

Figure DB 7: David Bower One-G Mid-Lower Position

Figure DB 8: David Bower Zero-G Mid-Lower Position

End Position for the Straight Leg Deadlift:

Figure DB 9: David Bower One-G End Position

Figure DB 10: David Bower Zero-G End Position

Motion for the Straight Leg Deadlift:

Figure DB 11: David Bower One-G Motion

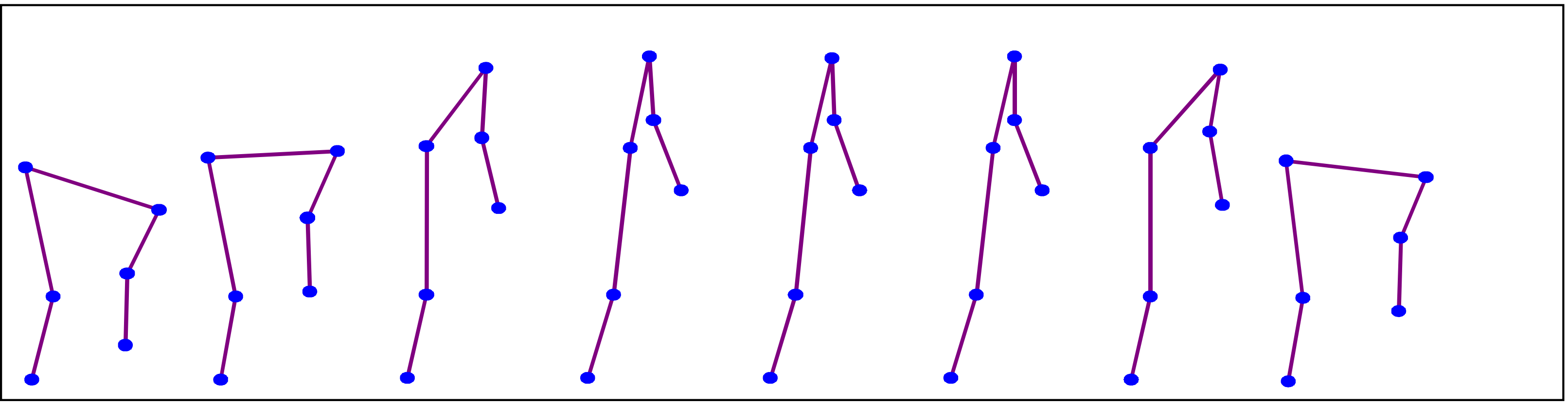
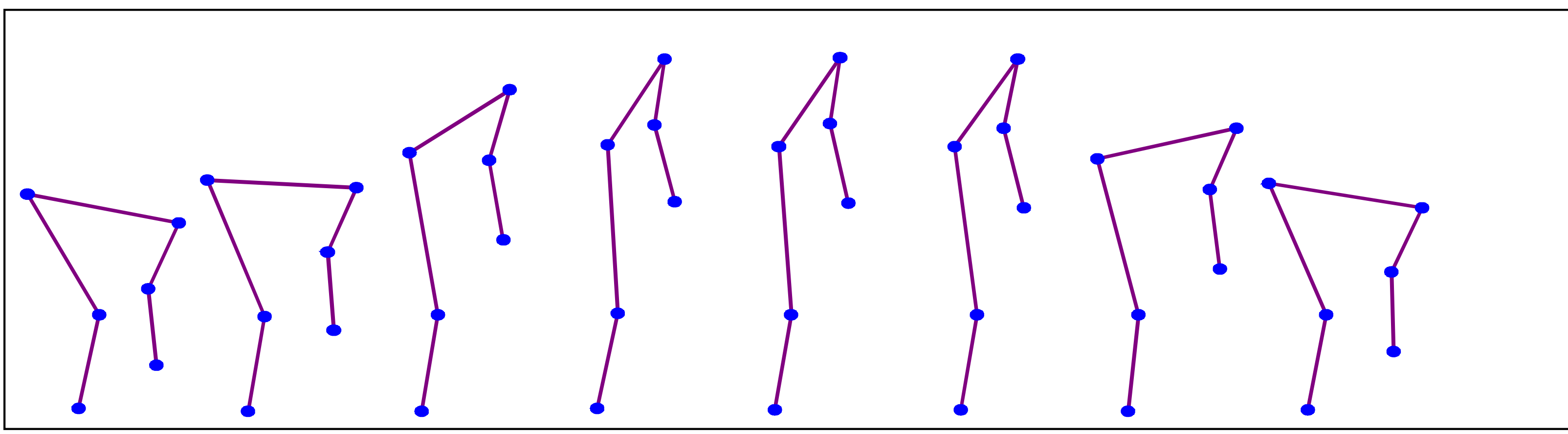


Figure DB 12: David Bower Zero-G Motion



<u>Outreach Activities Report:</u>

In review of the Colorado State University (CSU) Floatn' Rams participation in the Summer 2001 Reduced Gravity Flight Opportunities Program, we would like to reflect on the success of the outreach portion of our project**.** We have participated in several conferences (see below) and were awarded first place for our presentation (see attached file for Power Point Presentation and Poster) at all three seminars.

- Colorado Space Grant Consortium Student Paper Symposium (4/7/2001)
- Rocky Mountain Regional American Institute of Aeronautics and Astronautics Student Conference (4/17/2001-4/20/2001)
- Colorado State University Research and Creativity Undergraduate Symposium (4/23/2001)

We also have presented to several school tours and academically focused camps that have been interested in science and math academics. Currently, we await response to our letter to speak at six different high schools in Colorado, one junior high school, one elementary school and a local Head Start program. (Fig 1.0) We these schools and anticipate presenting at these schools in the Fall 2001 semester. During these presentations we hope to extend a feeling of excitement about our opportunity as undergraduate college students, but also to encourage the younger students to begin thinking about their futures in math and science. We believe that taking the opportunity to speak at these functions allows the students to anticipate developing their own projects related not only to the space program but to any project in school to help increase their sense of achievement and motivation.

Our website, has photos of our interaction with these student groups, awards from our conferences and seminar presentations, results from our project and pictures from our participation in the Reduced Gravity Flight Opportunities Program. **(http://www.engr.colostate.edu/student_orgs/aiaa/kc135for2001/index.html)**,

In addition to the above, we have granted interviews upon request from several local newspapers, television, and radio. Fig. 2.0. It is our goal is to keep CSU involved with the Reduced Gravity Flight Opportunities Program by continuously recruiting more students to participate and submit proposals on an annual basis and to have them, in turn, share their experiences with other CSU students and perpetuate the trend for years to come.

<u>Fig. 1</u>

To Whom It May Concern:

Colorado State University (CSU) and the Colorado Space Grant would like to offer you the opportunity to have undergraduate students from the **CSU Floatin Rams** present at your school between August 21-31, 2001. We are a group of six students participating in NASA's Reduced Gravity Flight Opportunities for Undergraduates Program (RGFOUP). We have been given the opportunity to run an experiment on the KC-135 aircraft at Johnson Space Center. The KC-135 aircraft simulates weightlessness by flying in a parabolic arc. Specifically, we are using an exercise machine we have modified to test NASA's current exercise protocol in gravity versus microgravity.

We are committed, as participants in NASA's RGFOUP, to provide outreach to the local community. The CSU Floatin' Rams team has decided that we would like to provide education to schools around the Fort Collins, Colorado Springs and Denver Metro areas. The team's background is extraordinarily diverse and we would be willing and excited to talk about any topics related to engineering, exercise and physiological reactions to space environments, space and aeronautical science, or general science topics such as physics and biology. During these presentations we hope to extend a feeling of excitement about our opportunities as undergraduate college students, but also to encourage students to begin thinking about their futures in math and science.

Additionally, we would be happy to talk about college life and general reasons to strive hard in school and reach for continuing education. We believe that as college students involved in NASA's RGFOUP, we would encourage students to anticipate developing their own projects related not only to the space program, but to any project in school to help increase their sense of achievement and motivation. These presentations are intended for small groups or classes, but can be adjusted to meet each group's specific need.

If you are interested in taking advantage of this opportunity or interested in more information, please contact any member of the KC-135 team at (970) 491-2685.

Sincerely,

The Floatin' Rams:

Erin McFadden	Dave Bower	Kirsten Kilbourn
Michael Blackledge	Josh Porter	Donny Newsom

Fig.2

NEWS

Rocky Mountain Collegian Page Designer: Angela Ziegler, 491-3807

Machine tested in micro gravity

NASA
Continued from Front

creates an environment called micro gravity for 90-second periods. The team is scheduled to leave to test their machine for two weeks at Johnson Space Center in Houston beginning on July 16. They will test their machine 30 times a day.

"Micro gravity is basically zero gravity," said Josh Porter. "The plane will climb very fast and come back down simulating a zero gravity environment. It's like the feeling you get when you're going over a hill in a car really fast."

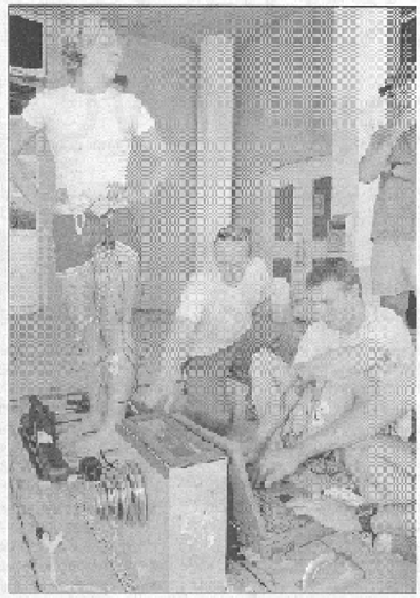
The machine designed by this year's team is a new and improved version of a machine that was created by students Paul Colofsky and Tara Rutley last year. Colofsky and Rutley now work for NASA developing a similar machine. The CSU team's new machine is a lighter and smaller version of the previous machine, but still operates along similar principles.

The machine uses torque springs and pulleys that provide a constant resistance to the muscles being worked. They say this has proven more effective than machines using elastic bands that NASA has experimented with before. The machine is also hooked up with sensitive pads made of semiconductors under the lifter's feet, laptop computers and a video camera to record the experiments.

"The machine gives us the chance to put several data acquisition systems together to see what happens," Newsom said. "Pressure sensors measure changing current through semiconductors in 2400 sensors on a pad. Video analysis can tell us if a person stands too far back or their joints aren't aligned."

Team members are excited about their trip to Houston.

"I'm really looking forward to going to Houston," Bower said. "It's exciting to work with NASA to help them put something on the International Space Station. It's exciting to have them say that this is something that's worthwhile and important." ■



JOSH HARDIN/The Collegian

CSU students Erin McFadden, Josh Porter, Donny Newsom, David Bower and Michael Hinchledge run the first test of an improved exercise machine for NASA astronauts.

Fig 2a

Students aid NASA astronauts

BY JOSH HARDIN
The Collegian

In the halls of the Engineering Building a group of CSU students work in a small room on a machine that has earned the interest of NASA, and given them the opportunity to travel to Houston for two weeks to test it out in a near zero gravity environment.

"We attract a lot of attention from professors around here," said Josh Porter a member of the team working on the machine during it's first test run on Friday as several students and professors walked by and looked inside the room with interest.

The CSU team is made up of students Erin McFadden, Michael Blackledge, Donny Newsom, Josh Porter, Kirston Kilbourn and David Bower.

They are working on an exercise machine that will simulate a dead lift (a lift which involves bending from the waist, grabbing a weight or exercise machine handle and slowly standing up, keeping the knees slightly bent and bringing the weight near the waist to strengthen thigh and back muscles). They are trying to simulate the lift because weight has no value in the zero gravity environment of space and astronauts can't exercise the same way they do on Earth. That's why NASA is so interested in the team's exercise machine.

"We want to make sure that when an astronaut does exercises they don't throw their back out," said Bower. "This machine is relevant because in space bones and muscles atrophy. People are used to working against gravity so it is especially important to do exercises that keep the muscles growing. We need to figure out how to create exercises for space."

"We need to figure out how we are going to make sure astronauts stay in great physical condition," said Newsom. "Astronauts who stay in a space station a couple of weeks come back and they have to be carried off of the shuttle. Our machine works so they will be able to walk off the shuttle."

The NASA program, called the Reduced Gravity Flight Opportunities Program, will give the group of students the opportunity to test their machine on a KC135 aircraft (otherwise known as the "Weightless Wonder or the "Vomit Comet") that

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Fig 2b

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